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On the Need for System Alignment in Large Water Infrastructure: Understanding Infrastructure Dynamics in Nairobi, Kenya

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ABSTRACT: In this article we contribute to the discussion of infrastructural change in Africa, and explore how a new theoretical perspective may offer a different, more comprehensive and historically informed understanding of the trend towards large water infrastructure in Africa. We examine the socio-technical dynamics of large water infrastructures in Nairobi, Kenya, in a longer historical perspective using two concepts that we call *intra-systemic alignment* and *inter-level alignment*. Our theoretical perspective is inspired by Large Technical Systems (LTS) and Multi-Level Perspective (MLP). While inter-level alignment focuses on the process of aligning the technological system at the three levels of niche, regime and landscape, intra-systemic alignment deals with how components within the regime are harmonised and standardised to fit with each other. We pay special attention to intra-systemic alignment between the supply side and the demand side, or as we put it, *upstream* and *downstream* components of a system. In narrating the history of water supply in Nairobi, we look at both the upstream (large-scale supply) and downstream activities (distribution and payment), and compare the Nairobi case with European history of large infrastructures. We emphasise that regime actors in Nairobi have dealt with the issues of alignment mainly to facilitate and expand upstream activities, while concerning downstream activities they have remained incapable of expanding service and thus integrating the large segment of low-income consumers. We conclude that the present surge of large-scale water investment in Nairobi is the result of sector reforms that enabled the return to a long tradition – a 'Nairobi style' – of upstream investment mainly benefitting the high-income earners. Our proposition is that much more attention needs to be directed at inter-level alignment at the downstream end of the system, to allow the creation of niches aligned to the regime.

KEYWORDS: Water development, infrastructure, developing countries, development policy, Large Technical Systems (LTS), Multi-Level Perspective (MLP), Kenya

INTRODUCTION

On 24 February 2015, the Athi Water Services Board – an entity under the Kenyan government – commenced the implementation of the Northern Collector Tunnel project, augmenting the water supply to the capital Nairobi (AWSB, 2016). This billion-dollar project is but one example of a recent trend witnessed in Africa, where we again see large-scale infrastructure projects for capturing, diverting and using water resources for human needs. Monumental water technology, such as the Grand Renaissance Dam in Ethiopia, has reasserted its place in the limelight of political and environmentalist discourse, along with its substantial potential benefits and challenges (Taye et al., 2016). This trend is not unique to Africa, but is seen elsewhere in low and middle-income regions of the world, as

corroborated by the many other stories told in this special issue. Dams, large-scale irrigation, hydropower systems complete with regional transmissions, bulk water systems, deep wells, water distribution systems and sewage systems; these are huge, centrally planned and extremely costly infrastructure that are among the most demanding types of undertakings any water sector actor could make in terms of finance, planning, design, operations, and management.

Perhaps it is relevant to talk of a marked turn toward – or rather a return to – a large-scale paradigm of water infrastructure that we have not seen for decades (see this WaA special issue). However, this 'turn' needs to be put into a longer time perspective. Are we witnessing a new phase in water infrastructure development in Africa and if so, why is it happening now? Not least important, what are the prospects for these investments to become more socially, economically and environmentally sustainable than previous attempts? We believe that if we are to understand the processes of development and change of large infrastructure, there are important historical lessons to be drawn by looking at the long-term dynamics of these systems.

To understand the (re)turn to infrastructure, we will introduce and explore two concepts that we call *intra-systemic alignment* and *inter-level alignment*. Our theoretical perspective is inspired by seminal research of Thomas P. Hughes on Large Technical Systems (LTS) and by the so-called Multi-Level Perspective (MLP), introduced by Arie Rip, Frank Geels and others. In short, intra-systemic alignment (derived from LTS) deals with how components within a technological system like urban water supply are harmonised and standardised to fit with each other. Of particular importance is to understand the intra-systemic alignment between the supply side and the demand side, or as we put it, *upstream* and *downstream* components of a system. Inter-level alignment (derived from MLP) focuses on the process of aligning the technological system with its surroundings, its institutional and physical context as well as the user and market context.

These concepts, we believe, will be useful for unpacking the current return to infrastructure, and especially the resurgence of large-scale investment. Large upstream investments, for example water dams, can boost the performance of the system in order to meet increased demand. In a European or Western context, the history of infrastructure building gives clear evidence that upstream investments have been a preferred, and in many ways successful, strategy. But is this strategy also favourable in an African context? The cities of Africa grow at an unprecedented pace, and will be tripling their number of inhabitants to reach a total of over US\$1.3 billion by 2050. Moreover, UN-Habitat estimates that at present, 61% of urban populations live in informal areas – or 'slums' – where infrastructural and public services are categorically under-provided (UN, 2015). Clearly, aligning infrastructural systems with their rapidly shifting context, both upstream and downstream, seems to be a critical task for policy-makers committed to sustainable development. We argue that history matters in these processes, and therefore, history matters for future policy making.

Our purpose in this paper is twofold. First, we wish to contribute to the assembling of a new theoretical perspective suited for analysing infrastructural change in Africa. Second, we want to explore how this perspective may offer a different, more comprehensive and historically informed understanding of water infrastructural dynamics. We do not claim to disclose totally new and unknown empirical facts here. Instead we want to re-engage with some of our own earlier fieldwork (and that of others) using our new perspective. At this critical juncture in time when local and global leaders call for transformative change in order to reach global sustainable development, understanding change processes in their historical context is necessary (Bayly et al., 2011). During colonial times, water system builders in Africa – i.e. European officials and engineers – imported and imitated European solutions. Certain adaptations to local conditions took place, but the systems fairly soon stabilised around a piped water and sewerage technology that bore close resemblance to European systems (Nilsson, 2006). The reliance on European technologies prompted Okke Braadbaart to talk of the transfer of a 'piped

paradigm' from North to South, which "has settled itself at the heart of local political debates and has become a main recipient of international aid" (Braadbaart, 2009: 81).¹

As noted by several scholars, we are often too quick to compare African cities with the historical experience of the West, a comparison which invariably portrays the African cases as 'failures' or 'backward' (Fourchard, 2011; Lawhon et al., 2014; Silver and Marvin, 2016; Schindler, 2017). Yet donors and international policy-makers have tended to draw their reference points (and their recipes for development) directly out of Western experience and a focus on economic growth (Escobar, 1995; Rist, 1997, 2007). If development ideals, socio-technical solutions as well as theories are drawn from this limited repertoire, we must ask ourselves 'what could be the reasons behind the difference in system evolution between European and African water systems?'

One explanation that has been offered is the mismatch between European 'high modernism' and the realities in Africa (Scott, 1998). As pointed out by Matthew Gandy (2006) the transfer of the modern ideal to city-building in the colonies in Africa produced an 'incomplete modernity' which aspired to the values, infrastructures and service levels of Europe but that in reality was little more than an elusive thought-figure. Nilsson (2016) has argued that modernity ideals in fact undermined innovation activities in African water systems, as political leaders (and their development partners) remained unwilling to challenge Western ideals of technology and progress after decolonisation. Monstadt and Schramm (2017) have shown in their study of water supply in Dar es Salaam that there were indeed different processes of 'translation' of the European ideals into local contexts by various mediators, none however resulting in a major transformation of the centralised public socio-technical system for providing water. As van der Straeten and Hasenöhr (2016) have argued, despite the growing body of literature on infrastructure with postcolonial influences, a vast gap remains in terms of conceptually understanding technology change in Africa.

In this article we look closer at the systems for water provision that were transferred to African cities – by the use of a historical case study – to get a better and more detailed understanding of the system's evolution and how it differs from those in Europe. Our approach builds on the assumption that piped water infrastructure can be understood as a Large Technical System (LTS), embedded in institutional, socio-political and cultural dimensions that profoundly affect its change pattern over time. The LTS school of thought traces back to the work of Thomas P. Hughes (1983; 1987; 1992; 2000), further developed by Kaijser (1994; 1999), Blomkvist (2001) and others (see e.g. Summerton, 1994; Janáč and van der Vleuten, 2016; Bichsel, 2016). Several scholars note that African urban water infrastructure only partly fits the 'typical' LTS trajectory (Furlong, 2014; Nilsson, 2011). We will return to this discussion later in section three. In the remainder of this section, we explain and justify the theoretical concepts used in our analysis.

Large infrastructural systems, like piped water, electricity, railroads, etc. are *tightly coupled* systems (Blomkvist and Johansson, 2016). In a tightly coupled system the connections between system components or subsystems (technical and institutional) are robust and especially designed for system purposes. The technical core of the systems is built by physical connections of pipes, wires and rails. They are centrally planned and managed, access for other operators is very limited, the technical standardisation of components is high and they have a top-down perspective as distribution systems of services. The system builder or the system manager has one overarching goal: to avoid technical and institutional mismatch in the system – to *align* system components *within* the system (see e.g. Hughes, 1983; 1992; Summerton, 1994; Blomkvist, 2004). A key lesson from system building experience is thus the importance of, what we would like to call *intra-systemic* alignment of system parts (social,

¹ This notion of a historically based path dependence or trajectory is formulated by Hughes in this way: "Durable physical artefacts project into the future the socially constructed characteristics acquired in the past when they were designed. This is analogous to the persistence of acquired characteristics in a changing environment" (Hughes, 1987: 77).

economic and technical alike). It is evident that the intra-systemic alignment includes also business models and cost-recovery schemes aligned with the system (Tongur and Engwall, 2014; 2017). In water infrastructure, *upstream* activities can be to secure new water resources, build dams and collector tunnels. *Downstream* activities are for example to build distribution pipes in cities, to connect end users/customers to the grid and to find business models to get users to pay for the water (cost recovery). Using a concept from corporate strategy research we suggest that, in tightly coupled systems like a water system, the intra-systemic alignment takes the form of *vertical integration* of both upstream and downstream system activities.² In European cities, where vertical integration is high, the utilities can thus control each and every part of the service delivery chain, from the water source and all the way to the consumer's tap. In this article we will not specifically discuss business models and such. We plan to return to those in future work. For now, we use the concepts of intra-systemic alignment and vertical integration interchangeably.

To the above-mentioned concepts we add elements from the Multi-Level Perspective (MLP). MLP does not focus on the history of system building, but instead on change dynamics or 'transitions' in already existing large-scale socio-technical systems. These systems are not necessarily infrastructural systems in a strict sense; MLP has been applied to a wide range of technologies from ship propulsion to greenhouse farming to innovation policy (Geels, 2005; Berkers and Geels, 2011; Kern, 2012). The central MLP claim is that system changes are essentially governed by the interplay of factors and actors operating at different levels of aggregation and time scale. The key analytical levels are known as 'niche', 'regime' and 'landscape' (Rip and Kemp, 1998; Geels, 2002; Geels and Schot, 2007).

When using MLP concepts on a tightly coupled infrastructural system, the regime level would be equivalent to the infrastructural system as a whole. Thus, the regime of a large infrastructure consists of the physical infrastructure (roads, grids, pipes, tracks, etc.), the organisations and institutions created for support, laws and regulations and not least financial and industrial organisations and individuals (engineers, scientist, politicians), all with vested interests in the survival and expansion of the system (Hughes, 1983). Regime actors would then be equivalent to system builders and system operators. In the rest of the article we will use the terms *regime* and *regime actor* when analysing the development of the water system in Nairobi.

Some important differences between LTS and MLP must be noted. Firstly, the regime in MLP does not have any distinct physical form. In MLP the regime is an abstraction used for analytical purposes. Regarding the use of the system concept, MLP is similar to other research approaches like 'innovation systems studies' – i.e. national, regional, sectoral (Laestadius and Rickne, 2016). But a large technical system does have a material, physical geography. An LTS is actually built up of physical links and nodes and the system is clearly defined through its physical form. The absence of a geographical dimension, as well as the obscured role of power relations have earned MLP substantial criticism over the years (Lawhon and Murphy, 2012; Silver and Marvin, 2016). Rosenbloom et al. (2016) argue that politics and agency can be integrated into the MLP framework through a discursive approach. Raven et al. (2012) have suggested the introduction of geographical relationships as the basis of a second-generation of 'multi-scalar MLP', which may offer a more nuanced and place-based analysis.

Adding to these important contributions, we want to point the importance of *alignment* as a key concept also for MLP. But alignment is used in a slightly different meaning compared to LTS research, where it denotes the connection between system parts and components *within* the regime. As mentioned, LTS analysis focuses on *intra-systemic alignment* in contrast to the MLP, where the focus is on what could be labelled *inter-level alignment*. The extent to which there is alignment across levels – niche-regime-landscape – will be decisive for the trajectory of socio-technical change patterns (Geels,

² The concept is borrowed from Porter (1998). The similar concept 'Forward and backward linkages' was coined by Hirschman (1969).

2005). MLP research insists that inter-level alignment is crucial for successful technological and institutional transitions (Rip and Kemp, 1998; Geels, 2002, 2011). Changes in the landscape, such as economic growth, population growth, or depletion of natural resources force the regime to adapt. Vice versa, the technological regime can prompt changes at landscape level. But the regime can also transform due to innovation activity in niches situated outside the regime (Geels, 2005). Our analysis only implicitly deals with the landscape level. Instead we focus on the regime and the niche level, and in particular, the interface and alignment between these two levels, which we hope to illustrate is necessary for the appearance of a sustainable and equitable water service system.

Our paper is structured as follows. After this introduction of our objectives, concepts and research arena, we go directly to our case study. We outline the history of water supply in Nairobi, the capital of Kenya, over the past century. We use LTS concepts in narrating a story of water supply in Nairobi, looking at both the upstream and downstream activities. Thereafter, we compare the Nairobi case with European history of large infrastructures, focusing on urban water systems. Here, we emphasise that regime actors in Nairobi dealt with the issues of alignment mainly to facilitate and expand upstream activities, while in downstream activities they have remained incapable of expanding to the large segment of low-income consumers. In the fourth and final section we use MLP concepts to draw out the main conclusion from our analysis and outline the policy implications. The present surge of large-scale water investment in Nairobi is the result of sector reforms that enabled the return to a long tradition – a 'Nairobi style' – of upstream investment mainly benefitting high-income earners. Much more attention needs to be directed at inter-level alignment at the downstream end of the system, to allow the creation of niches aligned to the regime.

THE CASE OF NAIROBI, KENYA

Upstream: Supplying a thirsty city

What follows is a short overview of how regime actors in Nairobi have managed to bring water into the city since its founding in 1899. Our focus is first on the main steps taken to develop raw water supply, i.e. what we in our perspective call an upstream activity.

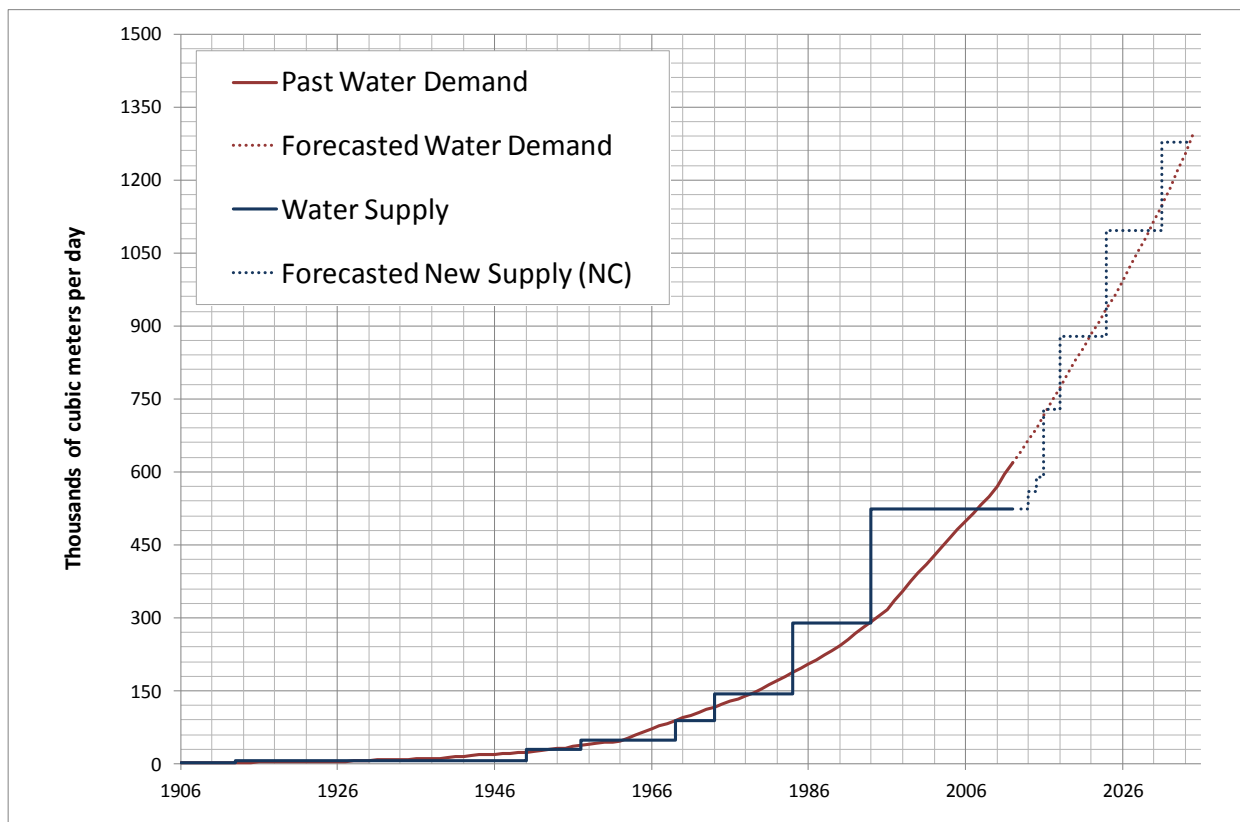
Nairobi is located in a tropical highland area some 140 km south of the equator. It rests at the foot of the Great Rift Valley escarpment where the forested and well-watered hills to the North meet the dry grasslands of the Athi plains, stretching out for hundreds of kilometres towards the Indian Ocean. Water was a key factor for the founding of Nairobi, both for supplying people and for economic activities, and for supplying the locomotives on the railway that connected the interior of Africa – notably Uganda – with the coast. However, ever since the railway builders set up a base camp here in 1899 the city has witnessed a constant struggle to supply more and more water to its growing population – today over 3 million – through transfer from increasingly remote sources (Ledant et al., 2013).

The first piped water system, built in the first years of the 1900s, was owned and managed by the Uganda Railways. A first upstream activity was to find a suitable source of raw water away from the unsafe water of the river, which prompted the development of a raw water source at Kikuyu springs some 13 km away (Nyanchaga and Ombongi, 2007; Nilsson, 2013; Nyanchaga, 2016). As the population and demand grew there was soon a shortage of water. In 1926, there was not enough water to even supply the fire hydrants, and firefighting was compromised on several occasions (Smart, 1950). The 1920s saw radical transformations of the water sector in Kenya, with the state taking a much stronger role. New water legislation was developed and in Nairobi the responsibility of water supply was transferred from Uganda Railways and a few small private operators to the municipality (Nilsson and Nyangeri, 2008). This change of institutional and organisational setup enabled Nairobi to undertake its

first large-scale dam project with the opening of the Ruiru Dam in 1938 (Nilsson, 2013; Nyanchaga, 2016).

In 1946, Nairobi experienced water shortages again. As an emergency solution, the relatively small Nairobi Dam was constructed to collect water from the Ngong River (Nilsson, 2013). The colonial government embarked on a phase of expansion of water infrastructure across the country after the Second World War, to boost development and economic growth. One critical aspect was how to access finance. The expansion was aided by funds from the UK under the Colonial Development and Welfare Act, but measures were also taken to leverage funds from financial markets. From 1949, Nairobi municipality was permitted by the colonial government to take up loans independently. Their ability to do so naturally banked on a strong municipal balance sheet and a good track record of cost-recovery from consumers (Nilsson and Nyangeri, 2008). The municipality opted to develop a new source at Sasumua, on the Chania River approximately 50 km away from the city. The Sasumua Dam was opened in 1956 after which Nairobi’s inhabitants on average accessed 140 litres per person per day. The Sasumua supply was augmented in 1968 to meet the continuously increasing demand (Ledant et al., 2013).

Figure 1. Supply and demand of water in Nairobi (from Ledant et al., 2013).



Water demand was largely driven by population growth. During the period 1945-1970, the population grew from a little more than 100 000 to around half a million. The search for new raw water supplies for Nairobi hence continued. With assistance from the World Bank, several expansions of the raw water supply were carried out in the 1970s and 1980s, through the First, Second and Third Nairobi Water Supply Projects (World Bank, 1996). This included upgrades on the water transfer system and new intakes from Chania River. When the large dam at Thika was completed in 1994, there was considerable excess capacity in the system (see Figure 1). The stepwise expansion has largely followed the projected

water demand curve. The investments in raw water supply in the late 1980s and early 1990s took Nairobi water supply to the current design capacity of approximately 550,000 m³ per day (EGIS Bceom, 2011). However, according to a study carried out in 2005, as little as 248,000 m³ per day reached the consumers due to large transfer losses, leaking pipes and operational problems. The demand, on the other hand, stood at 337,000 m³/day (SOGREAH, 2005).

In 2009, the Athi Water Service Board (AWSB) – which is the regional authority charged with responsibility for water development in Nairobi since 2002 – commissioned a feasibility study for an expansion of the water supply to Nairobi. Again, focus was on boosting raw water supply in order to catch up with, and follow, the projected demand curve. All solutions that were proposed included capturing more surface water from rivers up in the highlands and channelling this water down to the main supply line from Thika and the Chania rivers. This is the so-called 'Northern Collector' system. It consists of a series of intakes and tunnels and is meant to increase the total supply of water to Nairobi up to 1.2 million m³/day when fully implemented in 2035 (Egis Bceom, 2011). The total cost of the project was estimated at around US\$1050 million. In 2015, the AWSB officially launched the construction of the first phase of the Northern Collector project (AWSB, 2016).

Downstream: Providing the services

For any benefits to accrue from the upstream activities, the water has to actually reach people, plants and machines in the city. This delivery of service to intended users makes up the downstream side of water supply systems. In this section we give a short history of the downstream aspects of the Nairobi water supply.

During Nairobi's first decades, very simple technology was used to distribute water including stand-pipes from which consumers fetched water. The consumption was low; around 40 litres per person per day (British East Africa Protectorate, 1907). After the municipality took over responsibility for water supplies in Nairobi in 1923, the network was equipped with meters for measuring consumption from individual households, and from then on, payment by volumetric use has been the rule (Nilsson and Nyangeri, 2008).

Total water demand was driven by population change, but it was also affected by changes in engineering standards. The *per capita design demand* is an important normative factor used when designing the system. The design demand, aggregated for the population, creates a gross target for the supply side. The consumption had been only around 40 litres per person per day around 1907, but the design demand was increased to well over 220 litres per capita per day in 1934 for the European population, while Asian and African consumers were expected to demand only 135 and 90 litres, respectively (Colony and Protectorate of Kenya, 1934). The importation of European water technology to the colonial cities of Africa also inferred modernity and progress, which affected ideals and norms, not just in Kenya but in other colonies as well (Gandy, 2006; Bohman, 2010; Monstadt and Schramm, 2017). Emulating the high-modern European lifestyles by the engineers and decision-makers in Nairobi resulted in increasing water demand.

The municipality – from 1950 known as Nairobi City Council – undertook development and operations of the water system relatively independently. As mentioned the City Council had been authorised to raise loans for municipal investments on its own. This allowed the piped system established in the preceding period to expand its coverage, with metered in-house connections dominating as the main provision model (Nilsson and Nyangeri, 2008). The racially segregated structure of design demand introduced during colonial rule was discontinued after independence in 1963, but replaced with service segregation between income groups. Where 'Africans' had been allowed less water than 'Europeans' in the colonial era, the system was now designed to give low-income groups and informal settlers – so called 'squatters' – a lower amount of water. The legacy of racial service

segregation in Nairobi can still be traced in today's inequality of access, consumption and price (Ledant et al., 2013).

In the period following independence, the urban growth increasingly consisted of low-income people moving into unplanned informal settlements. More and more people lived in the city, and it was now necessary to build more pipes to reach all consumers. In 1970, the Government of Kenya had pledged to provide every Kenyan citizen with clean water by the year 2000 (Republic of Kenya, 1970). The conventional piped network was expanded with World Bank financing in the 1970s and 1980s (World Bank, 1996). However, the provision of water using standardised in-house piped and metered connections, the standard model in Nairobi – is incompatible with the physical, socioeconomic and legal conditions of informal settlements. In short, provision in slums is a risky business for the system-builder/regime actor (Nilsson and Kaijser, 2009).

As part of the donor-funded Nairobi Water Supply Projects in the 1970s, Nairobi City Council began constructing water kiosks and public standpipes in low-income areas (World Bank, 1996). But these pro-poor efforts seem to have remained at a pilot level, and experienced a range of problems including the appropriation of kiosks by criminal organisations in the Kibera Slum. Soon the water utility and donors lost interest (Katui-Katua and McGranahan, 2002). Moreover, as Nilsson (2016) argues, these low-cost and simpler solutions were in conflict with the ideals and values of political leaders in post-independent Kenya. The high-modern ideals and large-scale infrastructure left behind by the colonial administration were simply adopted and reproduced by Kenyatta's government. This created a pressure to expand upstream, but not to change its technical configuration downstream. Put in our wording, there seems to be poor alignment between these attempts for pro-poor provision at the local level and activities at the regime level.

The response to informal urban growth from regime-level actors was to define the informal areas as 'illegal' rather than seeking out low-cost innovations. The water LTS could deliver services to the high- or middle-income, formally planned areas. But population growth was much faster in the other low-income and informal areas. In these growth pockets, which were excluded from the network system, local alternatives started appearing. Without a formal utility, small-scale private entrepreneurs and non-government organisations (NGOs) provided most of the services in low-income areas. These alternatives included water vendors, tanker trucks, water kiosks, re-selling by neighbours, local networks and even private boreholes (Collignon and Vezina, 2000; Sharma and Shukla, 2009; Castro, 2009; Chakava et al., 2014). Local service provision in informal areas is organised through a complex social web involving community organisations, individual entrepreneurs, illegal organisations and corrupt officials (Katui-Katua and McGranahan, 2002; Birongo and Quyen Lhe, 2005). Providing services to the large groups of people in informal settlements has proven difficult, not just in Nairobi. Despite the adoption of a National Pro-poor Implementation Plan (PPIP) in 2007 the government itself has acknowledged that the implementation of the PPIP is seriously lagging behind expectations (Republic of Kenya, 2012).

An important part of what we call 'downstream activities' is to collecting payments – through taxes, land rates, a billed water tariff or by other means – to financially sustain the system. Nairobi City Council long upheld the colonial tradition of full cost recovery, ensuring that every consumer paid the full price of water service. Nairobi City Council had a substantial surplus for water revenues throughout the 1960s (SWECO, 1973). However, several studies report that cost recovery in all of Kenya's urban centres was dwindling fast in the 1980s (Republic of Kenya, 1984; Hukka et al., 1992). Government institutions are among those with a poor payment track record, a problem that has persisted over the years (Heyman et al., 2014). Cost-recovery problems also haunted Nairobi in the 1980s and 1990s. By the end of the 1990s, the water and sewerage operations of Nairobi were completely insolvent, and showed huge payment arrears. The poor financial situation affected the operation of the system, which experienced lack of maintenance and repair, as well as lack of technical knowledge and trained personnel (Halcrow, 2001). After years of donor-sponsored sector reforms, financial viability has slowly

returned to Kenya's water sector. Nairobi is now one of 33 (out of a total of 99) water utilities in Kenya to recover its costs for operation and maintenance, although not for capital costs (WASREB, 2015).

UPSTREAM AND DOWNSTREAM SYSTEM ALIGNMENT IN A COMPARATIVE PERSPECTIVE

Is there anything remarkable about our story of Nairobi's century-old search for more water to supply its growing number of inhabitants? This focus on upstream activities has been seen in many cities elsewhere. Yet, we believe there is something important to learn from how large-scale technical systems evolve in different locations and contexts. If nothing else, we want to expose in what ways the 'piped paradigm' in Nairobi has developed differently over time compared to its sources of origin in Europe.

In European cities, evolution of LTS has been described with the classical S-curve. Systems evolve and grow in three phases: establishment – expansion – maturity. The first phase is characterised by pluralism and uncertainty; about technology, about organisational structures as well as institutional frameworks. As controversies are settled and uncertainty is reduced, a dominant model emerges paving the way for an expansion phase. In the last phase, systems become increasingly difficult to change and expansion slows down when markets are near saturation. The mature system is deeply embedded in society and not easily changed or transformed (Hughes, 1983, 1994).

Does Nairobi water supply follow a 'typical' S-curve and the development phases of a 'typical' LTS? Yes, basically it does. An establishment phase can clearly be identified around 1900-1920, when technology was simple, organisation was fragmented, institutions were lacking and uncertainty was high. After municipalisation in 1923 and the passing of dedicated water legislation in 1935, an expansion phase sets in, which speeds up after World War II. The expansion phase met with problems such as need for additional raw water sources, and feeding the growth with sufficient capital, both of which problems were essentially resolved. Regime actors addressed these expansion obstacles – or 'reverse salients' in Hughes' terminology – as they arose, in a fashion similar to other LTS evolutionary patterns. In the 1980s the expansion phase stalled as the services became increasingly financially unviable due to poor cost recovery. With population growth predominantly in informal areas, the LTS faced yet another problem in distribution of services to these areas. Sector reforms, which set in *de facto* from the early 2000s, concentrated on the cost-recovery problem (Bayliss, 2003; Mwangi and Githau, 2003; Nilsson, 2011). The historical account above suggests that after improving financial viability and restoring investor (donor) confidence, the main emphasis has been on solving the upstream problem of raw water supply, albeit complemented with minor attempts of expanding downstream services in informal areas.

With regard to upstream investments, it is clear that regime actors in Nairobi – on the whole – followed the same path as in European infrastructure. For example, Swedish urban water provision history contains many similar attempts to consolidate and centralise the water system. Also in Sweden, and particularly in Stockholm, the system design ideas and the technology (pipes, etc.) were imported from England. The water system in both Nairobi and Stockholm was designed as a centrally managed and tightly coupled system. The systems grew top-down, from the centre to the periphery. And just as in the Nairobi case, Swedish water systems and the regime actors constantly searched for new upstream solutions to cope with the ever-increasing need for water in the cities (Stockholm Waterworks, 1961; Anderberg 1986; Cronström, 1986; Hallström, 2003). This focus on upstream solutions is of course also evident in other infrastructures, and perhaps best formulated in the credo of traffic engineers when building the modern motor road system – *Predict and Provide!* (Seely, 1987; Østby, 1995; Blomkvist, 2001).

On the downstream side, however, the history of Nairobi points to a markedly different direction. Comparing European infrastructure development and the Nairobi case, one will first of all note that the European systems delivered services to all. Not at once of course, but they quite soon covered almost

all locations and most of the population could access affordable water, electricity, telephone, etc. To put this observation into systems language: Although different in purpose, the systems managed to get full coverage by vertical integration of the users furthest away from the system centre and transforming them into local nodes in the system and the system was fully vertically integrated both in upstream and downstream directions. Swedish urban water history gives many examples of this ambition towards downstream alignment and that, although not always in a speedy process, the regime actors eventually managed to vertically integrate the water system downstream as well as upstream (Hallström, 2003). In Nairobi, currently around 70% of the population is connected to the centralised water grid while the remainder – typically the poorest – is relying on small-scale providers, paying up to twenty times the price of the official water tariff (Ledant et al., 2013). In fact, it appears as if the Nairobi system has reached the maturity phase in relation to the high- to middle-income earners, i.e. those with in-house water supply. In the peripheral low-income areas system, in contrast, growth resembles more the establishment phase, with its technical uncertainty, institutional vagueness and plethora of stand-alone or hybrid solutions.

History can also give us some clues to explaining the diverging patterns. The global North saw a lot of technology and design transfer taking place, for example Thomas P. Hughes' famous account of the transfer of Edison's electric light system from USA to Germany and Great Britain. Regime actors in Berlin and London adapted the imported system to fit into regional/national institutions (Hughes, 1983). Hughes calls this variation in system design between regions of the world 'technological style' (Hughes, 1987). But the transfer of water technology from Europe to Africa took place under the special conditions of colonialism. The Nairobi water system was imported by the colonizers and only slightly adopted to local conditions. It is easy to see that the transfer of the British water system to East Africa was part of the 'ideal of the networked city', which has profoundly shaped urban planning and infrastructure building in the global South and that this ideal has been adopted without sufficient adaptation to the reality of the cities in Africa (Nilsson, 2016; Monstadt and Schramm, 2017). On the pretext of colonial segregation (underpinned by supremacist and racist ideologies), the systems were not designed to cater to everyone in the city, but mainly to the European elite (Ngalamulume, 2005; Nilsson, 2006; Gandy, 2006; Bohman, 2010). This type of segregated design demand, based on race or class, is not a typical feature in the building of European water systems (or other types of infrastructure). Class and income level did play a part in deciding in which order certain areas in European cities came to be connected to the grid. The piped, in-house water connection was offered to high- and middle-class areas first, and working class areas had to cope with an outside standpipe in the neighbourhood, often as long as 20 years after the city centre had a functioning water system. In some cases, the building of the piped network was even used as a motive to evacuate working class and poor people from dilapidated housing and to clear up slums. However, the segregated water system did not become permanent. Eventually all inhabitants were connected to the grid (Sheiban, 2002; Hallström, 2003, 2005).

Thus, system growth in European infrastructure was directed to both upstream and downstream intra-system alignment, and required an increasing degree of standardisation also of consumer appliances. The European systems eventually developed an almost total vertical integration, where regime actors controlled standardised customer appliances such as sockets, telephone handsets and plumbing, not just 'out there' on the grid, but even in the private homes of the users.³

Also in Nairobi the downstream water installations followed standards, namely the British standards. But, paradoxically, it was precisely these imported standards, which were difficult for low-income

³ One striking example of downstream vertical integration was the so-called 'connection monopoly' in the Swedish telephone system. The public telephone company, the central regime actor, not only controlled the actual grid but also owned each and every telephone in the home of the subscribers. This monopoly was gradually replaced from 1980 and people could install their own telephones – but they still had to conform to the technical standards set by the regime (Statskontoret, 2004).

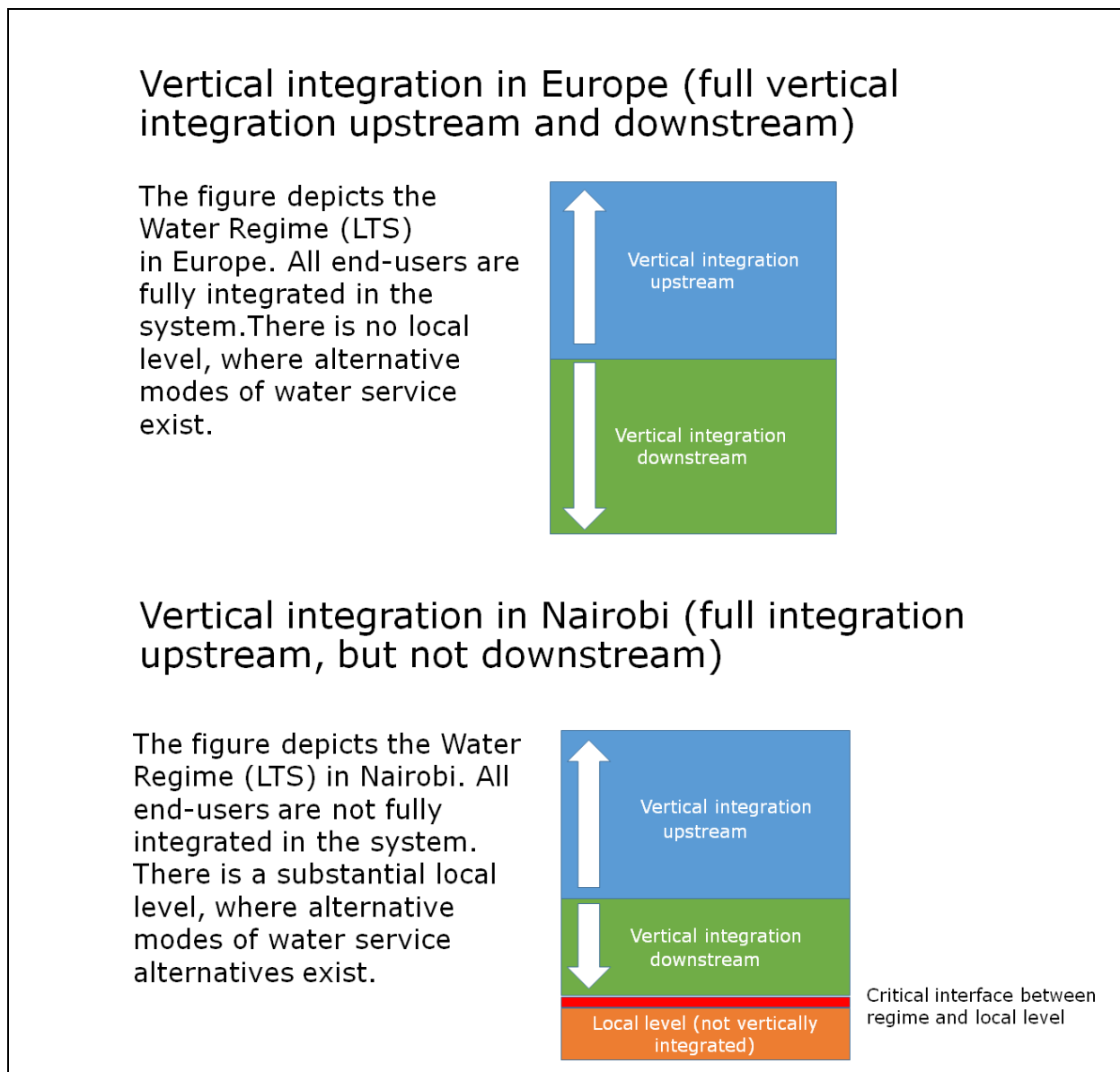
people to meet, that prevented the system from reaching more customers (Nilsson, 2011). Instead of adjusting the standards, it seems that the regime actors used another strategy to deal with these obvious shortcomings of downstream intra-systemic alignment. Nairobi regime actors did not incorporate more and more of the downstream system environment. On the contrary, they drew a sharp border between the system and its environment and treated what was left outside as an 'externality'. People in the low-income category who were unable to meet the high standards inside the regime were simply left outside, and classified as illegal 'squatters'. The regime actors placed the border of the system in such a way that the issues related to water provision in the outskirts of the system were defined as being outside their area of responsibility (Nilsson, 2016).

We can see that in Africa the LTS for urban water were imported in the form of a completed whole and introduced top-down, as a number of authors argue (Gandy, 2006; Bradbaart, 2009; Bohman, 2010; van der Straeten and Hasenöhrl, 2016). But is it possible and meaningful to talk of an African 'technological style' in Hughes' sense? Our study shows that we, at any rate, can talk about a 'Nairobi style' of water system evolution. As the water system – once transferred from Europe – was locked in to serve mainly higher-income classes, the Nairobi water system stopped growing without ever reaching into low-income brackets. The system became saturated at a level where only relatively rich people were in a position to use the services delivered. Instead subsystems appeared, like vendors, stand pipes and water kiosks, taking care of service delivery to a large proportion of the end users. These subsystems were only partly connected to the infrastructural grid. They were not standardised according to the central systems logic. And the end user did not, in the same sense, become a system node. But the various subsystems (loosely coupled or stand-alone) did in fact deliver. They provided the 'last mile' of water provision for ordinary people – but at a high cost per litre of water.

To sum up the comparative analysis: In *tightly coupled* systems the connections between system components or subsystems (technical and institutional) are robust and especially designed for system purposes. The regime actor has one overarching goal: To avoid technical and institutional mismatch – to *align* system components *within* the system. In a comparative perspective the Nairobi system and European urban water systems (and other LTS) have a lot of similarities when it comes to upstream activities. But when investigating downstream activities, we can see large differences. European urban water systems have managed an almost total downstream vertical integration, with nearly 100% of all end users connected to the grid. The Nairobi water system reached about 70% coverage, with a plethora of other service providers – external to the regime – taking care the residual 30% of local water provision. Just where the formal centralised system provision ends, we suggest the existence of a critical interface between the regime and the unconnected users at the local level (see Figure 2).

The inability to vertically integrate the low-income consumers at the local level has many explanations such as weak legislation and enforcement, lack of political or economic incentives, poor accountability, and capacity constraints, to mention a few. It is beyond the scope of this paper to analyse all these factors. In the last section of this paper we focus on ways of understanding inter-level alignment across the critical interface between the regime and the local (unintegrated) level, which we believe can be a key for sustainable transformation of the urban water regime. We will also see how such a move towards local-regime alignment can fit in to the larger pattern of an infrastructure turn.

Figure 2. The European and Nairobi technological styles.



CONCLUSIONS: THE NEED FOR INTER-LEVEL DOWNSTREAM ALIGNMENT

So far, we have analysed the dynamics of Nairobi water supply using the perspective of Large Technical Systems. We have shown that the evolution pattern of the water supply system in Nairobi, which was largely imported from Europe, has relatively well followed the traditional European trajectory for an urban water LTS in terms of vertical integration upstream (supply). But the downstream integration process has been halted. For anyone in infrastructure and development studies who is just briefly acquainted with East Africa, this observation does not come as a surprise. The dualism of infrastructure and public services systems in many African cities has been pointed out by numerous scholars, where heterogeneity and polycentrism rather than homogeneity and centralism emerge as a common trait in the everyday lives of its citizens (see e.g. Kjellén, 2006; Terreni Brown, 2014; Marvin and Silver, 2016; Monstadt and Schramm, 2017; Lawhon et al., 2017).

Our contribution is on how this dual system came about. In this historical account, we believe, lies a seed to understanding how such systems can be transformed towards sustainability. From our analysis

it should be clear that the surge of water investment currently witnessed in Nairobi, of which the Northern Collector Project is the flagship, does not represent a genuinely new phase or a paradigm shift seen in a longer historical context. Ever since the construction of the Ruiru Dam in the 1930s the regime actors in Nairobi have consistently focused on large-scale development of surface water to keep the regime aligned upstream to meet increasing demand. What we currently see, is a return to an investment cycle within the same paradigm, re-enabled by sector reforms which have restored investor confidence after a 20-year period of financial mismanagement.

In Hughes' terms of *technological style*, the 'Nairobi style' of water provision is based on the European style of a tightly coupled system. But in the downstream part – the user-oriented components – the Nairobi style is different from those in Europe, as large groups of the consumers have not been integrated as nodes in the regime and instead, over long periods of time been defined as externalities. To the extent the central regime tries to provide services in the local setting, uncertainty and fragmentation are rife, with multiple provision modes clinging at the boundary of the system, none, however, being able to create any major shift in the regime.

The significance of this difference in evolutionary style cannot be overstated. The upstream and downstream parts of the Nairobi system seem to be at different phases in the LTS trajectory. While the upstream part – the dams, the treatment works, the transfer lines – behave like mature systems, the downstream part – distribution, customer service and cost recovery – resemble much more the early establishment phase, with its uncertainty, low investment, and sluggish development. This has a huge impact on the overall system performance, and on the preferred strategies of regime actors. It is precisely this imbalance that should draw more attention from policy-makers, civic leaders, planners and engineers.

We argue that in Nairobi the existing water system has a relatively good *intra-systemic alignment* between its components. And thanks to sector reforms, it is now functioning in a more satisfactory fashion and can attract additional finances. But regime actors in Nairobi already know how to supply more water and actors tend to keep on doing the things they know how to do. Our key conclusion is that continued intra-systemic downstream alignment will not lead to improved services for low-income consumers. Instead, it will be necessary to focus on downstream integration through inter-level alignment, where the local level, its people and its physical realities are taken as a point of departure.

We like to suggest that shifting focus towards downstream alignment and innovation at the local level is the most fruitful strategy. This shift can also be noted in many parts of the industrialised world, where rapid innovation is taking place in infrastructural systems long considered to be mature, such as electricity, waste and telecom. And these innovation activities are increasingly induced from the local level and the users, prompting some scholars to talk of 'inverse infrastructures' (Egyedi and Mehos, 2012). As pointed out in a recent *Economist* article about the transition in electricity networks in Europe: "for the last 100 years everyone has made money upstream. Now the added value is coming downstream" (The Economist, 2017).

Thus, if regime actors increasingly focus their attention on the downstream part of the system, interesting opportunities will open up. It will be crucial to understand this *critical interface*, its actors, subsystems and processes; and how a better *inter-level alignment* between local innovation and the regime level can be achieved. One central theorem in MLP and system transition theory is that transitions take place through *niche innovations* – which, in our wording, can hopefully be found among innovations on the *local* level (Geels, 2002; 2011). Through an evolution-like process of selection, the most useful innovations are taken up, *but only if they are aligned* with the regime level (Schot and Geels, 2007; 2008; Blomkvist and Larsson, 2013). The problem is that in tightly coupled systems less variation is allowed. Incremental change is therefore a more likely transition pathway for tightly coupled systems than radical shifts from niche innovations (Geels, 2006). This underscores the role of the regime actors in leading an incremental, or step-wise, transformation.

In our view, the key water regime actors in Nairobi – the water company, the Nairobi City County (which replaced the City Council after 2010), the Water Service Board and the donors – have not clearly understood the need of local-regime alignment in their attempts for innovation. This has led to repeated failures, leaving pro-poor projects at pilot scale. Nairobi's piped water regime is misaligned not just with local socioeconomic contexts, but also with the plurality of service provision modes outside the regime. These local initiatives, innovations and highly varied modes of service provision must be consciously turned into niches, and cautiously 'nursed' to develop within the regime or on the regime fringes with the explicit goal to be assimilated at regime level. Hence, the key actors must have a strategy for how to make this happen, and they need to appreciate the importance of alignment between the regime and the local level. We wish to end this paper on a constructive and forward-looking note, outlining what form such a localised alignment process could take, and what kind of outcomes it could produce in more concrete terms.

First, acknowledge the amount of innovation activity already in place at the local level. There are countless NGOs, community based organisations, cooperatives, churches, schools, neighbourhood associations, companies, and individuals that are experimenting and trying every day new ways to provide water to the unconnected users. This is a formidable asset for the Nairobi City County and the water utility, Nairobi City Water and Sewerage Corporation, and we suspect that chances are pretty high that many viable solutions are already 'out there'. To align the regime and the local level, a first step will be to take stock of what is already there and widen the dialogue with the multitude of local actors.

Second, review and renew the innovation strategy for downstream innovation at NWCSC. How can incentives be changed within the regime to open up for innovation, leading to much more search activity to solve the problems of distribution – both physical and institutional – at the local level? It is critically important to convince national government and donors that more water upstream is not going to solve the problem, in other ways than detracting attention from the more acute issue of service provision.

Third, look for business models at the interface that make business sense both upstream and downstream. If service provision in informal settlements is associated with high risk for the utility, business models for risk-sharing can be found through outsourcing, franchising or retail to local distributors. In areas where the water utility lacks a commercial model for pro-poor distribution (downstream operation) it can still be a bulk supplier (upstream operation). The commercial viability for the local operator must be balanced against the need for fair tariff setting and affordability, but with the current huge gap between the NWSC official water tariff and the actual retail price (up to 20 times higher) in low-income areas, there is great scope for finding a balance that ensures viability both at regime and local levels.

Fourth, ensure political support for combating corruption, revising outdated standards and reducing bureaucracy, barriers that solidify the regime and inequalities in service provision. In this paper, we have not focused much on the broader system context – the landscape level – but it requires little imagination to see that regime-local alignment cannot be achieved isolated from politics or detached from the rights discourse. The new business models may also require tough measures to deal with mafia-like organisations, for which there must be no political support.

In concrete terms, we envisage that this can lead to a range of downstream solutions, where the regime and local level are aligned. It might entail establishing contracts with NGOs or cooperatives that take care of local distribution in one neighbourhood using simple piped networks in shallow trenches or ground culverts that do not require huge capital costs and are easy to maintain and control for local organisations. A more formalised version of this is the so-called Delegated Management Model which has been considered successful in other African cities (World Bank, 2009; Messas and Estienne, 2011). Water kiosks may still be viable, although the experience of water kiosks in Nairobi since the 1970s has

often been negative. However, combining the distribution technology of the water kiosk with the business model of delegated management has been a successful recipe in other Kenyan cities (WSUP, 2011).

New technology can also offer solutions in low-income areas. Examples that have already been tested in Nairobi include pre-paid automated water vending machines, which effectively cut out the middlemen in distribution, thus controlling the consumers' price for water (Heyman et al., 2014). Another example is the installation of sensors on the water networks connected through 4G mobile networks. The rapid spread of mobiles and the reduced cost for sensors enable application of an 'internet-of-things' also in the water sector, increasing transparency, control and user engagement also in informal areas which reduce risk and losses for the utility (Heland et al., 2015). However, our key message here is that such technology will not be successful beyond pilot scale unless aligned with the regime; technology needs to come packaged in business models that are viable on both regime and local level.

Other solutions at the critical interface may be found far away from the technology side. Increasing local ownership, building awareness and capacity in local contexts, with, for example, water vigilantes and champions, health clubs and self-help groups,, can go a long way in creating a more favourable and attractive local environment for risk-weary utilities and investors. Institutional changes at regime level may also be needed. This should include easing the standards requirement, allowing for a simpler distribution technology in low-income areas, and a much higher tariff for the high-end consumers to cross-subsidise downstream investments in marginalised areas. It is also necessary to reduce overall water demand and create incentives for conservation and reuse. According to Ledant et al. (2013), almost half of the water distributed in Nairobi today is consumed by the richest 10% of the population.

In the coming years, we see an important and fascinating area of study opening up around infrastructure in African cities, where we think understanding regime-local alignment may play a huge role. This research agenda is just beginning to take form. It may hopefully contribute to the transformative shift of Africa's urban life towards sustainability, a path that must be grounded on African practical realities, local context and history rather than on ideals and solutions imported from elsewhere. We cannot say that Nairobi is representative of an 'African style', or even that it is meaningful to lump together historical experience from 54 nations under one term. But it can be easily argued that a situation of duality in service provision exists in many other African cities. We hope that this paper has offered some useful concepts for unpacking and understanding these cities, their infrastructures, where they come from and where they could be heading for. We are also convinced that the study of infrastructure in the African context is going to produce a lot of knowledge and new theory that will help us understand socio-technical change and sustainability in many other places, including in the global North. It is rather intriguing to think that perhaps Nairobi, and other African cities, can become a source of inspiration and learning also for the global North in local innovations and downstream infrastructural alignment. The existence of a local, unconnected level in the Nairobi water system could be seen as an opportunity for innovation – and not only as historical failure.

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