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Replacing centralised waste and sanitation infrastructure with local treatment and nutrient recycling: Expert opinions in the context of urban planning

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ABSTRACT

Solutions for resource scarcity should be sought from urban waste management and sanitation, which are characterised by central plants and long networks. The socio-technical transition to more sustainable infrastructure is expected to include partial decentralisation based on local conditions. This paper focuses on drivers, barriers and enablers in implementing a decentralised circular system in a new residential area (Tampere, Finland). In the alternative system, biowaste and feces are treated in a local biogas plant, and nutrient and energy output are utilised within the area. This research aims to understand what kind of urban planning enables alternative infrastructure, as well as the characteristics of an innovation capable of making a breakthrough. Seventeen infrastructure planning experts were interviewed, then assembled to re-develop ideas arising from the interviews. Based on these qualitatively analysed data, 11 factors which help the adoption of the alternative system were formulated. The results indicate that sustainability transition can be facilitated through impartial urban planning that allows the early participation of actors and improved communications. Additionally, studying the impact of alternative solutions and city guidance according to environmental policy aims may enhance transition. Innovation success factors include suitable locations, competent partners, mature technology and visible local benefits.

1. Introduction

Resource scarcity is a topical issue whose solutions should be sought not only from the energy sector, but also from the waste management/sanitation sector. Currently, urban infrastructures are characterised by centralised treatment plants and long transportation distances, and they have been criticised for high energy and resource usage as well as inadequate resource recycling. The EU has been supporting a circular economy through the Horizon 2020 Research and Innovation programme (Horizon 2020 sections, n.d.). Consequently, there are new technical solutions available, but their testing and implementation are still in the initial stage. The adaptation of technical innovations has been resisted by stable infrastructure regimes, which carry out essential societal functions and are therefore characterised by lock-in and path-dependency processes (Smith and Raven, 2012). In past decades, the centralisation of infrastructures has inevitably provided health and environmental benefits. However, a revival of decentralised urban infrastructures should be considered today to counteract new sustainability challenges.

To understand the present infrastructures and the motivation to change them, technical solutions and resource flows need to be observed critically. At the beginning of the food chain, current agriculture depends on irrigation (Valipour, 2015) and artificial fertilisers produced in an energy-intensive process (nitrogen N) (Brentrup and Palliére, 2008) and mined from scarce reserves (phosphorus P) (Cordell et al., 2009). Agricultural products, and consequently food products, contain high amounts of nutrients that the human body mainly excretes in urine (Spångberg, 2014). In addition, garden and kitchen waste (hereafter referred to as biowaste) contributes to urban nutrient flow (Sokka et al., 2004). In a conventional wastewater-treatment plant, energy and chemicals are used to remove nutrients according to ever stricter environmental requirements. In wastewater treatment, N is converted to atmospheric nitrogen and P is often precipitated into an insoluble form, limiting its reuse. Finally, biowaste and treated sewage sludge are landfilled, incinerated, composted, anaerobically digested (Manfredi and Pant, 2011) and/or recycled into agriculture.

Anaerobic digestion is an attractive treatment technology because it generates renewable energy in the form of biogas, supports nutrient recycling and potentially creates local jobs. Furthermore, anaerobic digestion is suitable for urban areas because the process occurs in enclosed tanks, and emissions are easier to manage than in other treatment methods (Edwards et al., 2015). However, recycling end products from centralised plants to agriculture is marginal (Meers, 2016), so the nutrient loop is not closed. In addition to process limitations, the risk of recycling harmful substances, lack of acceptability (Aubain et al., 2002),

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unsupportive or unclear legal frameworks (Hukari et al., 2016), and governance aspects such as poor source-separation or inefficient plant operation (Zabaleta and Rodic-Wiersma, 2015) are hindering the recycling of waste-derived nutrients.

Source-separating sanitation and decentralised treatment of domestic wastewater have been suggested as an alternative with the potential to improve nutrient recycling and energy efficiency in the sanitation system (Tervahauta et al., 2013). Furthermore, decentralised water systems have the potential to reduce infrastructure costs and support innovations that can be exported to emerging economies (Quezada et al., 2016), whereas distributed energy systems may increase renewable energy production capacity and energy self-sufficiency (Ruggiero et al., 2015); moreover, such systems may enhance sustainability in terms of flexibility, locality and networking (Alanne and Saari, 2006). To promote local resource cycles and renewable energy production, the authors have designed a *decentralised circular system* (Fig. 2, in Section 2.2) that consists of source-separating low-water toilets, small-scale biogas plants, and the local utilisation of nutrients and produced gas within a residential area (the case city: Tampere, Finland).

In addition to technological advancements, planning in diverse forms is required to improve urban infrastructures. The most comprehensive is land-use planning, which coordinates sectoral policies and decisions with spatial impacts. Planning systems vary between countries. In Finland, municipalities have a planning monopoly, as well as the power to approve and ratify master plans and detailed plans (Finnish Parliament, 1999). Stakeholder participation and sustainable development are emphasised in planning legislation. As a complementary planning instrument, cities use unofficial land-use planning based on public–private partnerships (Junnila et al., 2010). This increases their strategic capacity and flexibility to react to new possibilities. In addition, land policy is an important resource for cities in their planning. At the moment, more instruments and cooperation are needed in Finland for integrated planning between administrative sectors and between municipalities (Hirvonen-Kantola and Mäntysalo, 2014). Related to these challenges, it is worth noting that land-use planning is determined not only by legal and administrative rules, but also by informal institutions. Political, socio-economic and cultural forces affect the planning system.

In this paper, the objective is to determine the preconditions for implementing the decentralised circular system. The authors explored the system's feasibility in semi-structured interviews with 17 water-, waste-, gas-, energy-, and urban land-use planning experts, and in a workshop with seven experts. In directed content analysis (Hsieh and Shannon, 2005), drivers, barriers and enablers (Quezada et al., 2016) for alternative system implementation were sought. The results were organised based on a multi-level perspective (MLP) (Geels, 2010) that views socio-technical transition as an interaction between three levels: niches (novelty), regime (dominant actors, institutions and technologies) and landscape (political environment). The authors aim was to answer the following research questions:

A) How can a decentralised circular system be supported in the context of urban planning?
B) What are the characteristics of an alternative system capable of achieving a breakthrough?

Previous research has generated knowledge on various aspects of sustainable urban infrastructure (Ferrer et al., 2016), but a gap remains between infrastructure planning scholarship and the realities of public infrastructure planning (Malekpour et al., 2015). The decentralised circular system considered in this paper and placed in the context of urban land-use planning contributes to fulfilling this research gap. Another contribution of the paper is to introduce the innovative methodology of using expert opinions to investigate the preconditions of an alternative infrastructure.

2. Material and methods

2.1. Multilevel perspective on the research setting

The authors organised the preconditions for implementing the decentralised circular system in a new residential area according to a multilevel perspective. In MLP, *landscape* refers to an exogenous environment that changes slowly and affects niche and regime dynamics (Verbong and Geels, 2010). This study is motivated by global *resource scarcity* and aims to enhance *sustainability*, *liveability* (de Haan et al., 2014) and the *circular economy* (Fig. 1), which questions the performance of current regimes and generates opportunities for the studied system. On the other hand, there are also opposite landscape processes, including strong *consumption culture*, which fit with current regimes and may hinder transition.

Regimes are the prevailing means for realising key societal functions (Smith et al., 2010); they consist of material and technical elements, networks of actors, and rules that guide activities (Verbong and Geels, 2010). In the context of this paper, regimes include *municipal water, sanitation and waste infrastructure*. When an (alternative) infrastructure is realised in new residential areas, the strongest actors come from *municipal land-use planning*, where the planning power is, and from *construction companies*, which invest in building houses (Fig. 1). Characteristically, infrastructure sectors are highly institutionalised socio-technical regimes that enable certain rationalities and actions while hindering others (Fuenfschilling and Truffer, 2014). Innovations might be rejected because they do not fit with existing industry structures or decision-making processes (Smith and Raven, 2012). Socio-technical transitions are about changes in regimes, and they require both strong alternatives in niches and favourable openings in regime-selection environments via dynamics and tensions within and between regimes as well as due to landscape pressure (Smith et al., 2010).

Niche is defined as a protective space for path-breaking innovations which fail to successfully compete within the selection environments of incumbent socio-technical regimes. In this paper, the decentralised circular system is a potentially path-breaking innovation which the public sector is expected to protect in the context of urban land-use planning (Fig. 1). In niches, innovations can become competitive within unchanged selection environments (fit and conform) or when mainstream selection environments change in a way favourable to them (stretch-and-transform). When an innovation is developed to fit and conform to an existing regime-selection environment, its sustainability is often compromised (Smith and Raven, 2012).

2.2. Decentralised circular system

The authors have developed a decentralised circular system that consists of an alternative sanitation system (Maurer et al., 2012) (source-separating and urine-diverting low-water toilets); a small-scale biogas plant to treat feces or black water, biowaste, energy crops and plant residues; and the local utilisation of nutrients and gas (Fig. 2). In source-separating sanitation, black water (from a toilet) is collected separately from other domestic wastewater. Furthermore, low-water (dry or vacuum) toilets enable concentrations of black water and, subsequently, direct treatment in an anaerobic digester. Urine contains most of the nutrients but has low energy potential, and it may be diverted from black water using a urine-diverting toilet. In the decentralised circular system, nutrients recovered from urine and anaerobic digestion feedstock are used in local scenery fields to cultivate energy crops and/or in nearby greenhouse cultivation. After upgrading, biogas can be used locally, e.g., in household gas cookers, as vehicle fuel, or it can be injected into a gas grid. Grey water is treated either on site or directed to centralised treatment; it can also be re-used, e.g., in greenhouse irrigation or as flush-water, if it fulfils quality criteria. In Finland, fields are not typically irrigated; but when global applications are considered, irrigation methods (Valipour, 2012) have greater importance.