Role of policy in managing mined resources for construction in Europe and emerging economies

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A B S T R A C T

Rapid urbanisation, with associated housing and infrastructure demands, leads to increased mining and use of non-renewable mineral raw materials needed for the construction industry including concrete and cement. In an emerging economy, like Thailand, which is part of Association of Southeast Asian Nations (ASEAN), current environmental management policies are insufficient to reduce raw material requirements or waste from demolition by generating inputs to construction through reuse or recycling. As part of the European Union (EU), Great Britain has successfully implemented integrated policies and achieved high rates of recycled aggregates in construction (29%) and a 70% reuse and recycling target for construction and demolition (C&D) waste. In this paper, Material Flow Analysis (MFA) of cement/concrete materials is combined with an interpretation of related policies to provide a deeper understanding how to achieve more sustainable management of natural resources. A comparative MFA for the construction industry in Great Britain and Thailand (representing an ASEAN country) has been developed that quantifies raw material inputs, buildings and infrastructure outputs, so that the practices in the two countries can be contrasted. We report domestic cement production and import/export data, and calculate the raw materials needed for cement and its calcination process for concrete production. Considering the most relevant policies and taxation in Great Britain, we identify possible ways forward for Thailand by introducing new policies and taxation that will have positive effects on raw material extraction, processing, construction and disposal practices and disposal behaviors. Following the MFA and policy analysis, we believe that similar benefits apply to other emerging economies.

1. Introduction

Current and future socio-economic changes associated with population growth and urbanisation lead to increased housing and infrastructure growth, particularly in developing regions, with increasing pressures on natural resources and the environment (Agudelo-Vera et al., 2011; Giljum et al., 2014; Schandl et al., 2018). As a focal point of growth, emerging economies may lack the necessary financial and institutional capacity to guide rapid changes in line with good environmental management practices and local or indeed global exploitation of natural resources and local consumption (OECD, 2011). To highlight sustainable extraction and consumption various studies have used Material Flow Analysis (MFA) to illustrate consumption and production at an aggregated country level or across multi-national levels (Ervasti et al., 2016; Kovanda and Weinzettel, 2013). However, there are few reports concerning the construction sector, its use of raw materials, natural resource requirements and the policies that can influence environmental management positively (Anand et al., 2006; Harvey et al., 2014; Pomponi and Moncaster, 2016).

This is a significant oversight as the construction industry is one of the largest sources of wastes and greenhouse gas emissions, and advances in governing structures have to be made in order to reduce its negative impacts, via for example reverse logistics (Nunes et al., 2009). In terms of volume, construction materials dominate both the raw material sector associated with economic development, especially the cement, aggregate and concrete industries, and the waste sector in terms of amounts generated through demolition. Asia consumes nearly 20% of global construction resources, and many new cement plants are needed (Behrens et al., 2007; OECD, 2008). Cement production in Asia is expected to double between 2010 and 2050 (OECD, 2008), reaching 40% of global output. This ultimately will lead to increased extraction of valuable resources and end of life wastes at all stages in the supply chain.
change. In this context, clear and robust environmental policies are needed.

Global cement production in 2012 was estimated at 3.6 billion tonnes, accounting for 5–7% of global man-made CO₂ emissions (Benhalal et al., 2013). Most cement is used to make concrete (12–16% cement by weight) which also requires 84–88% of coarse and fine aggregates (see Supplementary Information). Like cement raw materials, these are mined from either hard rock sources, and then crushed, or from sands and gravels. Given the cost of transport, and the large amounts compared with cement, aggregates are usually sourced near the point of use, and so near population centres. Thus local governments are often the bodies responsible for their strategic management (Calaes et al., 2007a,b). To some extent, recycled concrete aggregates reduce the use of primary mined minerals (Boston Consulting Group, 2012; Kim et al., 2013). Waste is produced both at the end of life of a building (following demolition) and during construction and around 60–70% being concrete (Renforth et al., 2011). If such wastes are used, their potential to act as sources of contaminants harmful to health needs to be determined through well-established protocols e.g. Butera et al. (2014); Engelsen et al. (2017). Such studies have shown that reuse or recycling demolition waste need not be associated with unacceptable risks associated with contamination, provided that standard protocols are used for risk assessment, and that previous industrial associations are understood (Gao et al., 2015).

Addressing the Sustainable Development Goals (SDGs), it is essential that non-renewable resources are managed properly, with appropriate education, management systems and regulations (Agudelo-Vera et al., 2011; Vemury et al., 2018). The design of new management systems, and adaptation of existing systems, requires a sound understanding of the regulatory framework and environmental implications of changes, and one tool to aid this is material flow analysis. To assess the quantities of materials involved, and the implications for policy governing their management, this paper compares the material flows of construction materials in Thailand and Great Britain, representing and contrasting a rapidly developing country in SE Asia with one where policy and regulation, based on European law, are mature. It addresses the development of new regulatory systems that encourage reuse or recycling of demolition waste as an alternative to extracting primary raw materials. The experience gained from environmental and waste management in Great Britain is discussed in the context of developing new policies in Thailand, as a representative ASEAN country.

In this paper, we compare material flows for cement and concrete production in the UK and Thailand, based on published data and (where these are not available) calculated values are provided in the Supplementary Information permitting consistent comparisons. The quantification of the waste chains allows us to assess the implications for Thailand of adopting a regulatory process like that of the UK, and leads us to a set of recommendations that are applicable to many other countries that have rapid economic growth.

2. Cement, aggregate and concrete production in Great Britain and Thailand

Müller (2006) argues that changing lifestyle leads to higher demand for goods and services. For construction materials, national demand increases both the requirement for natural resources and the generation of waste, and can be associated with changes in the measured (or estimated) national useful floor area. Müller applied this theory to the Dutch housing and construction material stock (Müller, 2006), and others also considered stocks in China (Hu et al., 2010b), Norway (Bergsdal et al., 2007) and 11 European countries (Sandberg et al., 2016). Flows of C&D waste leaving the ‘stocks in use’ and moving into a waste stream can be projected from the activities of construction, renovation and demolition.

Great Britain (the mainland of the United Kingdom with 94.31% of UK territory and 61.9 million, 97.17% of UK inhabitants; the internally-consistent statistical data needed for this study are available for Great Britain but not the UK) is a significantly developed economy, while Thailand (64.5 million inhabitants) is an emerging developing economy with upper middle income. The Thai cement manufacturing industry was established in 1913 and Thailand is now a major exporter producing 56.42 Mt annually (total cement production capacity of ASEAN countries is around 265 Mt, from 139 plants; Saunders, 2015; TFCM, 2015). In contrast, Great Britain produces approx. 10 million metric tonnes: Mt) and exports little clinker and cement (BGS, 2013; OIE, 2013).

As part of the EU, the UK has access to a large single market and complies with standardised systems and laws applying to all EU member countries, which it helped develop (DBIS, 2015). These include environmental taxes (such as Landfill Tax and Aggregates Levy) that encourage the use of secondary materials (mainly recycled concrete aggregates), allowing the UK to achieve the highest rates of reuse of waste aggregates in the EU (Boston Consulting Group, 2012). The UK also sets and achieves targets for reuse and recycling of the C&D waste stream, exceeding a 70% target since 2009 (DEFRA, 2015; Monier et al., 2011). The UK is committed to sustainable development for planning and decision-making, and makes commitments on the industrial uses of natural resources for construction materials (DEFRA, 2011), which form part of a national strategy for use of the country’s mineral resources (MPA, 2018). For environmental taxes in 2015/2016, the UK receipts from Landfill Tax and Aggregate Levy were £919 million and £356 million respectively (HMRC, 2017a,b).

With a similar population, Thailand contrasts with Great Britain. A top-down planning framework is accompanied by the philosophy (individual to state) of the 'Sufficiency Economy', which stresses moderation, responsible consumption and resilience to external shocks, and was introduced as early as 1974 by His Majesty King Bhumibol Adulyadej (Curry and Sura, 2007; UN, 2006). This philosophy underpins subsequent development in Thai national policy, including exploitation and management of natural resources and possible impacts on the environment. However, at present Thailand's National Waste Management Plan does not specifically consider C&D waste management, and no data are available concerning the amounts generated or existing management practices. Moreover, the Thai government has only two budgets focusing just on municipal and household hazardous wastes and no environmental tax, one (provincial) under the Environmental Quality Management Plan and a second national Environment Fund under the Enhancement and Conservation of National Environmental Quality Act 1992 (OEF, 2011). Given the scale of use of construction materials in Thailand, development of an appropriate policy for the management of the associated wastes has the potential to change behaviour, reduce waste and increase use of secondary products (Harvey et al., 2014), provided associated technical and emission risks are assessed (Blankendaal et al., 2014).

3. Research methodologies

Our approach involves three steps (Fig. 1): (1) calculation of comparable data for inputs, based on the technical requirements for raw materials used to manufacture cement and concrete (see Supplementary Information), (2) material flow analysis to determine the amounts of raw material use and waste generation, and (3) assessment of regulatory factors and implications that arise from the material flow analysis.

In step one (Fig. 1) we utilise knowledge of the chemical reactions involved in calcination (Manning, 1995) to estimate amounts, where statistical data are lacking we calculate these (see Supplementary Information), of raw materials used in the clinker and cement manufacturing processes. The research methodologies are further described in the Supplementary Information. Finally, an outline of appropriate recommendations and environmental taxes that are adapted from the EU and Great Britain and their impact on countries with emerging
economies are described.

4. Recycled aggregates in Great Britain and Thailand

In 2012, the UK had the lowest domestic aggregate production per capita (2.39 tonnes per capita) in the EU–27 countries (average 4.78 tonnes per capita; (UEPG, 2015). A proportion of primary aggregates is replaced with recycled and secondary aggregates (Fig. 2), using 5 Mt (9.26%) of the 54 Mt of recycled and secondary aggregates (MPA, 2013b; The Concrete Centre, 2013). It has been estimated that 20–30% of primary coarse aggregates can be replaced by recycled coarse aggregates in new concrete (WRAP, 2007), leading to a target for use of 25% of total aggregates in precast concrete by 2012, achieving 21.3% (The Concrete Centre, 2013). In Fig. 2, secondary aggregates (15%) include wastes from quarries and other industries, and recycled concrete aggregates (85%) are derived from demolition (DCLG, 2007).

Thailand has no official recorded data for primary aggregate production and use, or data on recycled aggregates from the concrete industry. PCD (2007) reported that after separating recycled materials in construction and demolition sites in Bangkok, C&D waste was more than 80% concrete. C&D waste that was illegally disposed of consisted of 88% concrete with other masonry, metals and stone.

4.1. Material flows in Great Britain and Thailand

Summaries of material flows for concrete-based construction for 2012 in Great Britain and Thailand are given in Figs. 3 and 4 respectively. Using these diagrams, the contribution to material flow at every step is clearly identified (see Supplementary Information).

In 2012, Thailand mined 65.39 Mt shale and limestone, 6 times more than Great Britain (10.85 Mt) for clinker manufacturing (39.55 Mt). Thai exports of cementitious products (7.22 Mt clinker or 18.26% of clinker production and 7.00 Mt cement or 20.34% of cement production) were double the amount of cement used in the concrete industry in Great Britain (7.43 Mt). The volume of cement exported continuously rises and although other trading countries (especially ASEAN) reduced clinker demand after 2007, domestic demands for cement have increased (OIE, 2013). In contrast, Great Britain produces these materials almost entirely for domestic use.

Due to higher production, the Thai cement industry had a higher total fuel requirement and waste/emissions than Great Britain. Thailand used 3.49 Mt conventional fuels and 2.19 Mt alternative fuels to produce cement (Fig. 4), while Great Britain used 0.62 Mt and 0.41 Mt of conventional and alternative fuels (Fig. 3). Thailand generated 2.64 Mt CKD compared with 0.44 Mt for Great Britain. The main gaseous emission from cement manufacturing is CO₂ as a reaction product from the calcining of the raw materials, in addition to fuel combustion. Given process differences, we have not estimated total CO₂ emissions, but only those derived from the thermal decomposition of the limestone component of the raw material. For this, Thailand produced 28.68 Mt CO₂, compared with 4.88 Mt CO₂ for Great Britain.

In both countries, cement is mainly used in concrete (30.07 Mt for Thailand and 7.43 Mt Great Britain), and to a lesser extent in mortar (3.88 Mt for Thailand and 2.20 Mt Great Britain) and other uses (1.03 Mt for Thailand and 0.21 Mt Great Britain). Primary fine aggregate use for concrete is estimated to be 79.73 Mt for Thailand and 19.70 Mt Great Britain, and coarse primary aggregate use 134.93 Mt for Thailand and 28.34 Mt Great Britain. Other cementitious materials (such as pozzolans) are also used (19.07 Mt for Thailand and 4.45 Mt Great Britain). Unlike Thailand, Great Britain uses recycled aggregate, amounting to 5 Mt in 2012 for concrete manufacturing (MPA, 2013b).

Concerning concrete for construction, in 2012 Thailand produced 254.98 Mt (3.95 tonnes per capita) and 63 Mt (1.02 tonnes per capita) was consumed in Great Britain. Wastes generated during concrete transportation are estimated to be 1.28 Mt in Thailand and 0.32 Mt for Great Britain. During construction, concrete waste amounted to 13.48 Mt and 3.57 Mt for Thailand and Great Britain respectively.

In construction, Thailand used 51.51% (131.94 Mt) of concrete for residential buildings, followed by non-residential buildings (32.19% or 82.45 Mt) and infrastructure (16.30% or 41.75 Mt). Conversely, non-residential building was the main sector for concrete and mortar use in Great Britain (44.07% or 29.85 Mt), with 37.01% (25.07 Mt) for residential buildings, and 18.92% (12.81 Mt) for infrastructure.

One reason for the difference in concrete use is that Great Britain has a long-established brick and concrete-built housing stock (CHIB, 2013), while Thailand adopted such construction methods much more recently. This partly explains Great Britain’s lower requirement for cement and aggregates, although both countries have a similar population. Half of all residential buildings in the UK are > 50 years old, a fifth > 100 years old. Major refurbishment occurs every 20–30 years, and the annual value of refurbishment activities (47–64%) in residential buildings is higher than for new construction, which is between 37 and 50% (CHIB, 2013; ONS, 2009, 2010, 2011, 2012, 2014a).

In contrast, Thailand has more annual permits for new construction activities (> 90%) for residents than renovation activities (less than 10%; NSO, 2013). Without specific information, the life of Thai buildings is assumed to be similar to other Asian buildings; residential buildings in China have a lifespan around 15–50 years (Hu et al., 2013b; The Concrete Centre, 2013). It has been estimated that 20% of total aggregates in precast concrete by 2012, achieving 21.3% (The Concrete Centre, 2013). In Fig. 2, secondary aggregates (15%) include wastes from quarries and other industries, and recycled concrete aggregates (85%) are derived from demolition (DCLG, 2007).
4.2. Regulatory tools used in Great Britain

Improved resource productivity and use of natural resources requires a coherent policy framework based on shared management principles, standards, guidelines and targets to increase efficiency, combined with appropriate incentives to change behaviour. A number of obstacles need to be overcome to achieve sustainable material uses and improve C&D waste management. These include excessive compartmentalisation of policies, financial obstacles, mismatched time horizons among stakeholders, lack of awareness of economic and environmental benefits, modification of old consumption patterns, neglected regulations, and a lack of knowledge about resource scarcity and waste management (Heidrich et al., 2009; MPA, 2013b; Yuan et al., 2012). Factors that encourage Great Britain to achieve improved resource and waste management include (1) systematic recorded data, (2) integrated sustainable policies and regulations, (3) environmental taxes and (4) environmental funds (Fig. 5).

4.2.1. Collection and interpretation of recorded data

Successful management depends, amongst other factors, on the collection and interpretation of data. The categories of the European Waste Catalogue (EWC) provide a common terminology throughout the community to improve the efficiency of waste management activities (European Commission, 2010). Additionally, the potential for reuse and/or recycling of the materials concerned can be recognised (Pomponi and Moncaster, 2016), allowing identification of the requirements for treatment or disposal as accurately as possible (European Parliament, 2008). The EWC underpins all data gathering and management of waste materials in Great Britain.

For aggregates, an entity responsible for commercially exploiting or importing virgin aggregates into the UK needs to register for the Aggregates Levy, to account for production and to pay an aggregate tax of £2 per tonne (2018), allowing the activities to be measured and valued. The British Geological Survey (BGS) records aggregate consumption annually for different activities and regions, and the Office of National Statistics (ONS) and the competent authorities in England, Wales and Scotland report related national statistics that reflect the movements of national resources and waste management.

4.2.2. Integrated sustainability policies and regulations

Integrated policies and regulations in Great Britain come from two main governmental organisations. The Department for Environment, Food & Rural Affairs (DEFRA) aims to achieve sustainable development across the UK, through effective protection of the environment and prudent use of natural resources while maintaining high and stable levels of economic growth and employment (House of Commons, 2002). The Ministry of Housing, Communities and Local Government administers building regulations and national building standards.

The EU set a 70% target for reuse and recycling rate of the C&D waste stream by 2020 in the Waste Framework Directive 2006/12/EC, revised by Directive 2008/98/EC, which also sets general principles...
Fig. 3. Cement, concrete and construction industries in Great Britain. Italic and normal script: government and manufacturer records; bold calculated.

Fig. 4. Cement, concrete and construction industries in Thailand. Italic and normal script: government and manufacturer records; bold calculated.
and requirements for C&D waste management (European Parliament, 2008; Fischer et al., 2009; Monier et al., 2011). The EU has also developed new criteria to distinguish secondary raw materials from waste to create greater legal certainty and operating criteria for the recycling sector (OECD, 2011). These initiatives are important to enable the aggregate market to use recycled and secondary aggregates in Great Britain. Although Great Britain achieves the highest rate of recycled aggregates (29%) in the EU, this is still below the full potential (MPA, 2013a, b; The Concrete Centre, 2013). Increased use of recycled and secondary aggregates depends mostly on the identification of additional sources of supply and improved user confidence (EEA, 2008; MPA, 2013b), which often depends on perceptions of technical risks (Blankendaal et al., 2014; Butera et al., 2014). These limitations led some researchers to argue that secondary and recycled aggregate use cannot increase further (Brown et al., 2011; Mankelow et al., 2010; Thompson et al., 2008).

Nevertheless, growth in the use of recycled aggregates has been reinforced by actions such as revision of the British Standard on recycled coarse aggregates for concrete (BS EN 12630, 2013) and various projects by the Waste Resource Action Programme (WRAP) relating to a sustainable resource-efficient economy. It is clear that industry trade associations like the Mineral Products Association (MPA) have stimulated development.

### 4.2.3. Environmental taxes

Environmental taxes were first introduced in Nordic European countries (early 1990s), partly to reduce personal direct taxes, and partly to change behaviour to achieve specific environmental objectives; they have since been more widely adopted. In the UK, the Landfill Tax was introduced in 1996 and the Aggregate Levy in 2002. Aggregate that is genuine waste, disposed of at landfill and subject to landfill tax, is relieved from the Aggregates Levy (HMRC, 2016a). The Aggregate Levy since 1 April 2009 is £2/tonne for primary production of sand, gravel and crushed rock for construction purposes. It increases average prices in real terms, affecting production from land-based quarries, marine dredging and imports, and has no effect on UK exported products and recycled aggregate (Böhmer et al., 2008; Martin and Scott, 2003). Nevertheless the Levy generated less than the Landfill Tax (Fig. 6), which is relatively high for active waste (e.g. biodegradable and household) at £84.40/tonne, and lower for inert waste (e.g. aggregates, stones etc.) at £2.65/tonne. As taxation on environmental externalities is considered a fair way of levying charges that can endorse the ‘polluter pays principle’, a tax escalator over time is commonly used for both practical and political reasons to achieve required policy objectives.

Yuan et al. (2011) stated that a higher landfill charge may lead to higher net benefits but to avoid illegal dumping, strict controls and enforcements are required. Indeed in Great Britain, the introduction of Landfill Tax led to an initial increase in illegal dumping due to poor policing and limited sanctions in the early stage of the tax operation (Symonds, 1999).

Nevertheless, taxes and levies as part of the environmental management are a mechanism for ‘internalising’ environmental cost as a side effect of production processes. Thus EU members provide an incentive to the taxpayer to reduce their liabilities from the tax/levy. In the UK, environmental taxes are also used to avoid undesirable impacts on the environment, linking to a physical unit or a suitable proxy. However, Martin and Scott (2003) stated such taxes can be seen to be more concerned with revenue-raising purposes than addressing particular environmental objectives. Revenues raised in Great Britain provide some reduction in employers’ National Insurance contributions, and fund environmental projects that deliver benefits to local communities via environmental funds.

### 4.2.4. Environmental funds

As part of the introduction of environmental taxes, environmental funds have been established. Since the Landfill Tax was introduced in the UK in 1996, the Landfill Communities Fund has delivered over £1.4 billion to support over 52,500 local community projects. In 2013-14, the largest proportion of spend (77%) was on public parks and...
The revenue from the Aggregate Levy contributes to the Aggregates Levy Sustainability Fund (ALSF) (EEA, 2008; Söderholm, 2011), and is redistributed in particular to English Nature, English Heritage, and the Waste Resource Action Programme (WRAP). WRAP is a government-funded agency that encourages and enables businesses and consumers to be more efficient in materials used and recycling. The ALSF supports national ambitions by targeting the negative externalities from mining activities, improving quality standards for aggregates, raising awareness and increasing end-user confidence, providing access to capital for reprocessing infrastructure to increase supply, and delivering accessible robust information. It leads to targeted benefits for local communities affected by aggregate extraction (EEA, 2008).

5. Implications for Thailand and other countries

Within the context of the Philosophy of Sufficiency Economy, which aligns with the identification of a sufficiency culture as a prerequisite for sustainable development. Nevertheless, Thailand presently focuses on national economic growth led by business, giving the environment and natural resource management a lower priority. In some ways, Great Britain might have a higher concern for sustainability as it exports less clinker and cement, and by doing so preserves natural resources for future domestic consumption. It also recycles concrete aggregates from C&D waste for reuse in concrete manufacturing and other construction activities. Importantly, Great Britain has integrated policies to achieve targets that support sustainable development, in accordance with EU regulation.

Lacking the standardised waste classification codes defined in the EWC, the first step of waste management in Thailand (and other countries in a similar stage of development) is limited by the physical difficulty of identifying and distinguishing different waste types and sources. Therefore, Thailand needs to develop a classification system similar to the EWC, including Environmental Permitting Regulations in the waste industry, in order to systematically record waste generation and management, not only for C&D waste. It is necessary for government to understand clearly and quantitatively real situations and problems, and to handle waste in the early stage of policy orientation. Also, Thailand requires jointed-up implementation involving all stakeholders, from government, the private sector and communities, to create integrated sustainability policies with common goals. As concrete is an essential component for construction in Thailand, management of associated wastes is a high priority. This is difficult with no integrated management and regulatory system.

Environmental taxes like Great Britain’s Landfill Tax and Aggregates Levy, with revenue distribution by a non-profit private company, can lead to savings for a central budget. Adoption of similar incentives in Thailand would promote greater use of recycled aggregates, alongside measures to raise awareness about the associated environmental benefits (Garber et al., 2011). Other support, such as technical standards and risk-based assessments for recycled aggregate use in concrete (like EN or British Standards), is essential for Thai construction, and could be facilitated through the creation of organisations similar to the MPA and WRAP.

To help illustrate the value of environmental taxes, MFA (Figs. 3 and 4) provides estimates of the quantities of material that would be subject to an aggregate levy. In Great Britain (2012), 54 million tonnes of primary aggregate are used to make concrete, yielding £107 million through the levy. 5 million tonnes of recycled and secondary aggregate were used, saving £13 million on landfill tax (in addition to saved disposal and environmental costs), and reducing payment through the aggregate levy of £10 million. Thailand used (2012) almost 225 million tonnes of aggregate; a levy like that of Great Britain would yield to government the equivalent of £450 million (US$595 million). If developed as in Great Britain, a combination of aggregate levy and landfill tax that encouraged the use of secondary aggregates could yield savings equivalent to £100 million (US$130 million), giving an overall benefit...
of £550 million ($US275 million). Within ASEAN, Thailand is a leading cement manufacturer, consumer and exporter. Thus, problems faced in Thailand are also problems of ASEAN and other developing countries, and concern sustainable use of construction materials in the developing world. The regulatory tools and detailed guidance relating to natural resource and waste management developed in the EU has convinced EU members to follow suit. If similar tools can be set up for countries with rapidly growing economies, they will provide safeguards that provide the incentives and leadership to improve the use of non-renewable natural resources globally.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2018.11.141.

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