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Screening European market potentials for small modular wastewater treatment systems – an inroad to sustainability transitions in urban water management?

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ABSTRACT

Urban water management represents a core economic sector exposed to global water-related challenges. Recently, small modular system configurations have been identified to enable a potential sustainability transition in this lasting and rather conservative sector. The identification of current market potentials of decentralised wastewater treatment is a first step to assess whether decentralised treatment technologies could potentially be deployed on a larger scale in Europe, which would allow current decentralised wastewater treatment technologies to develop and mature. The paper elaborates a method to assess the market potential for decentralised wastewater treatment systems by starting from a raster-based geospatial modelling framework, to determine the optimal degrees of centralisation for the case of Switzerland. The resulting market potential is shown to be twenty times higher than the current market share of decentralised systems. In order to extrapolate these findings to other countries, the calculated optimal degrees of centralisation were correlated with different spatial density measures to determine a reliable and widely available proxy: population density. Based on this indicator, the European market potentials for decentralised treatment systems are estimated to be about 100,000 units per annum serving around 35 million population equivalents. The paper concludes by discussing implications for future sustainability transitions in urban water management by large-scale installation of small modular wastewater treatment systems.

1. Introduction

With investments of about 1% of the global gross domestic product (OECD, 2006) and an estimated return on investment of US$5.5 per US $ invested (Hutton and Haller, 2004), urban water management (UWM) infrastructure constitutes one of the major assets of the built environment and contributes fundamentally to human and environmental health (UN WWAP, 2017). To cope with multiple water-related challenges of global environmental change, the UWM sector needs to reconsider its former success conditions. What is at stake is the management of a sustainability transition which will depend on a whole series of innovations both in the technological and institutional setup of the sector, i.e. a renewal of its 'socio-technical regime' (Geels, 2006; Markard et al., 2012; Martínez Arranz, 2017). Sustainability transitions can be defined as "long-term, multi-dimensional, and fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption" (Markard et al., 2012). The currently dominant socio-technical regime of the UWM sector is considered to be quite uniform across the world (Fuenfschilling and Binz, 2018). Technologically, it consists of long-living network infrastructures (i.e. drinking water distribution pipes and sewers) and centralised water and wastewater treatment plants and it is predominantly supported by civil engineering expertise. These characteristics have led to strong technological path-dependencies over the past decades (Thomas and Ford, 2005). At the same time, a neatly aligned institutional and organisational governance structure has emerged, leaving the sector with a conservative take when it comes to dealing with innovative concepts and approaches (Kiparsky et al., 2013). As a consequence, we postulate that the UWM sector is confronted by an equivalent of the carbon lock-in in the energy sector (Unruh, 2000): an over reliance of long living centralised infrastructures, which prevents alternative, potentially more sustainable

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technological options to develop and mature.

Different key UWM services such as the provision of safe drinking water, urban hygiene, water pollution control and the management of urban runoff (effluent and storm water) are closely linked to and interdependent to each other (Larsen and Gujer, 1997), e.g. when storm water runoff and domestic wastewater are transported in combined sewers. The aim of this paper is to identify possible pathways for today's wastewater treatment infrastructures to transform into more sustainable directions by opting for the most sustainable mix of centralised and decentralised wastewater treatment infrastructure. The planning context of wastewater infrastructures is challenging as ideally different subsystems and its interdependencies need to be considered (Fagan et al., 2010; Makropoulos and Butler, 2010; Guo and Englehardt, 2015; Kavvada et al., 2018). The focus of this paper is limited to wastewater in order to cope with the complexity of the modelling task and because we are optimising for a "green-field" approach, where storm water is best treated and transported separately (cf. Section 2.2).

Even though the centralised regime has contributed to the eradication of diseases such as typhoid and cholera (O'Flaherty, 2005), it is confronted with increasing critics when it comes to its longer term sustainability prospects. It often turns out to be associated with considerable ecological and economic costs, due to sewer overflows, leaking pipes or water scarcity and it often results in a financial burden for local communities (Daigger, 2007; Bahri, 2012; Braga et al., 2014; Gawel, 2015; Sadoff et al., 2015; UN-WWAP, 2015; Hall et al., 2016). In many settings around the world, particularly outside an OECD context, the centralised approach is problematic, as complexity of centralised infrastructure investments generally requires 'significant complementary institutional capacity (and financial resources) for management, operations, and maintenance' (Sadoff et al., 2015).

The degree of dominance of the centralised socio-technical regime is geographically varied. Many countries have developed very high penetrations of their centralised systems: the United Kingdom, Switzerland or the Netherlands, for instance, have enforced central connection rates close to 100% (OECD, 2015; Eurostat, 2017). Lower connection rates are found in other OECD countries where considerable segments of the population are served by more or less functional decentralised wastewater treatment systems. A notable example is Japan, where the development of small-scale treatment units known as *Johkasou* results in a current connection rate of 78% (Gaulke, 2006; OECD, 2010, 2015; Yang et al., 2011).

The terms "centralised" and "decentralised" wastewater treatment systems need to be defined in the context of this paper, as they are used quite differently in literature (Sharma et al., 2013): Whereas centralised treatment is used to describe a system based on large-scale wastewater treatment plants and sewer based transportation, the key feature of decentralised systems is treatment of wastewater close to the point of origin (Wilderer and Schreff, 2000). A whole continuum of spatial arrangements of treatment scales are conceivable (Ambros, 1996; Libralato et al., 2012). We use the term 'hybrid systems' for combined centralised and decentralised systems. By decentralised treatment, we understand small-scale mechanical-biological treatment plants, i.e. treatment technologies offering the same or very similar performance to those of centralised treatment. Because no clearly quantifiable distinction exists in terms of scale (or "closeness") to distinguish between centralised and decentralised treatment, it is necessary to specify this for a given context (which is provided for a Swiss context in Section 2). Therefore, we us the terminology of "small modular" as outlined by (Dahlgren et al., 2013) for referring to fully matured decentralised wastewater treatment systems which are characterised by modularisation, automation and mass production. This terminology is used to clearly distinguish between fully automated decentralised systems where high economies of numbers are achieved in manufacturing and where total system costs are dominated by treatment instead of transportation (cf. Dahlgren et al., 2013).

Conventional decentralised approaches are often seen as a mere technological stopgap, with a far lower performance than centralised systems. In particular, they are considered as too expensive, performing worse in terms of treatment capacity, essentially unreliable and hard to regulate (McDonald et al., 2014; Sadoff et al., 2015; Huskova et al., 2016). Outside of OECD countries, connection rates to the centralised system have remained very low, with little prospect of increasing anytime soon. Also, decentralised systems are often unable to provide safe sanitation services, which is a particularly pressing problem in developing countries (Lüthi et al., 2011). However, membrane-based systems can achieve high levels of performance across a wide range of treatment plant sizes (Fane and Fane, 2005; Peter-Varbanets et al., 2009; Zodrow et al., 2017). Furthermore, recent developments in the realm of modular system configurations taking advantage of the latest information and sensor technologies may counter many of these assumed weaknesses: Excessive personnel costs may be avoided due to the availability of low cost automation and remote monitoring (Dahlgren et al., 2013). This would enable centrally operated contracting schemes for large fleets of decentralised systems and by this guarantee similar levels of technical reliability like todays centralised systems (Larsen et al., 2013; Larsen et al., 2016). One good example showing the success and advantages of such a contracting scheme is for example provided for a German context by Hiessl et al. (2010). In particular, recent developments in pathogen monitoring suggest that system reliability may be increased substantially by autonomous control systems which may prove far more effective than traditional monitoring and control protocols (Hering et al., 2013). The shift towards such small modular UWM infrastructures can also be witnessed in realms of water disinfection, water reuse, desalination and resource recovery (Friedler and Hadari, 2006; Alnouri et al., 2015; Shahabi et al., 2015; Guo et al., 2016).

However, the successful further development and maturing of decentralised systems depends on a vast array of interrelated socio-technical innovation processes. Their successful introduction depends on whether substantial entry markets can be identified and whether industry, utilities and regulators will actually formulate corresponding innovation strategies. A number of challenges have to be overcome along the way to fully functional and cost-effective small modular systems such as reliable system operation with comparable performance level to centralised treatment, the exploitation of economies of learning and scale in manufacturing to substantially decrease costs or the development of appropriate management and governance structures (Hoogma, 2002). A sustainability transition in the urban water sector will only be conceivable if these challenges can be tackled in a balanced way. This task therefore resembles a systemic innovation process rather than a static optimisation task where an suitable technology can be selected from the shelf (Truffer et al., 2013).

One crucial precondition for these innovation processes to happen is to identify the overall market potentials of current decentralised wastewater treatment systems in terms of numbers of units demanded for sale per annum. By assessing the market potential, we mean to estimate an order of magnitude of units that could be sold on a per annum basis for a given region. However, this number provides only a rough estimate of what companies might be able to sell in these markets in the future. The actual market volume may depend on all sorts of efforts that have to be spent to penetrate the market such as marketing costs, adaptations to local rules and regulations or the diversity of market segments. Our estimated market potential can only be taken as an indication for informing future firm strategies, not as a reliable prediction of future business volumes. Furthermore, we want to clarify that we base our estimations predominantly on the market in rural and peri-urban regions. This is however not to say that decentralised water treatment could only be applied in these contexts (Nolde, 2012; WERF, 2018). In that sense, our estimates will rather be at the lower end of the spectrum. Finally, we have to note that our analysis estimates market potentials with respect to cost characteristics related to techno-economic assumptions (see Section 2.2). The market potential of