Smart Water Management

Digital applications to reduce non-revenue water and increase the energy efficiency of water utilities in countries with emerging markets and developing economies

1st Edition

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Acronyms

BEP	Best Efficiency Point
EMDEs	Emerging Markets and Developing Economies
GIS	Geographic Information Systems
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GPR	Ground-Penetrating Radar
Int$	International Dollar
IT	Information Technology
KPI	Key Performance Indicator
LAC	Latin America and the Caribbean
MENA	Middle East and North Africa
NRW	Non-Revenue Water
PROEESA	Projeto de Eficiência Energética no Abastecimento de Água
VFD	Variable Frequency Drive
WaCCliM	Water and Wastewater Companies for Climate Mitigation
WWTP	Wastewater Treatment Plant

1 Introduction

1.1 Executive summary

Digitalization is transforming the way water and wastewater utilities plan and manage their infrastructure and interact with their customers and their staff. Globally, digital technologies have been playing a role in resource-efficient water management for some time, including in the management of water losses and the energy efficiency of utilities. Digital applications have been developed for customer engagement, leak detection, pressure management, energy efficient pumping, energy management and wastewater treatment.

The digital transformation of resource-efficient water management brings new challenges. But it also provides opportunities for the digitalization of utilities in emerging markets and developing economies (EMDEs), which, due to economic, technical, social and legal differences, are often quite different from those in high-income economies.

This document addresses these differences, from tariff structures to levels of water losses, and identifies opportunities for digitalization in resource-efficient water management that can work especially well in EMDEs. It also discusses some digital applications that are already in widespread use in high-income countries, but due to economic, technical or other factors are not currently suited to the needs of EMDEs.

The fields of opportunity identified are considered in three categories (see Table 1) – those related to reducing commercial (or apparent) losses; those related to reducing physical (or real) losses; and finally those related specifically to increasing the energy efficiency of water and wastewater utilities.

Factors that are common in EMDEs, such as high levels of unauthorized consumption and low water tariffs, mean that, overall, the requirements for digital applications in EMDEs are very different from those in high-income economies. This is particularly in regard to mitigating commercial losses, but also for reducing physical losses. These differences are significantly less marked when examining energy efficiency, where local and regional differences, particularly electricity tariffs and actual use of electricity, are much more important.

Reduction of commercial losses	Data mining for identification of illegal consumption and meter inaccuracies Customer applications Localization of illegal connections with ground-penetrating radar Detection of illegal bypasses analyzing hydraulic transient Smart metering for principal customers Apps for commercial field staff
Reduction of physical losses	Multipurpose geographic information systems Drone technology Data analysis for prioritization of leak control and asset management Leak monitoring in large-diameter water mains Smart pressure management valves Optimized flushing strategy for drinking water networks
Increase in energy efficiency	Smart energy management systems Smart pumps for maximum energy efficiency Pump load profile monitoring for energy efficient optimization Early or real-time detection of pump malfunction Pump maintenance with digital applications Analytics of biogas to improve energy efficiency

Table 1. Digital opportunities for three fields of water management

1.2 What is digitalization (and what is not)?

"Digitalization" is often used as a synonym for digital change, transformation or revolution, although a precise definition is still evolving (and may be dependent on context). This document uses the following definition:

"Digitalization is the combination of generation, transmission, recording, evaluation, representation and use of relevant data using new sensor, communication and information technologies, which in the case dealt with in this document contribute to the reduction of non-revenue water and the increase in energy efficiency in water utilities."

Digitalization does not mean the increased use of information technology (IT) (computerization) or the networking of IT components (connectivity) (Oelmann 2019).

1.3 Objectives of this document

The main objective of this document is to highlight useful digital solutions to decrease non-revenue water (NRW) and increase the energy efficiency of water utilities in EMDEs.

To do this, the document initially analyzes economic, technical, social and legal framework conditions that are common in EMDEs, specifically those that are clearly distinguished from industrialized countries. Taking these factors into account, it then catalogs digital applications that are frequently used in countries where the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH works. The applications have been selected based on experience gained in different countries by members of the Resource-Efficient Water Management Community of Practice;[1] the list is therefore non-exhaustive and can be expanded in the future.

For each of the applications, a brief description of its functionalities and an example of their use is given. There is also a brief appraisal of the direction in which the respective applications will develop in the near future and any important factors that might restrict their use.

Also, for each application, a chart provides an indication of investment needs, the return on investment, the implementation complexity (based on previous projects, necessary training, etc.) and the structural requirements of the operator, depending on the specific case, including factors such as existing data, capacity for use and maintenance. The values given in the charts should be seen as an initial indication only and cannot be generalized.

This catalog may help programs and projects of GIZ and its partner institutions to plan joint actions to use digitalization as an integral tool in their work. As a first step, this catalog could serve as the basis for programming knowledge exchange activities within the Resource-Efficient Water Management Community of Practice.

[1] The Resource-Efficient Water Management – Water Loss Reduction and Energy Efficiency in Water/Wastewater Utilities Community of Practice is a group of around 200 experts from GIZ and its partner institutions who have been sharing knowledge, lessons learned and best practices on different topics related to the field since 2018.

2 Relevant differences between countries with high-income economies and EMDEs

2.1 Economic factors

Before analyzing factors that affect the economic/ financial feasibility of the applications discussed below, it is necessary to consider environmental factors as well. From the perspective of reducing carbon dioxide emissions, digital applications could be useful if they have a very long payback period as a result of, for example, the tariff structure, high financing costs or subsidized electricity prices.

Water tariffs charged by the utilities

A major difference between high-income economies and EMDEs lies in the tariffs charged by water utilities. On average, water tariffs are three to ten times higher in Western Europe and North America than in EMDEs (Figure 1). This has a major impact on all measures taken to reduce NRW in EMDEs, as the time to achieve a return on investment will be much longer, or a complete return may never be achieved (Wyatt 2010).

Tariff structures

In many EMDEs, tariff structures include cross-subsidies of some kind, mostly using different tariffs for domestic, commercial and industrial users, with lower tariffs for domestic users. As these cross-subsidies vary from country to country and from utility to utility, it can be difficult to determine precisely the impact that they have. However, a recent study by the Inter-American Development Bank showed that the impact on billing is especially pronounced in the Middle East and North Africa (MENA) region and in Latin American and the Caribbean (LAC) countries, where the price per m^3 for a user of 100 m^3/month is about three times higher than for a user of 20 m^3/month. The same effect on the price per m^3 was shown for Asian and sub-Saharan countries, although it is less pronounced in these countries (Brichetti 2019).

Combining the overall lower average tariffs with the impact of these cross-subsidy tariff structures makes it clear that measures to reduce commercial losses in EMDEs must concentrate on low-cost solutions and/or on principal customers with high tariffs to be cost efficient.

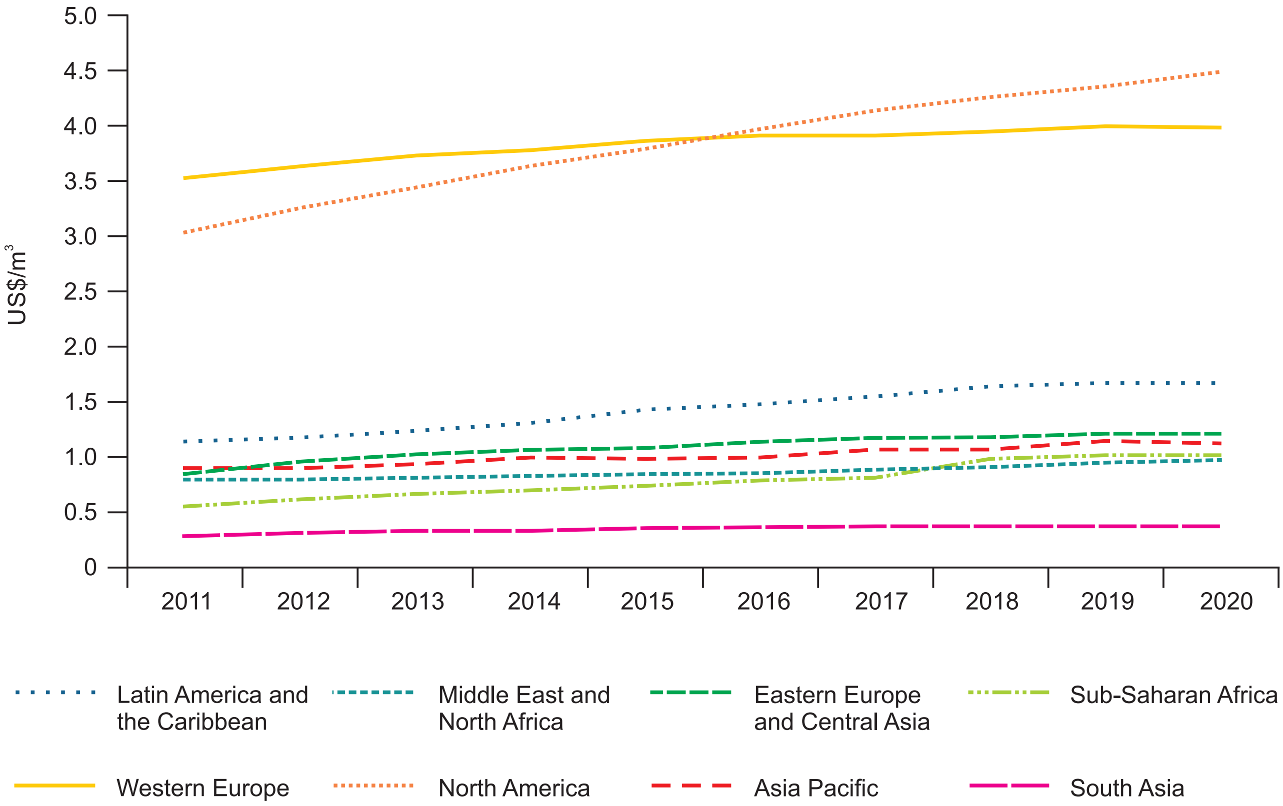


Figure 1. Average water tariff by region (includes wastewater), 2011–2020 (Source: Global Water Intelligence 2020)

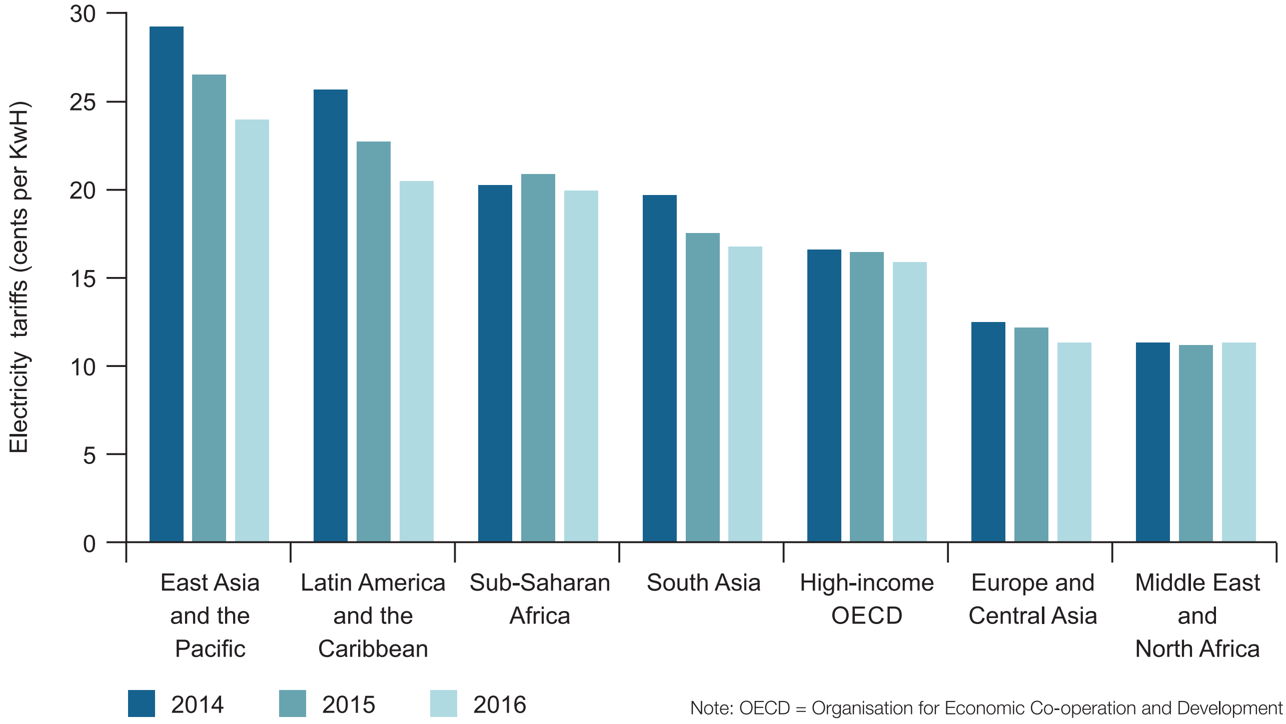


Figure 2. Average electricity tariffs by region 2014–2016 (Source: World Bank 2013)

Electricity tariffs and structures

The differences in electricity tariffs between regions – relevant for returns on investment in energy efficiency measures – are not as pronounced as those for water tariffs (Figure 2). Nevertheless, they should be accounted for locally, for instance in the MENA region, where tariffs are lowest, making investment in energy efficiency somewhat slower to achieve a return.

Electricity tariff structures are even more diverse than water tariffs, but in many countries electricity use by water utilities is charged as industrial use. The tariffs for industrial use in most countries with high-income economies are lower than those for residential use, but in most EMDEs, cross-subsidies (as in the water sector) are applied (Foster & Witte 2020). This increases electricity tariff rates for water utilities. Depending on the specific region, this effect could erase or even over-compensate for the often lower than average energy prices. In short, efforts to lower the energy bills for water utilities in EMDEs can often be as cost efficient as those in high-income economies.

Investment costs

Technical equipment, especially that used to reduce NRW (such as leak detection equipment or pressure management valves) and to increase energy efficiency (such as pumps), is almost exclusively produced in countries with high-income economies. Therefore, the investment costs for such equipment, including shipment, duties, insurance and retailer margins, are often up to 50% higher in EMDEs than in the countries of manufacture. This also frequently applies to “smart” equipment (such as smart valves, meters and pumps), although software products tend to be exceptions to this rule. However, as labor costs are normally much lower in EMDEs (see below), the installation costs of fixed equipment (such as smart meters) can be much lower, something that can compensate at least in part for the higher purchase costs.

Particularly relevant for larger investments are the frequently higher financing costs (interest rates)[2] in EMDEs, which may make investments with long payback times unfeasible.

On the other hand, many utilities in EMDEs, especially but not exclusively municipal or state-owned utilities, are frequently not the only ones investing in their infrastructure. They also receive grants or low-interest loans from national and international financial institutions and, in many cases, this external financing is the main source of new investments in infrastructure. Although this is not without its disadvantages, especially when it comes to sustainability, it also opens up opportunities for digital applications where the environmental aspect has greater importance for external investors than the utility itself.

[2] https://www.global-rates.com/en/interest-rates/central-banks/central-banks.aspx

Labor costs

Saving high labor costs through digitalization is a major motivation in many aspects of NRW management in countries with high-income economies – for instance, in permanent monitoring solutions for leak detection or remote water meter reading. Depending on the geographic region, this could also be a factor in some LAC or MENA countries, although it is much less significant in sub-Saharan Africa or South Asia countries, where labor costs are extremely low (Figure 3).

2.2 Technical factors

Levels of non-revenue water

Levels of NRW differ markedly even between countries with high-income economies, ranging from single digit percentages in Germany, the Netherlands, Denmark, Korea and Singapore, to around 25% in countries like Italy, Spain and the UK. In EMDEs, the share of NRW is consistently between 30% and 60% of water production, although the often non-existent measurement of water production is a major statistical shortcoming. Higher levels of NRW have important implications for digitalization, which will be discussed below; but, in general, the digital solutions needed to bring NRW down from 45% to 40% are completely different from the solutions needed to bring it down from 15% to 10%. Also, the accepted NRW indicator, expressed as water losses based on production, is not necessarily an optimal indicator for comparisons. It is also reasonable to compare levels of water losses based on the number of connections, the length of the network, or liters per capita lost (Figure 4). Recent studies show that although the underlying trend is the same, the differences between countries and regions are somewhat smaller when using these indicators. This is an ongoing discussion and all indicators have their shortcomings and advantages.

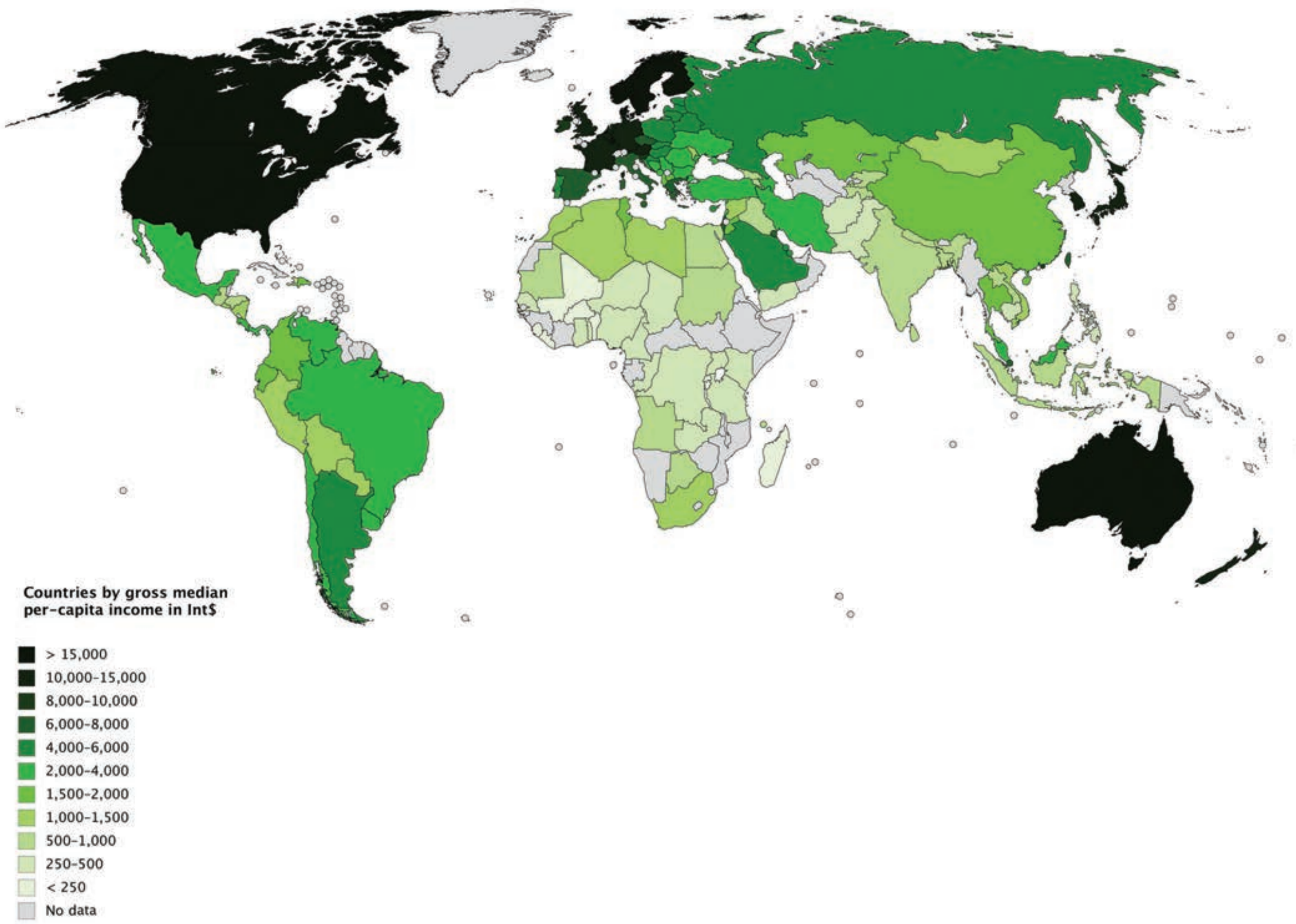


Figure 3. Gross median per-capita income at purchasing power parity (based on Phelps & Crabtree 2013)

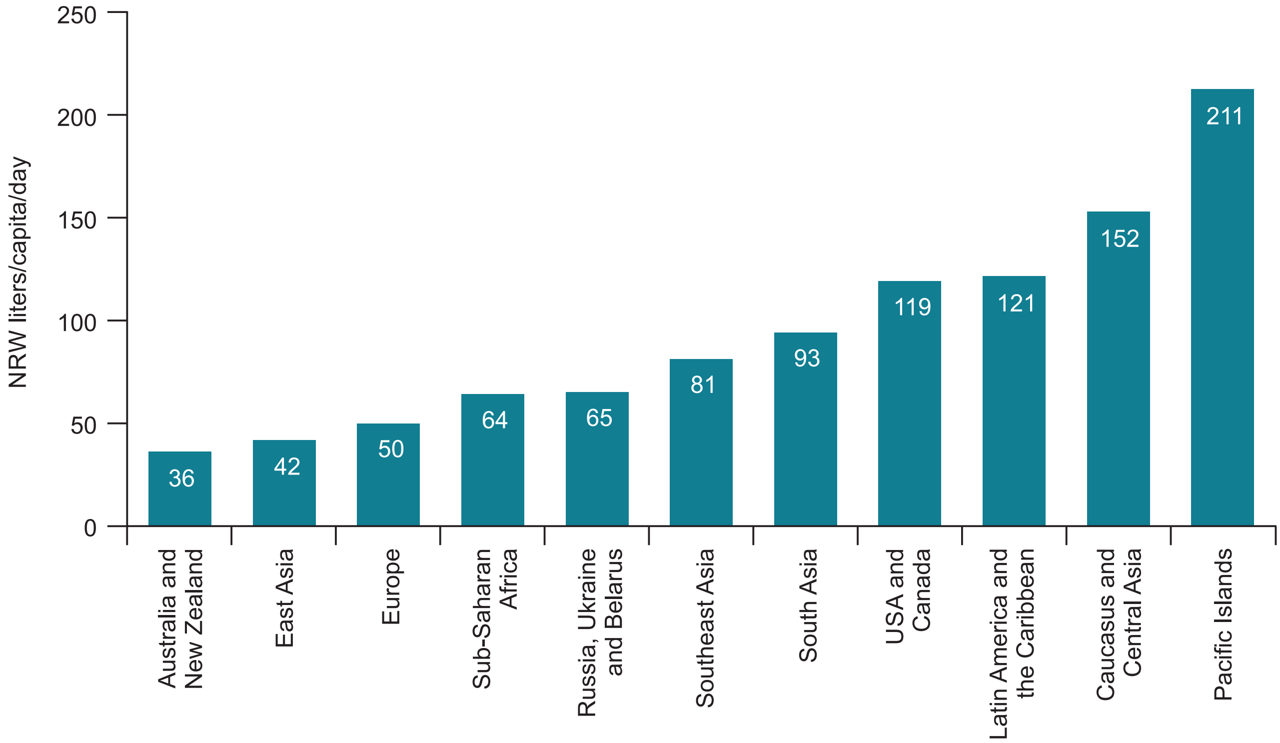


Figure 4. Non-revenue water (NRW) expressed in liters/capita/day (Liemberger & Wyatt 2019)

Levels of commercial losses

Due to their nature, commercial (apparent) losses are often difficult to estimate, especially when it comes to unauthorized consumption or water theft – something that is almost unknown in many countries with high-income economies. A World Bank report estimated the levels of commercial NRW losses in EMDEs to be almost five times higher than those in high-income countries, accounting for around 40% of NRW (Kingdom et al. 2006). As reducing commercial losses, rather than physical (real) losses, normally leads to a greater increase in revenue, it is often considered "low-hanging-fruit" in NRW reduction. This implies that solutions in this field, whether digital or not, must be a major focus of NRW management in EMDEs.

Intermittent supply

Intermittent water supply affects around a billion people globally; almost all of these live in EMDEs, where more than 40% of the population with drinking water connections can make use of them only part-time (Laspidou & Spyropoulou 2017). This has major implications for NRW management as well as for energy efficiency, including:

- A higher infrastructure degradation rate (more leaks);
- A higher degradation rate of pumps and severe energy loss due to operation far outside optimum ranges (low pump efficiencies and wear due to cavitation);
- Greater difficulty in finding and locating leaks – many pre-location and location methods do not work in these conditions;
- Erratic water meter readings due to air in the pipelines which partly escapes through service connections because air release valves in the distribution network are often not maintained and are not designed to evacuate large quantities of air;
- A higher degradation rate of many types of water consumption meter;
- Easier access to networks for illegal installations;
- Installation of many pumps at the household level, decreasing the overall energy efficiency of the system.

Technical cadastres

A common problem in countries with high-income economies is poor knowledge of the buried infrastructure (mainly piping). In EMDEs, this problem is even more widespread, as political and social pressure often leads to new networks being installed without proper planning. Because utility companies are not involved during commissioning and handover, new networks are often put into operation without documentation of their characteristics. Often only older field staff have knowledge of the actual locations, materials and diameters of the network infrastructure, and these details are not formally recorded anywhere. This has major implications for the management of NRW, because:

- Many leak localization techniques require precise knowledge of the location and characteristics of the network;
- Any hydraulic, pressure or flow model requires precise data;
- The schedule for maintenance and renewal of fittings such as valves and pipes relies heavily on such information.

Maintenance capabilities

Since systems and equipment are often offered through inadequately equipped or trained intermediaries, there are frequently bottlenecks when maintenance or repair is required. This can jeopardize sustainability or increase costs. Often there are no maintenance budgets and the recipient utilities do not have direct access to the manufacturer; for example, through a service contract. Due to the multiple donors and contracts involved, it is almost impossible for the recipient utilities to standardize materials and equipment.

2.3 Social factors

Crime rate

Many cities in EMDEs, especially those that are densely populated, for instance in LAC countries, are characterized by high crime rates (Numbeo 2020). This often has a direct impact on the management of NRW due to, for example:

- Theft of installed equipment such as water meters, control valves or sensors;
- A higher incidence of water theft by meter tampering, illegal installations or reconnection of services that had been cut off;
- Dangerous work conditions for utility personnel, especially, but not exclusively, commercial staff.

Population growth, urbanization and growing access to water

Populations are growing much faster in EMDEs (Figure 5) than in countries with high-income economies. Due to migration, growth is particularly rapid in urban areas (Figure 6) and access to drinking water in these urban areas is also increasing (Figure 6). Consequently, the overall importance of NRW and energy efficiency in EMDEs is increasing exponentially. This in turn means that in many areas, economies of scale in water supply and wastewater treatment become increasingly relevant.

There is a third effect that could be of even more importance for the subject of this document: in the coming years and possibly decades, a much greater share of investment in the water and sanitation sector in EMDEs will go into the extension of systems, including through new pipelines and treatment plants. The implementation of many digital solutions to reduce NRW and to increase energy efficiency is often much easier to achieve (and less expensive) if

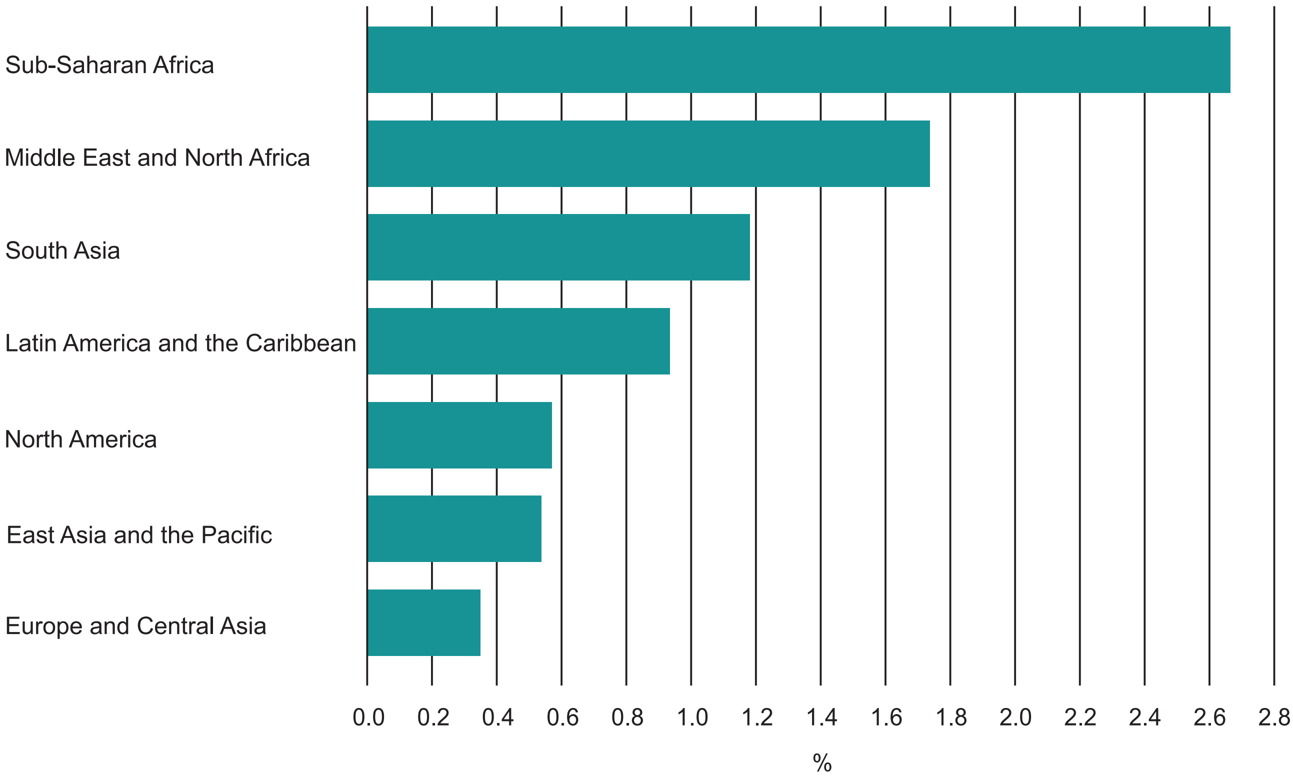
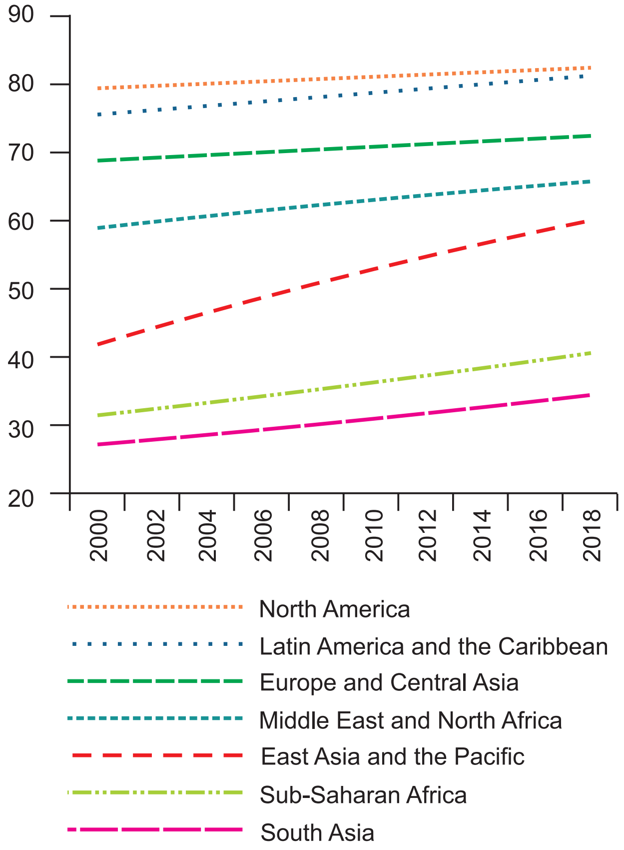


Figure 5. Population growth rate (%) by region, 2019 (Source: World Bank 2020)



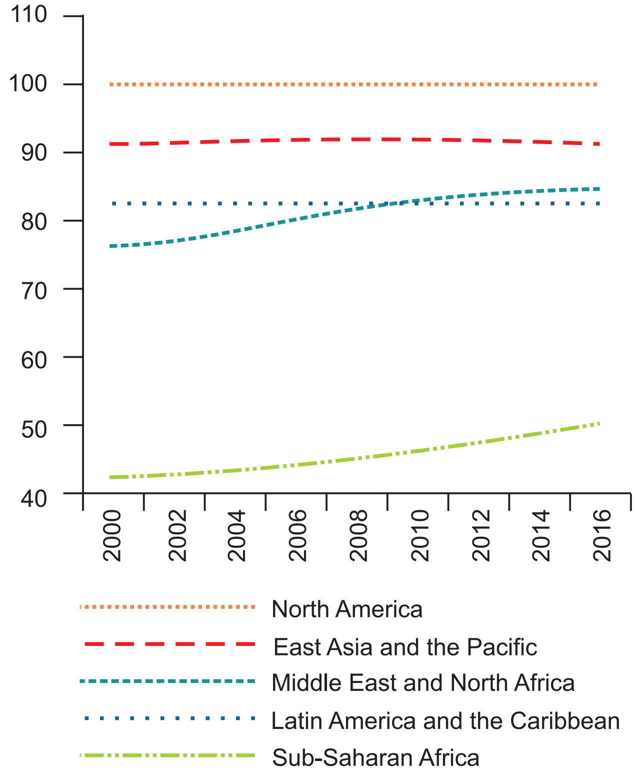


Figure 6. Left: Urban population, % of total population increase 2000–2019 (Source: World Bank 2020); Right: People using safely managed drinking water services, % of urban population 2000–2017 (Source: World Bank 2020, no data for Europe and South Asia)

it is undertaken during the construction phase of a system rather than by retrospectively adapting existing systems.

Staff turnover

Due to political influences, the staff of utilities in EMDEs often changes and rotates, making it very difficult to have appropriately qualified and experienced personnel available for the important tasks of NRW and energy efficiency management. Low wages in the utilities also make it difficult to contract or retain qualified and experienced staff. This is frequently a major threat to the sustainability of NRW and energy efficiency programs and must be considered when dealing with digital solutions. Solutions that rely mostly on human resources with digital competence to operate and maintain the digital systems in place – e.g. for data management, security management and IT administration – have been proven to be unsustainable in situations where staff turnover is high. In some cases, outsourcing can be a good strategy for mitigating this risk.

Poverty

Very low-income households are a widespread reality in EMDEs and must be considered when dealing with NRW for several reasons:

- The cross-subsidies discussed above could make consumption metering a loss-making business;
- People who cannot legally access drinking water for economic reasons will gain access to drinking water anyway, increasing unauthorized consumption;
- Fee collection management could prove to be very difficult or impossible in certain circumstances.

2.4 Legal framework factors

Legal certainty

The legal systems in many EMDEs are weak, slow or struggling with corruption. This could have several negative implications for efforts to reduce NRW and improve energy efficiency, including:

- Long delays to projects due to problems between utilities and contractors;
- Water theft going unpunished, leading to more unauthorized consumption;
- Less contractual certainty leading to higher costs for goods and services (outsourcing).

Information privacy and data protection

In many EMDEs, legislation on information privacy and data protection is weak or not strictly enforced. Although this may help in obtaining relevant customer data in certain cases, for instance for online billing or analysis of possible illegal consumption, a lack of data protection could also result in the abuse of customer data; for example, the use of smart meter data to analyze when properties are likely to be unoccupied and thus more vulnerable to thieves, or the use of client contact information to facilitate unwanted advertising.

Electricity feed-in rights

Smart solutions for the generation of electricity, for instance during wastewater treatment or with turbines, are often near impossible to implement in many EMDEs as a result of long-term, virtually monopolized energy generation and distribution contracts, preventing water utilities from accessing feed-in rights.

3 Digitalization to reduce commercial water losses

3.1 Data mining for identification of illegal consumption and meter under-registration

Unauthorized consumption by customers of water utilities is often difficult to detect in the field and requires the use of advanced technologies and specialized human resources. To use these resources cost efficiently, they must be prioritized where there are solid indications of unauthorized consumption. These indications can be obtained by data mining – identifying and analyzing existing data from water utilities' billing systems, including customer history and consumption patterns. This can generate lists of customers with suspiciously low consumption that can be attributed to either failure of the consumption meter, errors in registry data or unauthorized consumption.

Depending on the availability of data, other factors such as (commercial) customer complaints, records of unauthorized consumption and payment behavior can be included in multivariate analyses for more precise results. In some cases, it may also be possible to access information about a customer's electricity consumption. This is easily achieved where water and energy are supplied by the same utility, but is also possible via constant data exchange between two operators, as both will benefit (electricity theft is often an even bigger problem than water theft). Among other things, this information exchange may make it possible to identify users who are registered for one service but not the other, customers who are registered for both services but for whom consumption of only one of the services is recorded, and finally those customers whose consumption drops for only one of the services.

The data can also be used to predict meter failures (under-registration), taking into account the date of installation of the meter and the consumption (m^3) registered. The lifespan of meters depends on many factors, such as the frequency of service interruption, water quality and water pressure. Statistical analysis of the consumption histories of large groups of clients can help reach conclusions about the lifespan of meters under local conditions, something that is helpful not only for specific cases of suspiciously low consumption but also for helping managers decide when meter renewal is required to avoid NRW caused by meter under-registration. Combining details of consumption history with meter testing carried out by the utility can further inform this analysis. Finally, pre-existing data from the billing system can be used to identify fraud by field staff, by comparing , for example, meter reading information with customer complaints and (disconnection) dates with payment dates.

Depending on the size, quality and complexity of the data, such analysis may be considered a form of big data analysis.

Example

AQUAPRED software has been developed by Aqualogy (Suez Group) for the identification of irregularities in water consumption. It uses data mining through knowledge discovery in databases, meaning that its outputs are constantly being improved by adjusting the parameters assessed using real findings from field inspections triggered by the software. It was used first by Aguas Andinas in Chile, where 88,000 inspections were carried out following pre-identifications by the software, and 12,700 cases of unjustified irregular consumption were found.[3]

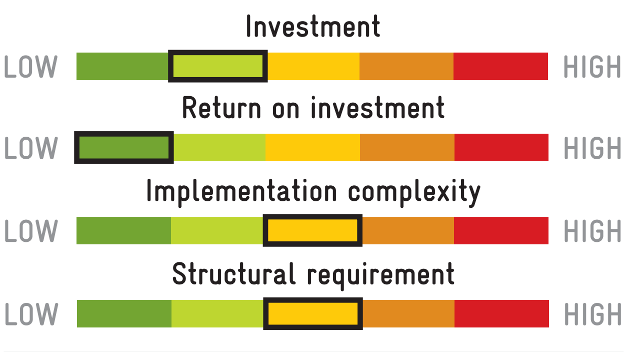
Conclusions and outlook

As water meter coverage is increasing worldwide, the proportion of NRW arising from unbilled and unmetered consumption is falling, while the proportion arising from unauthorized consumption and meter inaccuracies is rising. Therefore, applications like the one described above are of increasing usefulness. Statistical analysis of consumption histories has been carried out for many decades, particularly in the electricity distribution sector, where consumption metering has a much longer history. However, a recent development is the potential to use machine learning, informed by data from previously detected cases, to more accurately predict whether a drop in recorded consumption corresponds to a case of water theft or a case of meter failure, thus decreasing the number of false positives and undetected cases. This type of application is likely to be used more extensively in the near future.

[3] http://www.enerlogy.aqualogy.net/cl/en/notable-technologies/aquapred

This application is highly recommended for operators with high metering indices and especially for those with a high incidence of unauthorized consumption. It has three key characteristics. Firstly, it presents economies of scale, in the sense that the investment and operating costs are much lower for larger utilities. Secondly, its integration into billing software can greatly facilitate its implementation, so local or national solutions are preferable to ready-made individual software solutions, although this would make implementation more complex. Thirdly, it requires a certain level of commitment from the utility, as well as the economic capacity and human resources necessary to act on the results of the analysis.

INVESTMENT AND FEASIBILITY RATINGS



3.2 Customer apps

Customer apps are already used worldwide by utilities with varying success. In EMDEs, the apps are mainly used for billing and payment. Experience has shown that these apps can be useful for much more, for instance:

- Making the billing process transparent to customers: certain apps can facilitate paying via credit or debit cards or provide barcodes to make payment easier via authorized agents (Figure 7). The locations and opening hours of these agents can be indicated via integrated Google Maps;
- Allowing customers to check their registered data and request changes (address, type of use, etc.). This information is automatically forwarded to the relevant commercial unit of the water utility;
- Enabling customers to receive alerts for planned service restrictions in their area, allowing them to prepare in advance; they can also be alerted if they are to be disconnected due to non-payment, to give them an opportunity to settle their account and prevent the disconnection;

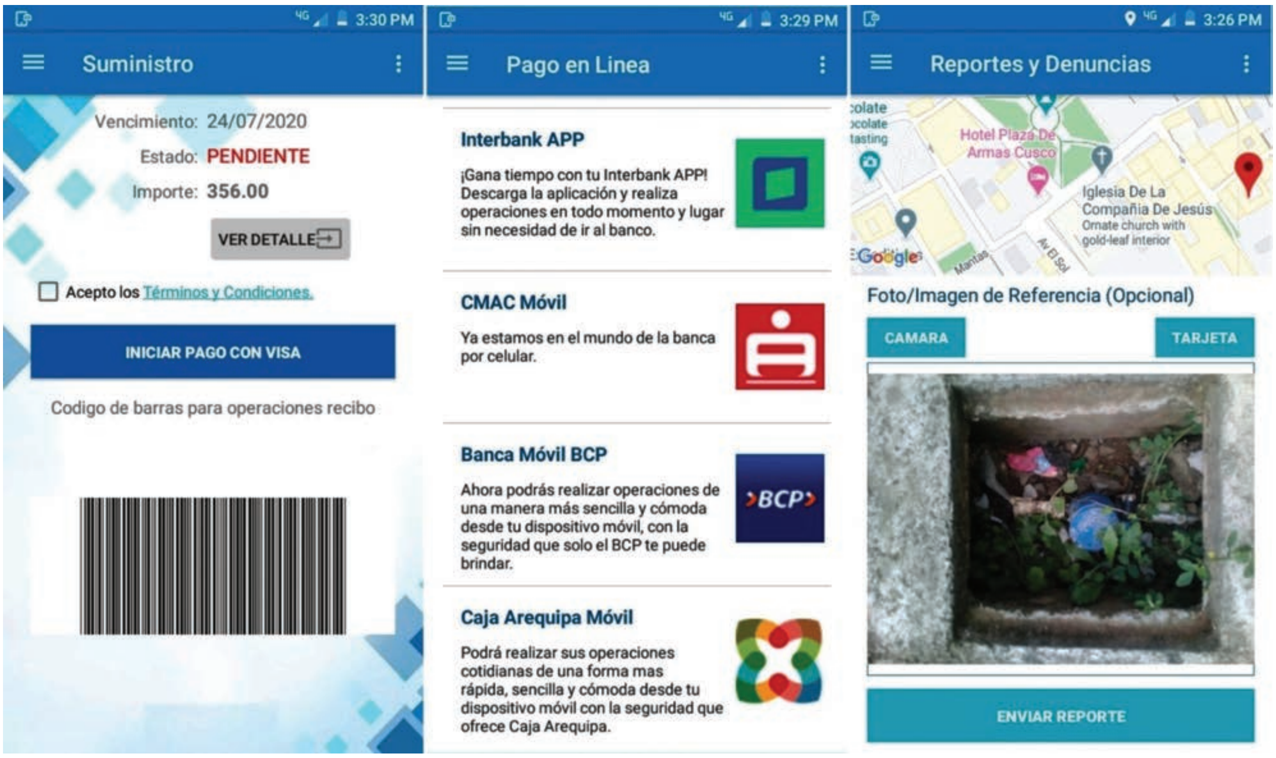


Figure 7. Screenshots Costzmer App (Source: SEDACUSCO, Peru)

- Allowing customers to report illegal connections, meter tampering or illegal reconnections. This information is automatically forwarded to the relevant commercial unit of the water utility;
- Allowing customers to report leakages or sewer overflows with a short description and photos of the leakage and its location marked. This information is automatically forwarded to the relevant operational unit of the water utility;
- Channeling some types of commercial complaint (such as meter reading errors). The status of all complaints can also be checked through the app, meaning that customers do not have to approach the utility for an update;
- Providing options for suggestions mailboxes.

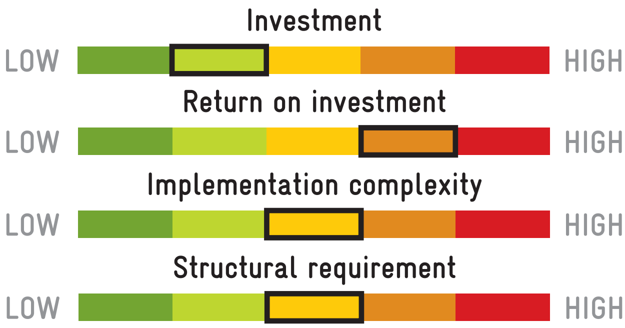
Example

This type of app is already available for download in many countries, although many are struggling with technical problems. An example of an app with most of the characteristics described above is the National Water and Sewerage Corporation (NWSC) Mobile app (Nairobi, Kenya).[4]

Conclusions and outlook

This type of app is already well established in many countries and utilities worldwide – just search for "water bill" in Google Play. The main barrier seems to be market penetration – the majority of customers are still not using these apps (although the COVID-19 pandemic has given many an incentive to do so). An obvious reason for this is that having an app for each separate public service can be cumbersome for users. Thus, to increase their use, a possible way forward may be to integrate water utility apps with apps for other public services (such as telecommunications and electricity) or with apps for useful services such as information about cultural and sporting events. Due to differences in national regulations (tariff structure, complaint management), these apps must be developed at a local or national level. However, since the functions of the apps are similar worldwide, a kind of "meta-app" is conceivable, to help develop local or national apps more quickly. A major challenge for these apps is the need for constant maintenance, and a lack of this is the main reason for the frequent low levels of user satisfaction. As with most software products, these apps offer important economics of scale.

INVESTMENT AND FEASIBILITY RATINGS



3.3 Localization of illegal connections with ground-penetrating radar

With unauthorized consumption of water forming a major component of NRW, it is important that it is properly addressed. A digital application that has been increasingly used in recent years for detecting and localizing illegal installation is ground-penetratring radar (GPR).

GPR emits ultra-wideband electromagnetic waves into the earth and records the reflections produced by different layers, which vary according to the material's conductivity. The depth at which the reflection is created is calculated by measuring the time between the initial transmission of the signal and the receipt of its reflection. The device is pushed slowly across the surface to be investigated (Figure 8, top) and the results of the scan are displayed on a screen connected to the measuring device (Figure 8, bottom). Scans can indicate the presence of buried objects (such as illegal water pipes) and can be analyzed further using additional software tools to enhance data interpretation, for instance to avoid false positives.

The main advantage of GPR over other non-digital methods (such as endoscopic cameras and acoustic methods) is that it is non-invasive – it does not require network access points. GPR can also be used to carry out technical surveys, locating buried infrastructure such as water and sewer pipelines, valves or cables.

Example

GPR is already in widespread use by several utilities in Latin America. A comparison of this technology with other methods for locating illegal connections was recently carried out and the results are available in English and Spanish (Ziemendorff & Kersting 2020 a, b).

[4] https://play.google.com/store/apps/details?id=com.nwsc.mobilepayment

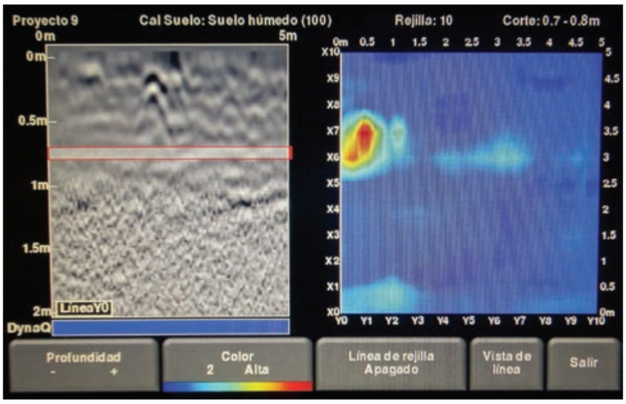
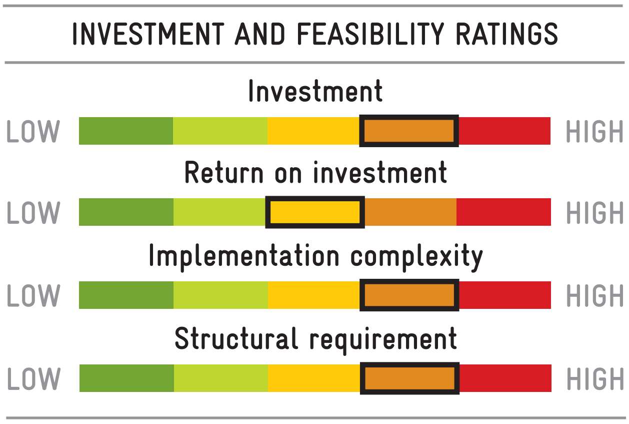


Figure 8. Top: Ground-penetrating radar being used to search for illegal connections (Source: Teony Alva); Bottom: Radargram (Source: Author)

Conclusions and outlook

Although the costs of the equipment have dropped considerably in the past decade and GPRs are now also increasingly user-friendly, this method has frequent limitations in its use (being affected by salinity or a high clay content in the subsoil). Also, without good training and experience the results are often proven to be suboptimal.



3.4 Detection of illegal bypasses by statistical analysis of pressure transients

A very common method of water theft is the "bypass" – a deviation from the customer's legal connection that bypasses the water meter. This type of illegal installation is almost impossible to find with common methods for detecting and localizing illegal connections, such as GPR or electro-acoustic methods.

Therefore, a new easy-to-replicate method was recently developed in Peru. It consists of creating a water hammer in the suspicious connection by closing the control valve of the connection quickly. The resulting hydraulic pressure transients are then recorded at a frequency of 100 times per second by a data logger for pressure transients. The data are analyzed graphically using special software which allows visualization of differences between a connection with a deviation and a connection without a deviation (Figure 9).

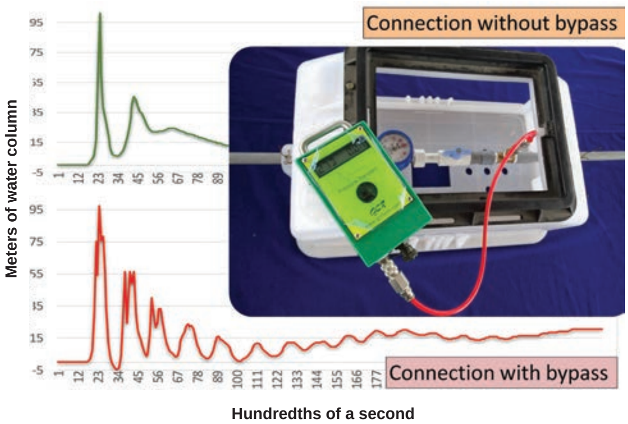


Figure 9. Detection of illegal bypasses with a hydraulic transients data logger (Source: Author)

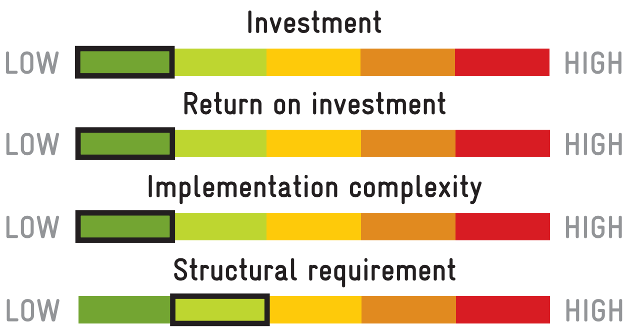
Example

The method was published recently in English and Spanish (Ziemendorff et al. 2020 a, b). It includes software simulations to determine the limits and scope of the methodology.

Conclusions and outlook

This very new method has yet to achieve widespread adoption and requires greater awareness of its existence among water utility companies. A first step towards this was recently made with the publication of the method in Spanish and English. This low-investment method, with equally low operating costs, easy application and immediate results, should be used by any utility that has problems with unauthorized water consumption by customers with meters. To make it more user-friendly, it would be helpful if the results of the pressure loggers were analyzed on site; for example, through an app for tablets or cell phones that allows the results to be visualized immediately alongside typical patterns to facilitate their correct interpretation.

INVESTMENT AND FEASIBILITY RATINGS



3.5 Smart metering for principal customers

A smart meter is a consumption meter that registers, stores and provides data that are useful for more than the simple metering of consumption for billing purposes. A smart meter is not defined by the type of meter used to register the consumption (velocity, volumetric, ultrasonic or other), but rather by the storage and transfer of data for analysis purposes. Smart metering is the successful use of these data and if the data provided are not used, then the smart meter becomes a "dumb meter". Smart metering can offer a utility the following benefits:

- Cost savings in water meter reading and data transfer to the billing system;
- Reduction of intentional or accidental data registration and transfer errors;
- Registration of maximum flow rates for the correct dimensioning of water meters;
- Detection of unusual consumption, e.g. constant night flow for internal leak detection;
- Detection of irregular consumption patterns that could indicate unauthorized consumption;
- Registration of night consumption to be used in a minimum night flow calculation for leak detection in networks.

Following the same logic, smart metering can be considered a very good option for principal customers in EMDEs because:

Is it feasible?

For several reasons the cost–benefit ratio is insufficient to support the widespread use of smart metering for domestic users in EMDEs:

- Cost savings are not as significant as labor costs are much lower;
- Widespread stealing or vandalizing of meters can lead to loss of investment;
- Low, often cross-subsidized water tariffs for domestic users, combined with higher investment costs, often make it impossible to achieve payback of the investment.

For instance, if a customer is billed less than US$ 3 per month, it would be least five and a half years before the cost of the smart meter had been covered – and this does not include the costs of the actual billing procedure and the service itself. But this is what happens to more than 90% of customers in large parts of South Asia, sub-Saharan Africa, the MENA region, Central America and, to a lesser degree, in other EMDEs.

- Higher tariffs for and higher consumption by principal customers make the return on investment much faster;
- These higher tariffs and levels of consumption mean that unauthorized consumption is much more widespread among principal customers;
- The meters of principal customers are usually read more frequently (e.g. once a week) and therefore savings on meter reading costs are higher;
- The registration of maximum flow rates is important for this type of client, not for domestic users;
- Night consumption is considerably more important for principal users than for domestic users and the data gathered can be sufficient to make minimum night flow calculations for leak detection.

Figure 10. Smart metering with automated meter reading (Source: Elaine Cheung)

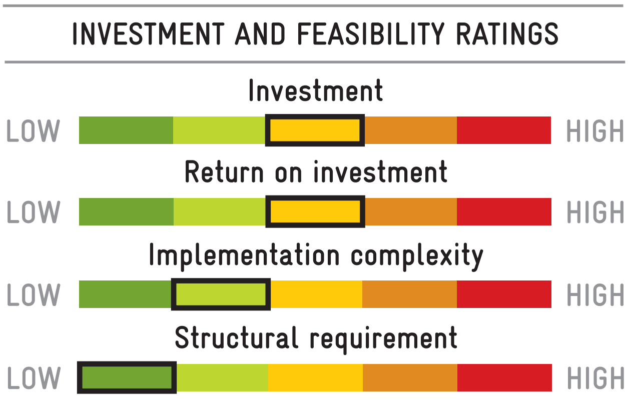
The threshold for determining when a customer is considered a principal customer will vary from place to place, according to factors such as tariffs, m^3 consumed and incidence of unauthorized consumption, but in most countries smart metering for a portion of these clients should be a good alternative.

Example

A major project to install smart meters is currently underway in Jordan´s capital Amman, with 400,000 smart meters already installed.[5]

Conclusions and outlook

As water tariffs show an increasing trend globally and smart meter costs are decreasing, the penetration of smart meters is likely to gradually expand to more consumer groups. An issue yet to be thoroughly investigated is how to prevent tampering with and vandalization of smart meters. Although suppliers of this equipment frequently report that meters are not subject to tampering, the experiences of the electricity sector, in which smart metering is much more advanced, have shown that this is not true. Another lesson from the electricity sector is that there are cybersecurity issues, with a need to avoid data hacking for tampering purposes and to protect customer data.



3.6 Apps for commercial field staff

The economic unfeasibility of installing smart meters on a domestic level does not mean that meter reading in that segment cannot benefit from the technological advances offered by digital apps. Meter readers can register readings through an app to avoid transcription errors, which often occur when consumption is registered manually and then copied to billing systems, thus reducing unnecessary customer complaints.

These apps can include multiple additional features, converting the meter reader into the "eyes of the utility", something that is impossible with smart metering. For example, apps can:

- Track the itinerary of the meter reader to avoid phantom (invented) readings (Figure 11) and also help the reader to find a meter more quickly –

5 https://www.iotsens.com/effective-solution-for-water-management-in-amman

finding the location of a meter often takes more time than the reading itself;
- Provide real-time feedback if a reading is not consistent with the previously registered consumption; for instance, because it is lower than the last reading or the difference is more than the double the average consumption of the user. In these cases, the reader receives an alarm and can check the meter again;
- Automate optical meter reading, independent of the meter type;
- Provide on-site printing of bills after a meter reading;
- Report the meter or meter box condition, indicating whether it has been tampered with or vandalized or is missing or otherwise impaired, or record reasons why a meter is impossible to read, etc.;
- Report the condition of the connection, including signs of illegal connections, illegal reconnections where the connection has been cut off, leaks in the meter box;
- Provide dynamic cadastral updates, automatically reporting any change in the circumstances of the customer or the condition of the meter, including changes in tariff category, use of services (non-registered sewer connection), or number of domestic units served by the connection.

Figure 11. Tracking of field personnel (Source: GIZ/PROAGUA)

Likewise, apps with similar characteristics can be used by the distributors of bills and the staff in charge of disconnection and reconnection, or can be integrated in a single app that can be used by all staff. Apps for registering leaks and their characteristics can be extremely useful, as described in Section 4.

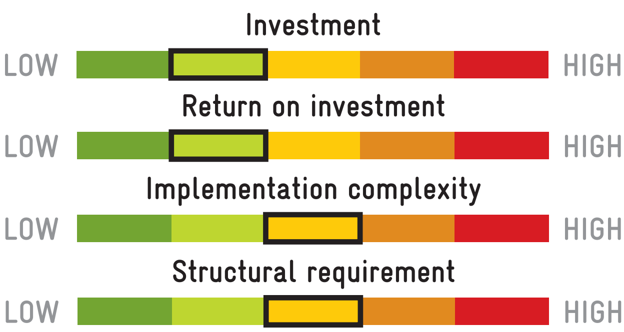
Example

Apps that include some or most of the functions described above have been used by several utilities for more than a decade in Nicaragua, Kenya and Peru.

Conclusions and outlook

Most of the apps described have reached the market in recent years and are just beginning to gain a foothold in increasing numbers of water utilities. The process of market penetration, expansion of functionality, improvement of user-friendliness and reduction of susceptibility to errors will overlap in the next few years. In particular, some technical limitations are expected to be overcome; for example, many cell phones do not have sufficient battery capacity to allow continuous intensive use of various functions (geolocation, internet, camera, etc.) over an eight-hour shift. There are still many areas without cell phone coverage and the optical reading precision of phones is still less than that of the human eye for dirty or scratched meters. Again, these types of app offer significant economies of scale but need constant maintenance and updates, and in certain cases they are not useful if the data obtained is not used.

INVESTMENT AND FEASIBILITY RATINGS



4 Digitalization to reduce physical water losses

4.1 Multipurpose geographic information systems

Geographic information systems (GIS) are systems for the acquisition, processing, organization, analysis and presentation of spatial data. Their usefulness lies in providing information that is easy to obtain and process for almost all areas of a utility, including many commercial and operational uses linked directly to the reduction of NRW. Because of the large number of potential uses, only a few are mentioned here:

- Geolocation of all elements of the network (Figure 12), helping field staff to find them quickly – for instance, valves for maintenance or flushing, meter boxes for meter reading, properties for invoice distribution;
- Instant access to information about materials, diameters and other characteristics of leak sites, enabling leak repair staff to assemble the right materials and spare parts;

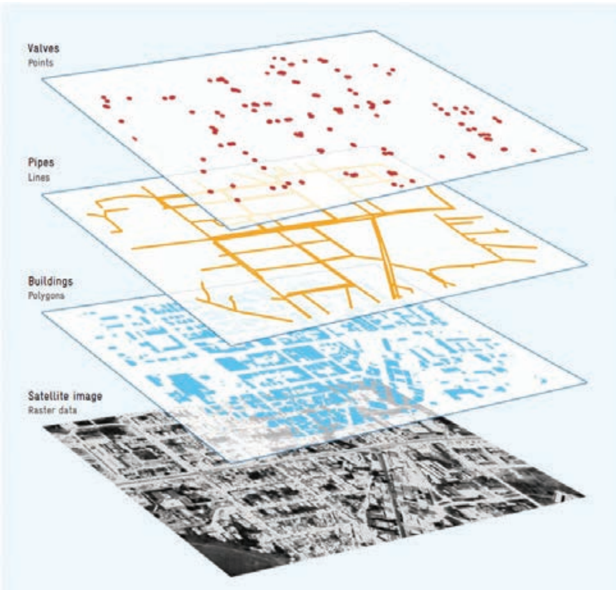


Figure 12. Representation of different types of data in GIS (Source: Baader et al. 2011)

- Real-time calculation of the budgets and materials necessary for new connections, enabling applications without prior inspection, saving time and money;
- Provision of thematic maps for commercial inspections to find illegal connections, under-registration or tampering of water meters, etc.

Such systems can serve as a basis for, and be interconnected with, the applications described in Sections 3.1, 3.6 and 4.3.

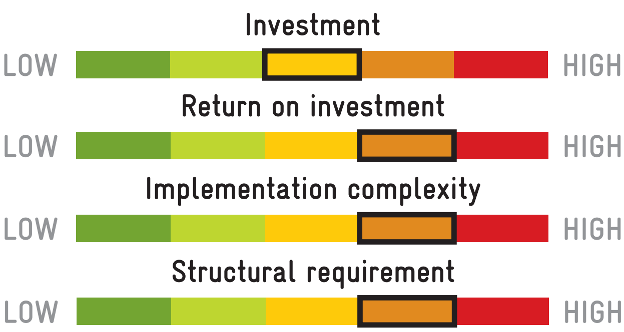
Example

GIS have been implemented and/or improved by GIZ in many utilities worldwide, including in Brazil, Peru, Cambodia, Tanzania, Egypt and Jordan.

Conclusions and outlook

GIS are one of the oldest and most established digital technologies globally. However, in many circumstances much of its potential is not fully exploited. These types of system regularly require new data – a demand that is frequently not satisfied, reducing their effectiveness. Training and support services, such as those provided by GIZ, are often required to solve both problems.

INVESTMENT AND FEASIBILITY RATINGS



4.2 Use of drone technology

Drone technology has developed very rapidly in the past decade, expanding into new fields of use, becoming much easier to handle and incurring lower associated costs. The following applications are particularly relevant for the management of NRW:

- **Mapping drones.** The latest generation drones, so-called RTK (Real Time Kinematic) drones, allow a centimeter-precise measurement of flying altitude above the ground which, when combined with GPS (the Global Positioning System), allows measurement and recording of topography combined with real images (Figure 13). This is a great, cost-efficient application for combined commercial and technical registries. The high-resolution, georeferenced images can show items like meter boxes, valve caps, drain boxes and elevated tanks, and can be a very quick shortcut to information that is otherwise difficult and very labor intensive to obtain.
- **Thermal imaging drones.** Thermal imaging can be used in some well-defined conditions (good capillarity of soils, big temperature differences between the water and the soil) to pre-locate leaks in very large areas.
- **GPR drones.** Drones with mounted GPR are especially useful for the mapping of long pipelines whose location is unknown. Mapping of the exact location is often a necessary first step for leak detection or rehabilitation measures. GPR is, however, limited to some well-defined conditions, especially regarding soil composition.

Example

Several Peruvian utilities have used mapping drones to compile commercial and technical registries. One of the major findings has been that the topographic information collected by this technology was not only more precise and faster to obtain but also seven times cheaper to acquire than that obtained with traditional methods (topographic stations).[6]

Conclusions and outlook

Some of the described uses of drone technology will remain fairly niche in the future, because they are used in specific uncommon situations. However, other applications, such as mapping drones, will most likely experience a rapid worldwide breakthrough because of the huge cost advantages they offer when

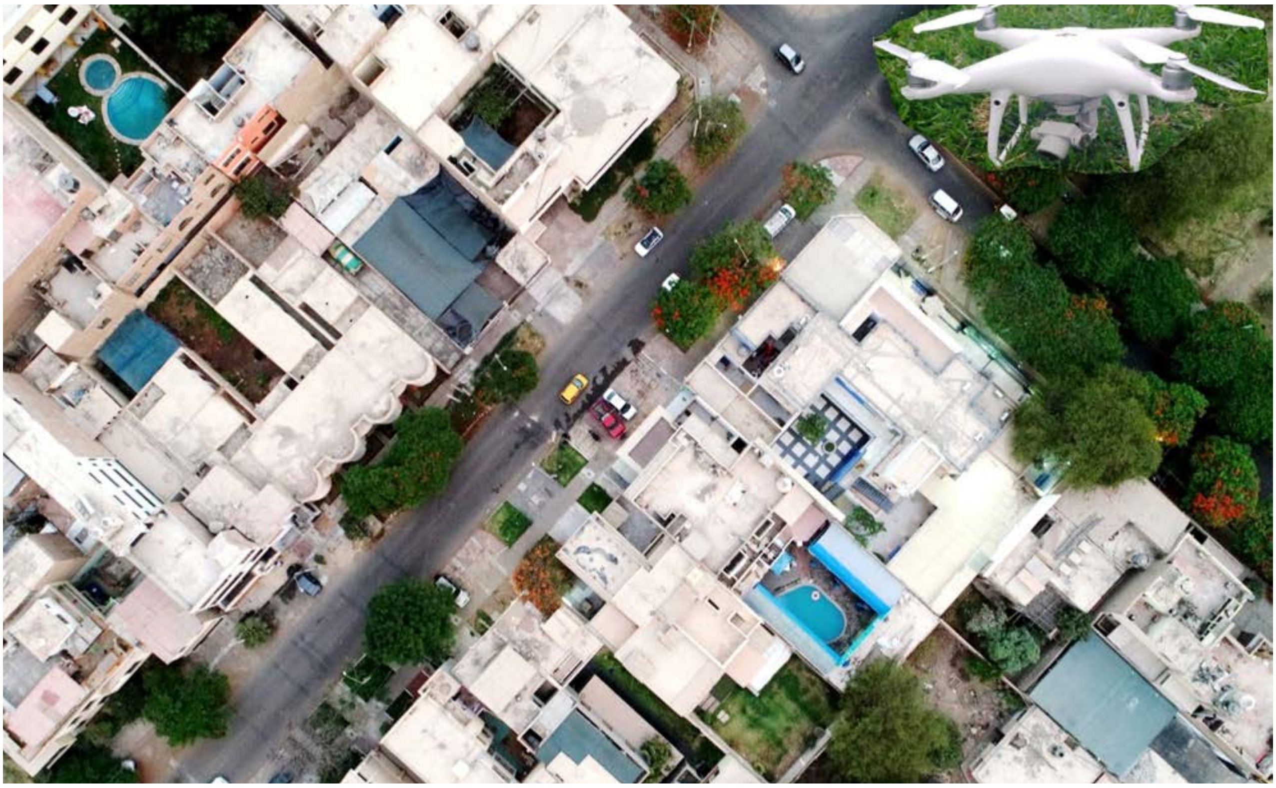


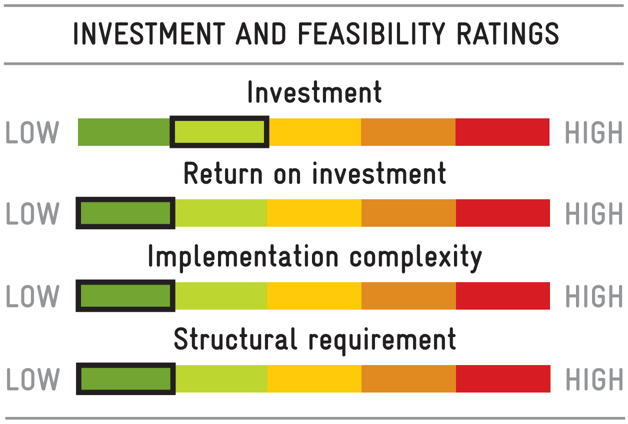
Figure 13. Mapping drone (Source: Oscar Perfecto Rodriguéz)

[6] https://web.otass.gob.pe/publicaciones/otras-publicaciones/5050-implementacion-de-la-cartografia-en-eps-en-rat.html

Is it feasible?

An application that has generated a lot of interest in the water sector worldwide is the satellite detection of leaks. This uses light detection and ranging (LIDAR)-type radar that can penetrate two meters into the subsoil and identify drinking water in areas of 70 km x 70 km. For large cities, especially, it is a cost-efficient tool to pre-locate many leaks very rapidly. The problem with the application of this technology in EMDEs is its level of precision: it indicates a probability of 50% that a leak exists somewhere in an area with a margin of error of 150 meters which then has to be searched using conventional pinpointing methods. For utilities with very few leaks, large areas without leaks can be discounted and leak detection teams efficiently allocated. But for utilities with high leakage rates (common in EMDEs) a satellite is not needed to obtain this information, as large areas are already known to have leaks. Also, in areas with intermittent water supply, the satellite often will not detect leaks if the flyby time does not coincide with the service time.

compared to traditional methods. Mapping drones should be considered as a user-friendly and cost-efficient alternative, particularly for topographic surveys, technical cadastres and integrated (commercial–technical) cadastres, although local exceptions (legal frameworks for drone use, areas with extensive arboreal vegetation) may occasionally occur. In some countries, the security situation can also be an issue. The chart below refers to mapping drones, not to other types of drone use.



4.3 (Big) data analysis tools for prioritization of active leakage control and preventive asset management

Leaks in water mains do not normally occur spontaneously or accidentally but because of underlying conditions, including aging infrastructure, poor workmanship, seismic events, heavy traffic, frequent and strong water hammers, and soil conditions. Many of these factors are not known about by water utilities, especially when it comes to previous unrecorded events. But there are also a lot of existing data that, used in a smart way, can be very helpful in prioritizing measures for active leakage control by predicting where leaks are more likely to occur. To that end, it is necessary to register the characteristics of all visible and non-visible leaks detected and compare these characteristics with data from technical registries. This can allow prediction of which elements of the networks (e.g. old iron clamps for service connections or certain types of valves) or which service zones (for instance, those where the network is aging or where there are high pressure conditions) are most likely to present leaks and what size these leaks are likely to be. With this information, it is possible to prioritize leak detection, localization and repair measures and help field staff to

Is it feasible?

Other, more advanced, leak prediction models that involve the heavy use of sensors, supervisory control and data acquisition (SCADA) systems or even digital twins, are much more precise, but also exponentially more expensive, especially for utilities that lack the data required to feed into those systems, including those with incomplete or non-existent technical cadastres or many non-metered or illegal connections. Also, for utilities with very high levels of NRW, the required precision for leak prediction is much lower, because the intention should then be "where do we start with leak localization and repair?", not "let's repair every leak the very moment it occurs".

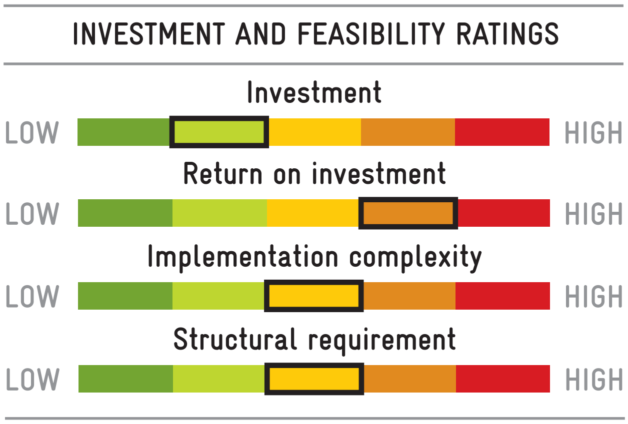
find the leaks faster. The same information can be used to prioritize preventive measures such as maintenance or renewal of certain fittings or other elements of the water network, preventing not only water losses but also collateral damage associated with significant pipe bursts.

Example

The city of Syracuse in New York state, USA, assisted by the University of Chicago program "Data Science for Social Good", successfully applied a statistical prediction system based on data gathered about leaks found in previous years. The analysis, which used machine learning, pinpointed less than 1% of the network, finding hotspots for the installation of noise loggers allowing real-time detection of leaks and prioritization of renewals.[7,8]

Conclusions and outlook

All utilities must prioritize their investments in some way and renew their conduction and distribution networks at some point. It can be said with certainty that this type of application will gradually be used by more and more utilities, starting with the largest ones, because with this type of software, economies of scale are very important. Although a lack of investment in the maintenance, repair and, above all, renewal of drinking water and sanitation systems is a global problem, it is aggravated in EMDEs because investments to expand the systems are often prioritized by political and social pressures, leaving less funding for existing systems. This makes applications like the one described much more necessary. One common obstacle to their use may be that the data required by the system are often unreliable, incomplete or simply non-existent in EMDEs. In these cases, the focus should be on starting to document the relevant information in GIS.



4.4 Leak monitoring in large-diameter water mains

Permanent leakage monitoring is a strategy aimed at detecting leaks the moment they occur and saving labor costs in leak detection teams through large-scale investment in noise loggers or flow monitoring.

An exception to that rule is some often long, large-diameter pipelines (so-called "unpiggable pipelines") where it is very expensive or completely impossible to detect and localize leakage. An ongoing evaluation of leakage localization methods has shown that, depending on local conditions, the inspection of 1 km of these pipelines can cost between US$ 1,000 and US$ 7,000, making it difficult to recover these high costs by means of the water saved.

But as was mentioned in Section 2, many of these pipelines are yet to be constructed in EMDEs, meaning it is still possible to avoid high costs for inspections (or the impossibility of inspections) and install relatively low-cost monitoring systems, many of which would require an additional investment of 1–2% in the overall pipeline costs. The specific monitoring system employed will depend on local circumstances, but some possibilities are:

- Installation of a fiber optic cable for distributed temperature sensing (DTS) or distributed acoustic sensing (DAS) beneath or near the pipe;
- Installation of cables that measure the dielectric constant beneath the pipe;
- Installation of hydraulic transient pressure sensors;
- Installation of (correlating or not) hydrophone or pressure loggers.

Every one of these systems is programed to give a leak alarm when the measured values exceed a certain threshold determined by previously measured and recorded values and adjusted constantly by the analysis of historical data. Machine learning is used to distinguish leaks from seasonal, temporary or local influences.

Example

This topic is currently being analyzed in much greater detail in an ongoing study about leak detection and localization methods carried out by the Resource-Efficient Water Management Community of Practice. The results of the study are due to be published in 2021. The first water pipelines with fiber optic cables in EMDEs have been installed in Saudi Arabia and Oman.

[7] https://www.politico.com/magazine/story/2017/04/20/syracuse-infrastructure-water-system-pipe-breaks-215054
[8] https://arxiv.org/pdf/1805.03597.pdf

Is it feasible?

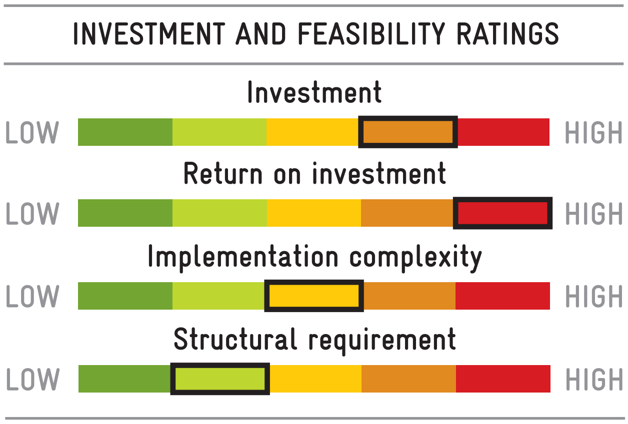
A strategy of active leakage control is best suited to utilities with very low leakage indices, as the labor costs per leak found are higher in these circumstances. While leak detectors in Germany are happy with one leak found per week, in many utilities with higher leakage levels, two or three leaks can be located each day. Combined with higher investment costs, cheap labour and lower water tariffs, permanent monitoring systems are often not a feasible solution in EMDEs.

Conclusions and outlook

The market for fiber optic technology is predicted to grow at very high rates in the coming years.[9] It is expected that its use for the detection and location of leaks will be widespread in the hydrocarbon sector, which will help to lower costs and make it a more feasible option for the water sector, as there will be more and more local providers capable of promoting and installing fiber optic cables.

Despite the fact that investment in this type of system is in its early stages and the recovery time is very long, because leaks occur over many years, it appears that the system is the most cost-efficient option for finding leaks in large-diameter pipes. The main obstacle to its implementation is that the laying of the cables has to be considered at the initial stages of planning pipeline installation projects.

Figure 14. Sensor unit for distributed temperature sensing (Source: AP Sensing)



4.5 Smart pressure management valves

Keeping pressures as low as the minimum required for an optimal service is important for many reasons. When it comes to NRW these reasons are:

- High water pressures lead to more leaks, especially in old pipelines and in households;
- High water pressures lead to larger leaks, as the pressure puts additional stress on existing cracks and widens leaks gradually;
- High water pressures mean that more water is lost from each leak;
- High pressures lead to higher energy costs.

These reasons apply particularly in EMDEs, where higher water losses resulting from more leaks are common. Therefore, solutions for pressure management can prove to be especially effective or even more effective in EMDEs than in water systems in high-income countries.

Smart valves regulate the water inlet to a system, receiving real-time wireless pressure values recorded at specific points in the distribution network. The recorded pressures in the selected points are enough to project the pressures in the whole network. The smart valve then allows a water flow that is just enough to keep the pressure at the minimum level required. This

[9] https://www.marketsandmarkets.com/Market-Reports/fiber-optics-market-238443438.html

measure is very effective, as the pressure differences between peak hours during the day and very low consumption at night can be very pronounced. Smart valves can be very effective in utilities with high leakage rates and continuous or virtually continuous supply.

Example

A pressure management system including smart technology was implemented in Ain Al Basha (Jordan) through a public–private partnership between VAG Armaturen GmbH and GIZ, reducing NRW from 47% to less than 30%.[10]

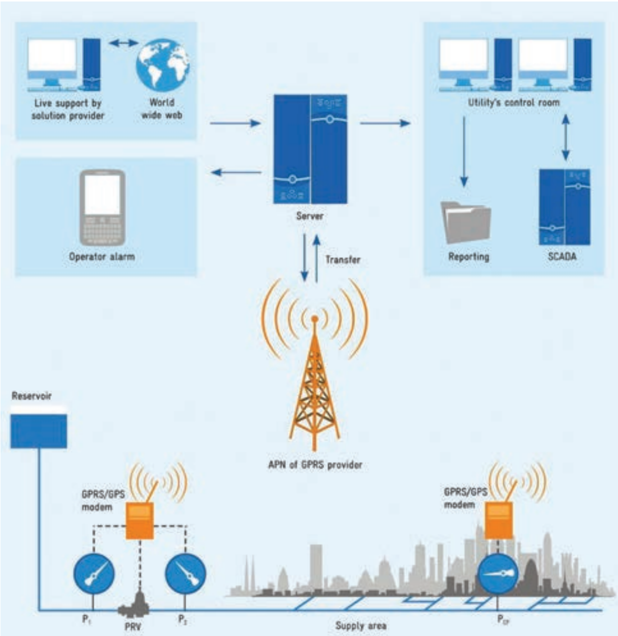


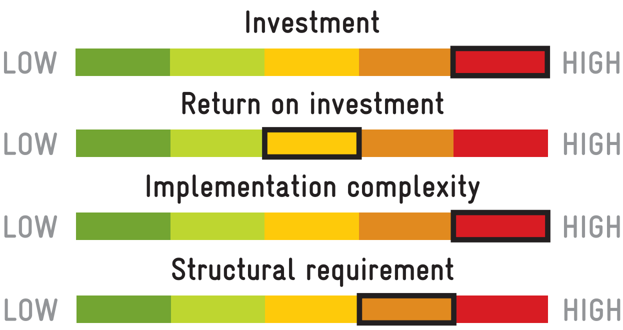
Figure 15. Communication in a remote control system with smart pressure valves (Source: Baader et al. 2011)

Note: SCADA = supervisory control and data acquisition; APN = Access Point Name; GPS = Global Positioning System; GPRS = General Packet Radio Service; PRV = pressure relief valve; P = pressure

Conclusions and outlook

Due to its tremendous complexity, managing pressures, especially in large city systems, has been a commonplace sector for digital change in the past four decades. The different technological leaps that have taken place in this field have been welcomed worldwide because they offer tools (such as the well-known hydraulic modeling software) that can facilitate this task and are now common in almost all countries of the world. This background leads us to believe that the new generation of smart technologies will find less resistance to their introduction in this highly specialized field, unlike some other of the applications discussed here. The efficiency gains offered by pressure management systems are particularly high in systems with large differences in altitude and, as a result, large pressure drops, and in systems with high leakage rates. However, an important limitation in systems with many power outages (as is common in some EMDEs) is the need to install backup batteries to ensure correct operation, which requires a significant additional investment.

INVESTMENT AND FEASIBILITY RATINGS



4.6 Optimized flushing strategy for drinking water networks

An important contributor to NRW is the non-billed water used by utilities themselves; for example, to clean filters, wells or reservoirs. Drinking water is frequently used by utilities for flushing their networks. This consists of cleaning the network to reduce turbidity and to prevent harmful micro-organisms from accumulating along with sediments. Flushing is carried out periodically in valves and hydrants at critical points in the pipelines (dead ends and sections with low flows).

A key aspect of this important activity is knowing when, how often and in which points of the network it must be carried out. Flushing too frequently can lead to water being wasted, while not flushing the system frequently enough can lead to issues with water quality, although both problems often occur at the same time.

To solve this, there are now digital applications, recently invented in Germany, that help to develop an optimized flushing strategy. They use the flushing device to acquire data on the level of contamination in every flushed pipe section and then use the acquired data to determine flushing intervals based on the state of the pipe. This saves not only a lot of drinking water, but also human resources, and always ensures optimum water quality.

[10] http://www.waterloss-reduction.com/images/download/Ain_Al_Basha_-_Jordan.pdf

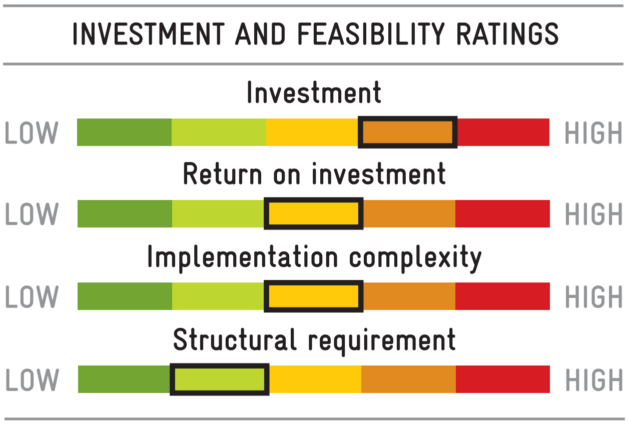
Figure 16. Left: Digital flushing device "Flush inspect"; Right: Map with a graph that shows turbidity levels per pipe section (Source: Fast GmbH)

Example

Although this digital application has only recently been introduced to the market, there is already a case study available from Suzhou City Water (China).[11]

Conclusions and outlook

OptFlush, a software-based algorithm, was developed in 2010 by TZW in Germany, and an integrated solution has been commercialized worldwide since 2015 (Figure 16). As it is relatively unknown, it is not yet widely used, but by offering a cost-efficient solution to a problem that exists in literally all water networks, it has broad future potential.



[11] https://www.fastgmbh.de/images/FAST/Produktbeschreibungen/EN/FlushInspect/SIGN_Flushing_Stoten_20180914.pdf

5 Digitalization to increase energy efficiency

5.1 Smart energy management systems

With the help of software-based energy management systems, the energy-saving potential in a water or wastewater utility can be identified and acted upon. For such purposes, energy consumption is recorded and assigned to the associated units (pumps, heating, ventilation, air conditioning, etc.) and then analyzed. The analysis uses power-consumption histories and power-consumption patterns, generating comparable key performance indicators (KPIs) for each pumping station and other energy-intensive system elements. Based on these KPIs, measures to save energy and energy costs or to increase energy efficiency can be planned, assessed for economic efficiency and then implemented. For instance, pump maintenance measures can be triggered if an increase in energy consumption/m^3 pumped is registered, and replacements or new investments in energy saving (see the following sections) or own energy generation (e.g. biogas, turbines for energy recuperation) can be evaluated.

Example

Water and wastewater utilities often operate many (dozens up to thousands) pumping stations and other energy-consuming facilities. For each of these facilities an electricity invoice is issued up to 12 times a year, generating a huge amount of data and paper (Figure 17). These invoices contain valuable information about energy demand and use, as well as consumption patterns, such as peak and off-peak consumption or power factors. All this is essential information for monitoring energy efficiency and mitigating low efficiencies. Analysis of these data can increase energy efficiency in two ways. The first is by helping the utility to reduce energy consumption at peak hours; this lowers the burden on the electricity infrastructure and avoids the need for system expansions. The other is by assessing energy efficiency monitoring in the different facilities of the utility. Additionally, it will also help the utility to lower the energy (kWh) and demand (kW) payment. However, it is difficult to extract value from this big data set if the information is not delivered in a form that can be analyzed digitally. Therefore, it is necessary to coordinate the transmission of multiple different digital invoices in a convenient format to a single address, where they can be automatically migrated to an analysis tool.

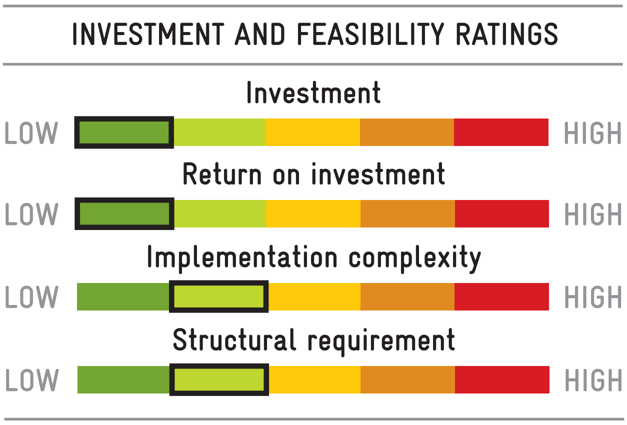
An optimization tool for the management of energy bills, which uses five efficiency indicators (fine avoidance, low-power factor penalty avoidance, tariff adequacy, excessive contracted demand, peak hour avoidance) has been implemented and encouraged by GIZ/Projeto de Eficiência Energética no Abastecimento de Água (PROEESA) in many Brazilian municipalities since 2016. The Excel-based tool is adequate for a few energy consumption units, where data import is done manually. Large data set analysis needs to be handled by software that does the same verifications and can be integrated into more complex energy data management systems.

Figure 17. Left: Electricity bills delivered in paper format (Source: Rita Cavaleiro); Right: Energy Performance and Carbon Emissions Assessment and Monitoring Tool (ECAM v2.2) (Source: GIZ/WaCCliM)

This type of application is especially useful in countries with complex tariff structures (e.g. with increasing block tariffs or time-of-use factors) and for those utilities that receive many electricity bills every month.

Conclusions and outlook

Although many utilities, especially the bigger ones, already perform energy checks, a digitized process needs to be implemented in order to run large-scale analysis for effective, accurate and efficient evaluation of all energy consumption and production units. Improved data management and timely evaluation will enhance energy efficiency in increasing numbers of utilities, including small and medium-sized ones, and indicate where improvements are needed and the kind of measures that might be implemented. The extremely diverse tariff structures for energy, as well as whether a utility does or does not produce its own energy, will always require local parameters to be accounted for in software solutions. The chart below refers to the bill monitoring system described in the example.



5.2 Smart pumps for maximum energy efficiency

“Electricity costs are usually between 5 to 30 percent of total operating costs among [water and wastewater utilities]. The share is usually higher in developing countries and can go up to 40 percent or more in some countries” (Feng et al. 2012). Water or wastewater pumping systems almost always make up the lion’s share of these costs. Decisions about the dimensioning of these pumps are most often based on the maximum required flow and pressure, taking into account a projection of future needs and certain safety margins. This consistently results in pumps being oversized for the normal pumping capacity required, which is very energy inefficient. Pumps with a variable frequency drive (VFD) could consistently run at the best efficiency point (BEP) and greatly reduce energy consumption. Variable energy tariffs (cheaper off-peak tariffs) can also help by encouraging the pumping of water and wastewater at certain times of the day, and the integration of pumping in pressure management (see previous section) could be required in certain cases. Smart pumps (Figure 18) can integrate all these needs and more: a smart pump can also log data on water pumped over time and, when connected to a level measurer in water tanks, can raise alarms in cases of unusual events that could indicate leaks in supply lines.

Example

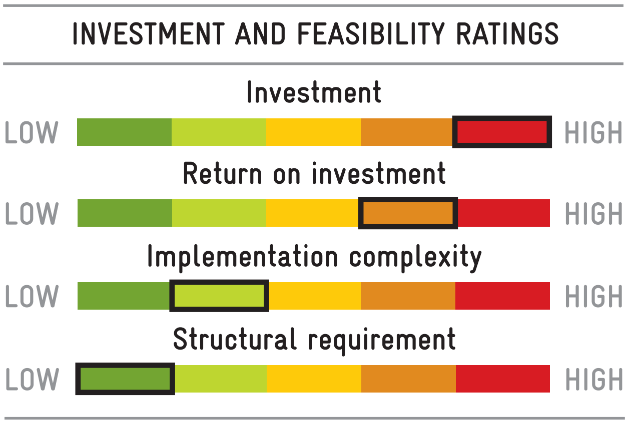
A study by GIZ/ACWUA WANT (Arab Countries Water Utilities Association’s Water Networking and Training program) of pump efficiency in Yemen’s capital Sana’a, where more than 35% of utility revenues were spent on energy, highlighted the usefulness of VFD pumps under different circumstances and the tremendous potential of energy savings in this field.[12]

Figure 18. Smart pump (Source: Wilo)

[12] https://www.pseau.org/outils/ouvrages/acwua_energy_efficiency_reader_good_practices_from_acwua_members_2015.pdf (see paper 5)

Conclusions and outlook

Several studies expect the market for both VFD pumps[13] and smart pumps[14] to grow very quickly in the foreseeable future. Several providers of these pumps already have a network of service partners in many countries on all continents, making them accessible worldwide. The time to recover the investment in these pumps depends mostly on the cost of the saved electricity, so they are especially recommended for utilities with high costs per kWh. The use of such pumps should be considered when planning new pumping stations or when replacing old pumps.



5.3 Pump load profile monitoring for energy efficient optimization

Many pumps, even if perfectly aligned and maintained, use more power than necessary because they are not operating at their BEP. This can also cause cavitation through the formation of bursting bubbles eroding the surface of the impeller, increasing the need for maintenance and repair and shortening the lifespan of the pump. Digital applications that determine a pump's BEP and whether it is operating near or at that point, have entered the market in the past decade. A sensor unit is mounted on the pump itself and measures, stores and transmits the suction and discharge pressure of the pump. With the use of specialized software, these data can then be analyzed and visualized in an easy-to-understand graph that shows if the pump is working efficiently or if corrective action is needed. The sensor unit can also calculate the energy-saving potential. Decisions about how to address pump inefficiencies, for instance by trimming the impeller, retrofitting a VFD pump or changing the pump's position within a system, still have to be made by experts in this field. The sensor unit can be used permanently on one pump or can be moved between several pumps.

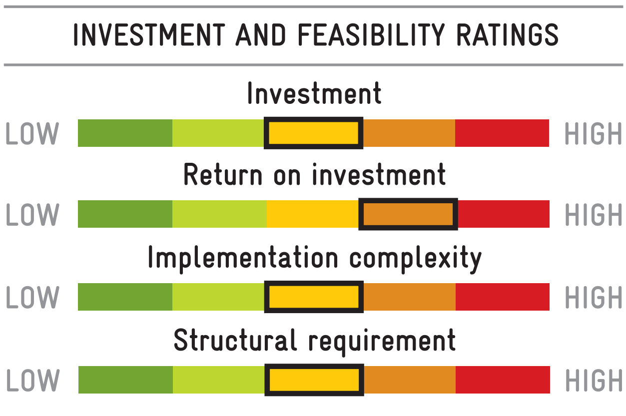
Figure 19. Pump monitoring unit "PumpMeter" (Source: KSB Group)

Example

An example of an application that has been in use for 10 years is the award-winning KSB PumpMeter (Figure 19).[15]

Conclusions and outlook

Finding the BEP of water and wastewater pumps has been a challenge since at least the 1950s. New digital applications can now greatly facilitate these calculations and make them much more precise. However, the analysis alone does not increase the energy efficiency of the pumps; instead, this is achieved through the intelligent and cost-efficient application of the information calculated, which in most cases requires some additional investment.



[13] https://www.grandviewresearch.com/industry-analysis/variable-frequency-speed-drives-vfd-vsd-market
[14] https://www.statista.com/statistics/975971/global-smart-pumps-market
[15] https://www.ksb.com/ksb-en/About-KSB/Research/Automation/PumpMeter

5.4 Early or real-time detection of pump malfunction

All pumps experience a decrease in their operational efficiency over time, due to problems in their operation, which, if not recognized and resolved, tend to worsen over time or cause a long-term waste of energy. Whatever the specific problem of a pump, it almost always manifests as friction in its internal operation. Friction also causes an increase in temperature in the affected part and across the entire pump, as well as unusual vibrations of the pump. Temperature and vibrations can both be measured. The easiest and most economical way of checking for friction within a pump is by using thermal-imaging cameras, which can also be used for monitoring electrical panels and other kinds of equipment. Vibrations during operation can be measured with the help of ultrasonic measurement technology on mobile devices and compared with historical values from the same pump or with already known reference values.

Figure 20. Sensor unit "KSB-Guard" on pumps (Source: KSB Group)

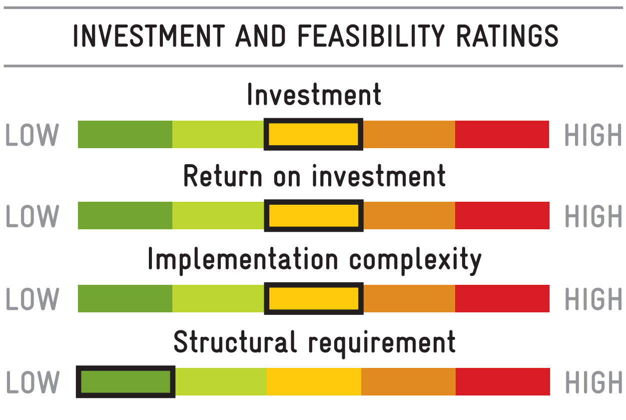
A much more advanced method, that avoids the need for regular checks by staff, is to constantly monitor both the temperature and vibration of valves in a pump (Figure 20), and compare the data gathered with previous values. This can give an immediate indication that something is not going well with a pump, for instance by issuing alerts if certain threshold values are exceeded. This would prompt further actions such as maintenance, repair or complete renewal of the pump.

Example

An example of an application already used by GIZ in Jordan is the ABB Ability Smart Sensor.[16] This integrates the aforementioned functions and combines them with the maintenance history of every pump, helping staff determine the type of maintenance required and avoiding unnecessary routine maintenance.

Conclusions and outlook

The applications described not only serve to reduce energy costs, but can also reduce maintenance costs by avoiding unnecessary maintenance actions and reducing the cost of personnel for inspection. Ultimately, they help to increase the lifespan of often expensive pumps by ensuring they are maintained or repaired as required. As they are highly cost-efficient applications, they should be promoted within the water and sanitation sector. The chart below refers to the permanent monitoring system, not to the mobile systems mentioned. If a lack of funds is a problem, or the quantity and proximity of the pumps makes permanent monitoring systems excessive, mobile systems are a better solution, although they require routine checks.



[16] https://new.abb.com/motors-generators/service/advanced-services/smart-sensor/smart-sensor-for-pumps

5.5 Pump maintenance with digital applications

The two most common causes of pump malfunction are shaft misalignment and a lack of lubricants. Both lead to higher energy consumption and higher equipment wear. Small pumps are generally monoblock, using the same shaft for the pump and motor. All other pumps have a separate motor, which means that the pump and motor have independent shafts that must be coupled together. For the equipment to work at its best efficiency, both shafts must be well aligned and within the tolerance range for each type of equipment, shaft coupling and rotation speed.

Figure 21. Laser shaft alignment tool (Source: Fernando Finger)

A laser shaft alignment tool is the perfect digital application for shaft alignment. In contrast to conventional alignment tools, the laser allows maintenance operators with little experience to quickly align parallel and angular motors with pumps with very high precision (Figure 21).

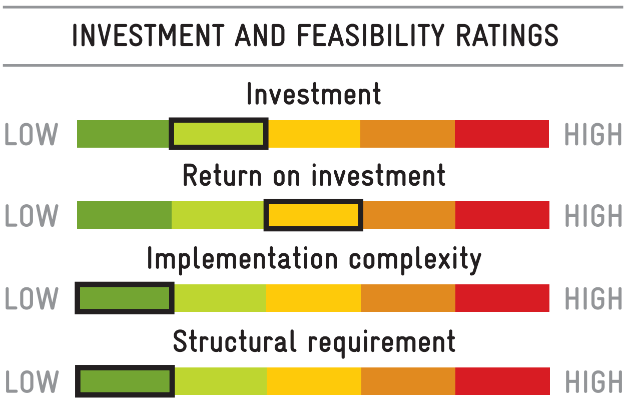
Likewise, with a digital grease tool, operators with less experience can perform greasing in an optimized manner. The tool can give alerts before greasing begins to say if greasing is even necessary. During the procedure it will indicate when the greasing is complete to avoid over-greasing, and it can also give advice on which lubricant is optimal. Greasing data can be stored and analyzed by special software for further maintenance planning. Both applications can be operated by a single user.

Example

A general overview of the effects of misalignment can be found online.[17] The laser shaft alignment tool has been used in Brazil by GIZ/PROEESA.

Conclusions and outlook

Both applications mentioned are already in widespread use in several energy-intensive industries, but they are less used in the water sector, especially in EMDEs, because utilities are not aware of them. They should be considered by utilities where pumps consume large amounts of energy, because with moderate investments they reduce the need for constant maintenance and spare parts, and increase the life expectancy of pumps. In addition, they are characterized by low training requirements and ease of use, making them highly sustainable in utilities with low staff stability.



[17] https://www.researchgate.net/publication/2237090_Effects_Of_Motor_Misalignment_On_Rotating_Machinery

5.6 Automatic analyzing technology for biogas plants

In wastewater treatment plants (WWTPs), electricity costs comprise the majority of the total operating costs. Depending on local legislation, another significant cost can lie in the disposal of sludge generated during the treatment process; sludge needs to be disposed of properly to avoid odor and environmental problems.

Using this sludge as an alternative energy source by generating biogas and converting it into power can make an important contribution to reducing the carbon footprint and energy costs of the WWTP – even achieving energy and carbon neutrality. In the best-case scenario, other substrates, such as high caloric biological residuals from food production or manure from farming, can be used to establish a powerful co-digestion with an even higher energy output.

Figure 22. Biogas analyzer with removable hand-held measuring device (Source: Hermann Sewerin GmbH)

The fermentation process itself is a highly complex biochemical process which, if not managed, may perform well below its efficiency potential. This can result in a lower calorific value and a smaller amount of biogas, leading to a significantly reduced energy yield, or to a severe disruption of the fermentation process. Financial losses are inevitable if components of the biogas, such as hydrogen sulfide (H_2S), quickly damage the engine by corrosion.

For these reasons, it is advisable to install sensors that automatically monitor and log the composition and amount of biogas, and use this to facilitate rapid intervention in the process if necessary through the use of online alarm functions. Based on information about the gas components, data-based decisions (e.g. regarding optimization of the substrate composition) can be taken. Additionally, the engine can be switched off automatically if the H_2S concentration exceeds a specific level. Further operational measures can also be triggered, such as the exchange of the filter material, or the dosing of chemicals or air to decrease the concentration of the corrosive H_2S in the gas. In this respect, a biogas analyzer (Figure 22) can increase the transparency of the digestion process and can support even less experienced staff in their daily work with the digester. Integrating the biogas analyzer control in the master computer of the WWTP also helps to automate processes.

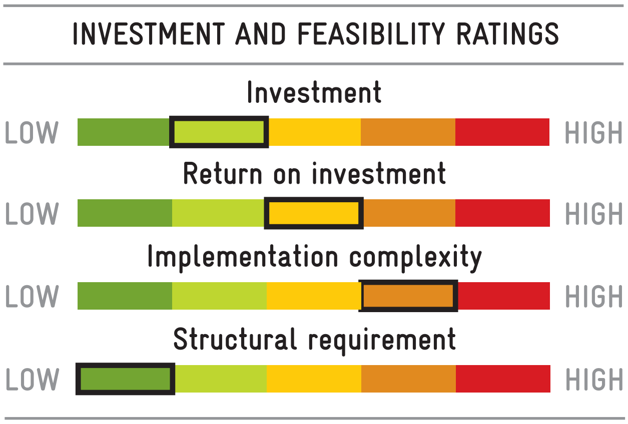
Example

An ongoing project being supported by GIZ/Water and Wastewater Companies for Climate Mitigation (WaCCliM) is the installation of a biogas analyzing system in the sludge digester of a WWTP in Cusco, Peru. This aims to optimize biogas generation and reduce the energy consumption and carbon footprint of the WWTP.

Conclusions and outlook

The volume of biologically treated wastewater is constantly increasing worldwide, often utilizing sludge digestion and ideally co-fermentation, and this application could find widespread use in the future, especially in medium-sized and large cities or in industrial wastewater treatment. Since electricity consumption is often particularly high in wastewater treatment, feed-in rights are not important, and if the energy generated is used for the wastewater treatment process itself, the WWTP will become more energy neutral. Against the background of the immensely high investment costs of constructing and equipping a WWTP, the acquisition costs of a gas analyzer are hardly relevant.

However, other factors (such as electricity tariffs, legislation governing sludge disposal and disposal costs, and availability of suitable co-substrates), which are very case-dependent, play a major role, and the feasibility of this application must therefore be checked through in-depth studies. A major challenge is to ensure that the measurement devices (especially sensors) are periodically maintained and adjusted, otherwise measurement errors can occur. To reduce the downtime of the analyzer during annual maintenance, manufacturers of the measuring technology should cooperate with a local service partner in the particular country to ensure quick support and maintenance. Some analyzers feature a self-adjustment function (using a test gas), which enables the operator to easily adjust the device with the push of a button at any time between maintenance work to retain the high precision of the measuring results.



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