Resources, Conservation and Recycling 123 (2017) 135–142

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

Material stock disparity and factors affecting stocked material use efficiency of sewer pipelines in Japan

Cherry Myo Lwin [a,*], Sébastien M.R. Dente [b], Tao Wang [c], Toshiyuki Shimizu [a], Seiji Hashimoto [d]

[a] Ritsumeikan Global Innovation Research Organization (R-GIRO), Ritsumeikan University, Japan
[b] Ritsumeikan University, Japan
[c] Circular Economy Research Institute, Tongji University, China
[d] College of Science and Engineering, Ritsumiekan University, Japan

ARTICLE INFO

Article history:
Received 29 March 2016
Received in revised form 21 July 2016
Accepted 8 August 2016
Available online 12 August 2016

Keywords:
Material flow and stock analysis
Resource efficiency
Resource productivity
Wastewater treatment
Sewered population

ABSTRACT

Service is most often measured with a flow and monetary perspective using indicators such as gross domestic product (GDP) or the value added or income of a particular economic sector. However, infrastructures and therefore the associated material stocks also participate to the service delivery. Our study contributes to this emerging research field through a novel method of measuring stocked material use efficiency (SMUE) of sewerage pipelines in Japan, beyond monetary measures. We estimated the Japanese national and prefectural material stocks (MS) using statistical data and used direct service indicators such as the population with access to sewerage treatment services and the amount of treated wastewater to find the SMUE. Later, decomposition analysis was used to ascertain the main factors influencing SMUE. Results show an MS increase for all prefectures and a doubling of the national MS from 207 million tonnes (Mt) 520 Mt between 1984 and 2012. Material stocks are found mainly associated with population size, the highest populated prefectures Tokyo and Osaka also accounting for the highest material stocks. Concerning SMUE ranging from 4 to 48 m3/ton for a national average of 27 m3/ton, its main determinants are population density and pipeline size. This research promotes greater understanding of our stock use condition and thereby facilitates appropriate stock management.

1. Introduction

1.1. Infrastructures and their services

Infrastructure is crucially important for many necessary activities that underpin industrial and economic development. Physical core structures provide services to society. Baldwin and Dixon (2008) demonstrated that economic growth, enhanced quality of life, and national security can be achieved through effective infrastructure. Mattoon (2004) pointed out that infrastructure ventures can engender organizational and management change. For example, railway systems produce standardized schedules that stimulate economic profits beyond the physical type of railway itself. Grundey (2008) and Burinskiene and Rudzkiene (2009) analyzed the implementation of sustainable development policies. They emphasize the progress of infrastructure as an important measurement in strategic planning to secure the sustainable territorial and socioeconomic development of a nation. Yerri et al. (2016) demonstrates the significant economic, environmental and societal consequences induced by large diameter water main break thereby showing the importance of infrastructure for the supply of basic services of our societies such as telecommunication, power distribution, irrigation, water supply, and wastewater treatment.

The infrastructure described above requires huge physical structures. In fact, material accumulations in that infrastructure are also gigantic. The building sector is known to have the largest inventories of materials in industrialized societies (Schebek et al., 2016) but sewer pipeline networks also represent large underground assets and material stocks, especially of concrete and cast iron (Pauliuk et al., 2014). Although high material stocks are accounted for in our society, little is known about stocked infrastructure efficiencies. Among the infrastructures and services explained above, this research specifically examines sewers in Japan, which are envi-

* Corresponding author at: Ritsumeikan Global Innovation Research Organization (R-GIRO), Ritsumeikan University, 1-1-1 Nojihigashi, Kusatsu 525-8577, Shiga, Japan.
E-mail addresses: cml-11@fc.ritsumei.ac.jp, cherrymyoolwin@gmail.com (C.M. Lwin).

http://dx.doi.org/10.1016/j.resconrec.2016.08.010
0921-3449/© 2016 Elsevier B.V. All rights reserved.

ronmental utilities that convey huge benefits directly to society by providing basic facilities to improve the quality of life within society.

1.2. Diffusion rate of sewer pipelines in Japan

Japan has expanded its sewer network during the past century, with average annual capital expenditures amounting to almost 5 trillion yen (50 billion US dollars) since 1998. After 2000, capital expenditures suddenly started declining, largely because of government modifications of public investment policy. Those reductions occurred as part of a restructuring program. According to the Japan Sewage Works Association (JSWA, 2012), 76% of the total population currently has access to public sewage systems, although the figure was only 34% in 1984. That percentage has increased, but Japan still has one of the lowest rates in per-capita sewer pipeline length for access to public sewage systems when compared with EUREAU member countries (JSWA, 2008; EUREAU, 2008). More details are available in S_note 1 of *Supporting information*.

Another important issue is the increasing age of sewer pipelines, especially of the most early laid sewers. Their increasing decrepitude might engender issues of safe wastewater management, demanding huge new investments. Growing maintenance backlogs underscore aging pipeline problems, but no sufficient amount of rehabilitation has been undertaken. Big cities undertake great efforts to maintain sewers according to their available human and financial resources while confronting problems of aging infrastructure as the more immediate threat. For operation and maintenance, hiring employees and allocating funds for expenditure have been nearly halted because of budget-cutting programs undertaken by municipalities. Therefore, a noteworthy point is that effective and efficient planning of sewerage is fundamentally necessary. Consequently, additional studies related to construction material accumulation in sewers and the consequent evolution of stock use efficiency have become necessary.

1.3. Material stock studies

Developing a sound material cycle society, as the Japanese government intends, requires knowledge of the amounts of stocked materials in our socioeconomic systems. Research related with accumulated construction minerals and possible construction waste amounts in Japan for future has already been done (Hashimoto et al., 2007). Tanikawa et al. (2015) evaluated the comprehensive and historical accounts of the construction material stocks of Japan to elucidate in-use construction material stocks of 47 prefecture-level administrative areas in Japan, particularly addressing buildings, roads, railways, and underground pipes, describing the spatial distribution of material stocks. Fishman et al. (2014) conducted a comparative study of material stocks in Japan and the United States, correlating their relations with their respective national socio-economies. Although those studies emphasized the estimation of construction material stocks, measuring the efficiency of stock use has not been done. Fishman et al., 2015 present an extremely interesting analysis of factors influencing buildings and transport stocks based mainly on population and economic activity, indicating that these are services from stocks. However, they only address population and economic activities in that study, not direct service indicators such as housing and transportation from those accumulated stocks. Moreover, sewer pipes are excluded from the research scope. Directly with stocks and their service indicators, some attempts have been undertaken to establish efficiency indicators: for the Netherlands, some researchers have already examined building stocks intensively. Often the effective living space in square meters is regarded as an indicator of service (Müller, 2006). For Japan, based on direct services (passenger flows, goods flows), stock efficiency is observed for transport infrastructure (Lwin et al., 2013). Research of this kind, although interesting and novel, demands further research exploring new indicators that directly link stocks and their direct services.

In this study, as a new indicator of stock efficiency, we introduce and explore stocked material use efficiency (SMUE), defined as the function or service performed by one unit of stocked materials, i.e., by relating the material stocks in use to its provided services. For example, the wastewater amount treated per unit of material stock (m^3/t). Evaluation of the stocked material use efficiency (SMUE) is necessary for environmental policy-making for two reasons: (1) stocked material use efficiency indicators should be evaluated as reflecting a level of "service" rather than economic value; and (2) it is time to measure the efficiency of material stock use to facilitate decision-making for Japan while producing a sound material society. Knowledge of such kinds can show how to obtain the maximum service from limited material stocks based on prevailing conditions. The highlights of this research are therefore the development of a new methodology to assess sewer-pipe-related stocks at the Japanese national and prefectural levels, and a consistent discussion of underlying reasons of observed stock efficiency. For the latter, we produced four hypotheses, tested through the study described in this paper, as follows.

H1: Material stocks are a growing function of population

This hypothesis corresponds to our expectation that prefectures with larger populations produce more wastewater than less populous ones, thereby demanding a higher amount of wastewater (level of service) for treatment and therefore requiring a larger stock.

H2: The derivative of the material stocks, population function, is a decreasing function

In other words, the stock per capita is less important in more heavily populated prefectures.

H3: The scale economy presented in H2 is valid for stocked material use efficiency

In other words, prefectures with larger populations are more efficient.

H4: Large-diameter pipelines are used mainly in prefectures with large populations

This hypothesis corresponds to the expectation that a high level of service favors the use of these high-capacity pipelines.

2. Research methodology and data requirements

2.1. Data source

The assessment material stocks, the main methodological novelty of this work, require information related to pipeline length and material intensity, i.e. the amount of construction material (kg) per meter (m), per diameter category. We collected 1984–2012 historical data from annual statistical yearbooks for sewer management published by the Japan Sewage Works Association (JSWA). These data include the accumulated length and renovated lengths including repair and reconstruction (renewal and improvement) according to the following diameter types: (i) smaller than 600 mm, (ii) 600–2000 mm, and (iii) larger than 2000 mm, (iv) vacuum type smaller than 100 mm, (v) vacuum type of 100–150 mm, (vi) vacuum type larger than 150 mm, (vii) pressure type, smaller than 100 mm, (viii) pressure type of 100–150 mm, and (ix) pressure type larger than 150 mm. Regarding material intensity, historical data from the 1980s through the 2000s for sewer pipeline types from (i)–(iii) have been estimated in earlier studies (Nagaoka et al., 2009). From our study, we therefore omitted sewer pipeline types of (iv)–(ix) as (a) no appropriate material intensity data can be estimated currently because of a lack of sufficient data and time and because (b) their share of sewer pipeline lengths is extremely small, e.g. 1.8% in