Renewable and Sustainable Energy Reviews 94 (2018) 1179–1191

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Carbon sequestration potential for mitigating the carbon footprint of green stormwater infrastructure

Emad Kavehei[a,*], G.A. Jenkins[a], M.F. Adame[b], C. Lemckert[c]

[a] Griffith University, School of Engineering and Built Environment, Kessels Road, Nathan, 4111, Brisbane, QLD, Australia
[b] Griffith University, Australian Rivers Institute, Kessels Road, Nathan 4111, QLD, Australia
[c] University of Canberra, School of Engineering, Mathematics and Statistics, Faculty of Science and Technology, Bruce 2617, ACT, Australia

ARTICLE INFO

Keywords:
Water sensitive urban design
Green stormwater infrastructure
Life cycle assessment
Carbon footprint
Carbon sequestration
Global warming potential impact

ABSTRACT

Green stormwater infrastructure is a common feature of urban cities which is mostly designed for hydrological and water quality purposes. The last decade has seen a rise in research on the environmental impact assessment of vegetated water sensitive urban design (WSUD) technologies. However, the added ecosystem benefits of these systems, such as carbon sequestration, have received less attention. In this study, the life cycle net carbon footprint of various vegetated WSUD technologies namely green roofs, rain gardens, bioretention basins, vegetated swales and stormwater ponds, have been reviewed and analysed including their carbon sequestration potential. The carbon footprint of each vegetated WSUD technology was evaluated through the four phases of the life cycle assessment (LCA): material production, construction, operation and maintenance and end-of-life phases. The results of this study show that the initial embodied carbon associated with production, transportation and construction phases is the major contributor to the carbon footprint for most of the vegetated WSUD technologies. Rain gardens are shown to provide the highest carbon sequestration potential which offsets its carbon footprint. Carbon sequestration of bioretention basins, green roofs, vegetated swales and stormwater ponds can mitigate approximately 70%, 68%, 45% and 8% of their carbon footprint respectively. This study demonstrates the significant role of carbon sequestration in mitigating the carbon footprint from the assigned life time of the vegetated WSUD technologies. The results presented in this study will allow designers and policy-makers to include the carbon implication in their WSUD strategies.

1. Introduction

Urban populations around the world are increasing rapidly to the extent that 2.6 billion new residents (70%) will live in urban cities by 2050 [1]. This rapid urbanisation trend is causing the removal of vegetation and the expansion of impervious areas. Consequently, there is an increase in urban stormwater runoff and peak flow rates, leading to higher pollutant loads on stormwater control systems [2]. Sustainable stormwater management systems have evolved to mitigate the environmental impacts of stormwater. Various terminologies have been used to describe sustainable stormwater management systems and strategies such as best management practice (BMP), stormwater control measure (SCM), water sensitive urban design (WSUD), sustainable urban drainage system (SUDS), low impact development (LID), and green infrastructure (GI) [3]. As opposed to the traditional grey infrastructure such as engineered piping systems, these sustainable solutions use natural processes in vegetation and soil media to retain, detain, treat and discharge stormwater runoff [4]. The Australian term, WSUD, will be used herein to describe such systems holistically.

Traditionally, studies on WSUD systems have mostly focused on volume reduction, erosion control, and water quality improvement. In the last decade, the interest on the environmental life cycle assessment of stormwater infrastructure has been rising [5]. Due to the emergence of climate change concern amongst policy makers and the public, several studies have been conducted on the environmental impact assessment and the provision of ecosystem services of green stormwater infrastructure [6–9].

Life cycle assessment (LCA) is a standardised environmental management tool that systematically analyses and qualifies a variety of environmental impacts and benefits of products or processes throughout their entire life cycle [10,11]. The life cycle considers material and energy flow through all stages of a product, service or process from “cradle to grave”, i.e. the direct and indirect provisions from raw materials to end-of-life [12]. The concept of the LCA application was

* Corresponding author.
E-mail address: emad.kavehei@griffithuni.edu.au (E. Kavehei).

https://doi.org/10.1016/j.rser.2018.07.002
Received 24 November 2017; Received in revised form 4 March 2018; Accepted 1 July 2018

developed in the 1970's, and its first application to assess the water technologies was in the 1990's, mostly in European countries [13]. The focus of early studies centred mostly on wastewater treatment, drinking water production and distribution. As a result of this recent popularity, several reviews were conducted on the LCA of water-energy and urban water systems [14–16], sewage sludge management [17], wastewater treatment plants [18–21] and green infrastructure [22]. Despite the accelerated attention on the environmental impact of sustainable stormwater technologies, no meta-analysis review study has been undertaken on the carbon footprint of vegetated WSUD technologies.

Carbon footprint is an environmental protection indicator based on the LCA. It is a single indicator of the global warming potential (GWP) or climate change (CC) impact indicators. The carbon footprint concept has been introduced to provide a better understanding of the contribution of systems or processes to global warming, and it can be expressed as the total amount of greenhouse gases (GHGs) emitted from a process or product [23,24]. The life cycle concept of the carbon footprint is now being applied to stormwater infrastructure to investigate material and energy flow through all life cycle stages of stormwater infrastructure [25].

Green infrastructure has been claimed to provide various environmental benefits [8]. Recently, the potential benefits of designed urban green spaces and urban environment have been targeted by several researchers who focused on benefits including removal of air pollution, water quality improvement, cooling of local climate and carbon sequestration [6,26,27]. One of the most valuable ecosystem services for climate change mitigation is carbon storage and sequestration within the above-ground biomass and soil media [28–31].

Carbon sequestration is the long-term storage of atmospheric carbon dioxide (CO2) as organic matter in long-lived plants and in soil [32]. Vegetated soil media, in general, has significant capacity in absorbing and storing atmospheric carbon [33]. Fig. 1 illustrates the process of carbon storage in a vegetated WSUD basin which involves the lateral transfer of carbon through stormwater inlet and the carbon capture through plants photosynthesis and the long-term storage in the soil media. Due to this potential, vegetated WSUD systems can be employed as a strategic tool to mitigate their carbon footprint, either directly or indirectly [34–36].

In this study, the literature from two different disciplines of Engineering and Ecological science have been systematically reviewed and analysed to bring the life cycle carbon footprint and carbon sequestration under one cover. The founded studies were divided into two categories of life cycle carbon footprint and carbon sequestration for data analysis purposes. The method section (Section 2) provides information on the search methodology, the inclusion criteria, selection procedure and the applied system boundary. Following this, a net carbon footprint section (Section 3) provides a detailed analysis of

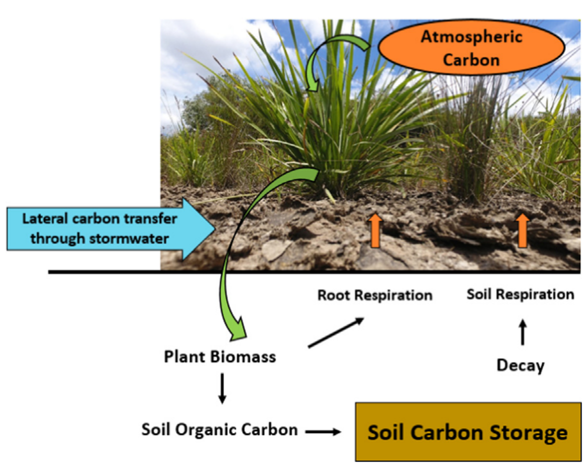

Fig. 1. The process of carbon storage in the vegetated WSUD technologies.

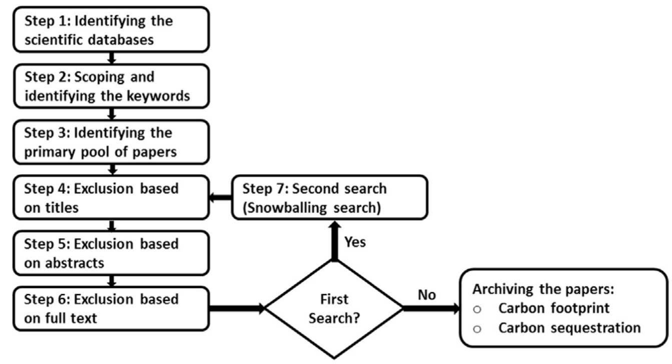

Fig. 2. Selection procedure of published literature.

assumptions and methodologies such as functional units, life cycle carbon phases, locations, climate, vegetation species, service life assumed and LCA databases and tools which allows higher transparency in communicating the results. Section 4 analyses the carbon footprint and carbon sequestration results for five different types of WSUD technologies. Lastly, the carbon sequestration potential, carbon footprint and the comparison between each WSUD technology are discussed in Section 5 and final conclusions are presented in Section 6.

2. Methods

This study followed a systematic review based on the guideline of Kitchenham [37] and the subsequent work of Ghanbarzadeh et al. [38] through a seven-step search process (Fig. 2). A combination of key terms and phrases (93 keywords) were selected based on scientific papers and knowledge of the research group. A search was performed in major scientific research databases: Science Direct, Scopus, ProQuest and ISI Web of Knowledge (ISI Web of Science). All databases were searched within the title, abstract and keywords. The scientific publications (peer-reviewed articles, conference papers, dissertation reports and grey literature) were assessed for inclusion based on their titles, then abstracts and finally, full text (Fig. 2). The application of inclusion criteria on the full-text reading was performed by two of the authors in order to limit the influence of individual bias. Details of the search procedure and statistical search findings are presented in Appendix A. The inclusion criteria were clarified and applied as a combination of the following items:

Populations: All the vegetated WSUD technologies which were designed to control or treat urban stormwater runoff such as bioretention basins; vegetated swales and buffer (filter) strips; green roofs; rain gardens; and stormwater ponds (retention, detention, wet and dry ponds).
Intervention/Exposure: The carbon footprint evaluation as a single indicator of the GWP; or the quantitative values of carbon sequestration.
Outcome: Quantitative and qualitative studies on the carbon footprint or quantitative measures of carbon sequestration.

The selection procedure was applied to 1057 primary studies based on the inclusion criteria. The articles were then filtered on the basis of their titles, abstracts and full text (675, 263 and 119 findings were excluded, respectively). Finally, 40 research studies were collected as a final pool of this review. From this pool of papers, 28 were related to the LCA approach to quantify the GWP impact. The remaining 12 studies discussed the carbon sequestration of vegetated WSUD technologies. It is noteworthy that non-vegetated WSUD systems such as rainwater tanks, sand filters and porous pavements were not the focus of this study and were not considered. Additionally, natural-like systems such as constructed wetlands, and ponds which are mostly used for