ARTICLE IN PRESS

Waste Management xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

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

Green residues from Bangkok green space for renewable energy recovery, phosphorus recycling and greenhouse gases emission reduction

Bussarakam Thitanuwat [a,b], Chongchin Polprasert [a,b,*], Andrew J. Englande Jr. [c]

[a] Department of Sanitary Engineering, Faculty of Public Health, Mahidol University, Rajvithee Road, Rajthewee, Bangkok 10400, Thailand
[b] Center of Excellence on Environmental Health and Toxicology, Bangkok 10400, Thailand
[c] Department of Global Environmental Health Sciences, School of Public Health and Tropical Medicine, Tulane University, New Orleans, LA 70112, USA

ARTICLE INFO

Article history:
Received 2 May 2016
Revised 11 October 2016
Accepted 4 December 2016
Available online xxxx

Keywords:
Greenhouse gases
Green residues
Phosphorus recycling
Renewable energy
Thailand
Urban green space

ABSTRACT

Effective ways to integrate human life quality, environmental pollution mitigation and efficient waste management strategies are becoming a crisis challenge for sustainable urban development. The aims of this study are: (1) to evaluate and recommend an optimum Urban Green Space (UGS) area for the Bangkok Metropolitan Administration (BMA); and (2) to quantify potential renewable resources including electricity generation and potential nutrient recovery from generated ash. Green House Gases (GHGs) emissions from the management of Green Residues (GR) produced in a recommended UGS expansion are estimated and compared with those from the existing BMA waste management practice. Results obtained from this study indicate that an increase in UGS from its current 2.02% to 22.4% of the BMA urban area is recommended. This optimum value is primarily due to the area needed as living space for its population. At this scale, GR produced of about 334 $kt{\cdot}y^{-1}$ may be used to generate electricity at the rate of 206 $GWh{\cdot}y^{-1}$ by employing incineration technology. Additionally, instead of going to landfill, phosphorus (P) contained in the ash of 1077 $t\ P{\cdot}y^{-1}$ could be recovered to produce P fertilizer to be recycled for agricultural cultivation. Income earned from selling these products is found to offset all of the operational cost of the proposed GR management methodology itself plus 7% of the cost of BMA's Municipal Solid Waste (MSW) operations. About 70% of the current GHGs emission may be reduced based on incineration simulation.

1. Introduction

Establishment of Urban Green Space (UGS) has been promoted in many cities. UGS may include parks, sporting fields, botanic gardens, greenways, street trees, streams, rivers, and nature conservation areas (James et al., 2009; Roy et al., 2012). Moreover, it can be defined as all vegetated areas greater than 25 ha; i.e., cemeteries, zoological gardens, vegetated spaces usable for recreational activities (Kabisch and Haase, 2013). In addition to providing recreational sites and aesthetic scenery, UGS is widely regarded as improvement for social, human and environmental health benefits (Govindarajulu, 2014; Wolch et al., 2014). Positive influences on social and human health include stress reduction and relaxation (Grahn and Stigsdotter, 2010; Ward Thompson et al., 2012). Other relevant environmental advantages are heat adsorption, cooling temperatures (Emmanuel and Loconsole, 2015), reduced energy consumption, air filtration, pollution reduction, rainwater runoff reduction (Zhang et al., 2015), increased carbon storage and sequestration which helps alleviate climate change (Silaydin Aydin and Çukur, 2012; Strohbach et al., 2012). Owing to the multiple functions of UGS there is no minimum scale of public green space required by law. Green space planning and strategies have gained increased attention countrywide as an important indicator for environmental

Abbreviations: BMA, Bangkok Metropolitan Administration; UGS, Urban Green Space, residential areas (households and public areas) in Bangkok which are covered by trees, shrubs and/or any kinds of plants that need maintenance and produce green residues; GHGs, Greenhouse Gases including carbon dioxide, methane and nitrous oxide; GR, Green Residues, wood chips, leaves, trimmings and cut branches produced from the processes of gardening, decorating and/or trimming in BMA; NPP, Net Primary Productivity; 3R, the principle of Reduce, Reuse and Recycle; E_{out}, energy flux from electricity generated from GR incineration; E_{in}, energy flux from solar radiation that touches the earth's surface (168 Wm^{-2}, 12 hd^{-1}); GWP, Global Warming Potential.

* Corresponding author at: Department of Sanitary Engineering, Faculty of Public Health, Mahidol University, Rajvithee Road, Rajthewee, Bangkok 10400, Thailand.

E-mail addresses: b.thitanuwat@gmail.com (B. Thitanuwat), chongchin.pol@mahidol.ac.th (C. Polprasert), aenglan@tulane.edu (A.J. Englande Jr.).

http://dx.doi.org/10.1016/j.wasman.2016.12.012
0956-053X/© 2016 Elsevier Ltd. All rights reserved.

quality and climate change mitigation (Jim, 2015). Hence, this work was conducted with a purpose to determine appropriate UGS proportion in a city that could provide more benefits to humans beyond the above environmental advantages. These include energy recovery and nutrient recycling.

Most researchers have generally focused on enhancing and expanding UGS so as to bring about city well-being and to comfort urban dwellers (Wolch et al., 2014; Klemm et al., 2015). However, opposite opinions regarding UGS areas have been documented. The negative side of encouraging green space includes the perception of personal safety (Schroeder and Anderson, 1984). Numerous case studies have provided evidence indicating a significant relationship between public green space density and criminal rate, particularly at night (Jansson et al., 2013; Sreetheran and van den Bosch, 2014). Troy et al. (2012) studied the correlation between the tree canopy and crime rate. Their results indicate that high density and unwell-managed UGS limits vision and aesthetics. Similar results from previous research have demonstrated that UGS density is a factor which increased the rates of crime including assault, robbery and theft (Kuo and Sullivan, 2001; Kuo, 2003). Lack of efficient maintenance programs, for instances, grass cutting, shrubs and trees trimming, park decorations and landscape design has the potential to contribute to an increase of crime and unsightly conditions. Negative environmental impacts can be induced by urbanization (Hua et al., 2015; Li and Lin, 2015). Nowadays, cities and towns from local to global scale are dealing with the consequences of damaged natural ecosystems associated with such growth (Roy, 2009; Dhakal, 2010). Exploration of potential substitutes for alternative resources and/or renewable energy supplies has gained wide attention with the goal of achieving sustainable urban development (Kwon and Østergaard, 2013), environmental pollution mitigation and efficient waste management mechanisms (Zsigraiová et al., 2009; Singhabhandhu and Tezuka, 2010).

The relationship between land conversion, urbanization and Net Primary Productivity (NPP) has been analyzed in many case studies. NPP is the amount of energy trapped in organic matter and/ or biomass during a specified interval. It can be quantified as the amount of energy obtained through the process of photosynthesis and is usually reported in the units of "$g{\cdot}m^{-2}{\cdot}y^{-1}$" or "$g\,C{\cdot}m^{-2}{\cdot}y^{-1}$" (Deyong et al., 2009). Numerous scientific studies have demonstrated that NPP values are changed due to urbanization associated with various types of green space (Tian et al., 2010; Tian and Qiao, 2014). The impact of landscape conversion within urban areas on NPP variations includes the generation of a great quantity of Green Residues (GR) such as yard trimmings, cut branches, dry leaves and wood requiring the implementation of routine maintenance of UGS. Importantly, this kind of waste has been accepted as a potential source of renewable energy used for electricity generation (Shi et al., 2013a, 2013b; Timilsina et al., 2014). Additionally, it is considered as a tool for the minimization of GHGs emissions when being used as biofuels (Patthanaissaranukool et al., 2013; Murphy et al., 2014).

One of the major challenging problems to humans today is climate change. This is a result of GHG emissions from the anthropogenic use of fossil fuels and/or fossil-derived materials (IPCC, 2007). In the year 2012, approximately 42 Mt CO_2 were generated in the Bangkok metropolis (DOE, 2013b). Transportation and electricity consumption in households shared over 80% of the total GHG emissions. The city's average temperature observed by the Thai Meteorological Department (TMD) has risen from 38.0 °C in 2002 to 40.1 °C in 2013 (TMD, 2013). Bangkok is one of the most densely populated cities in Thailand and demands a high rate of natural resources and energy. The Bangkok Metropolitan Administration (BMA) is now facing a variety of serious environmental issues. It has initiated several strategies and programs to achieve environmental mitigation targets. Green policies i.e. energy conservation, renewable energy promotion and greenery space expansion have been implemented to address environmental problems and protect human health in the city. For the year 2015, BMA has 31 Mm^2 of green space or approximately 2% of the BMA area. This UGS has been increasing continuously under the development plan of the city, called "Bangkok- the Green City" launched in 2009 (PublicPark, 2015). Moreover, integrating the reduce, reuse and recycle principle (3R), with its emphasis on renewable energy promotion has been encouraged to serve the energy demand in BMA and reduce GHGs emissions as well.

Current research has seldom been directed in the context of what is sufficient UGS for a city. It is important to increase UGS without resulting in an over-density of trees. It is also important to couple this with renewable energy promotion for the benefit of urban dwellers and as a contribution to climate change mitigation (Yang et al., 2012; Sevigné-Itoiz et al., 2015). Development of a "green city" has to be realized within limited spaces and demands balancing strategies and management practices. Using BMA as a case study, the aims of this study are: (1) to evaluate a recommended area of UGS in association with NPP estimation; and, (2) to quantify the potential renewable energy, electricity generation, nutrient recovery and GHGs emissions generated from the proposed management of GR produced by UGS in comparison with existing BMA waste management practice. Results obtained from this study can be used as an urban development strategy for UGS expansion schemes for many cities in the region. Findings may assist administrators to plan and manage UGS efficiently so that benefits from GR recovery and recycling and subsequent contribution to the mitigation of climate change can be maximized.

2. Methodology

2.1. Description of the study area

The Bangkok metropolis is located in the central part of Thailand close to the Chao Phraya River Delta. The city's area covers 1569 km^2 and is comprised of six area zones: Central Bangkok; Southern Bangkok; Northern Bangkok; Eastern Bangkok; Northern Thonburi; and, Southern Thonburi. Data from the Department of Agricultural Extension (DOAE) for land use in Bangkok are classified into six categories. These are as follows: residential area (47.8%); agricultural area (52.5%); fishery (7.7%); forestry (0.42%); industrial area (3%); and, miscellaneous (2.21%) (DOAE, 2014). Currently, an average of 5.7 million people registered and 2.2 million non-registered are living in the city (SED, 2013). High rates of consumption of food, natural resources and energy are required to satisfy the people's needs for their living. The city is presently facing a variety of serious environmental problems which include among others: air pollution; urban heat island effect; and, inadequate waste management.

Based on the current population and available public green space, the city has an average unit green space of 5.6 square meters per capita ($m^2{\cdot}cap^{-1}$) as shown in Fig. 1 (PublicPark, 2015). This value is close to that of China (6.52 $m^2{\cdot}cap^{-1}$) but very low compared to the WHO recommendation of 9 $m^2{\cdot}cap^{-1}$ and the average international ratio of 15 $m^2{\cdot}cap^{-1}$ (Masuda, 2003; WHO, 2010). BMA's unit UGS is extremely low when compared to that of the US (50.18 $m^2{\cdot}cap^{-1}$) and Singapore (66 $m^2{\cdot}cap^{-1}$) (Wang, 2009; TrustforPublicLand, 2011). Therefore, an increase in UGS in BMA is encouraged and supported by the Thai government. Its efforts have resulted in an increase in unit UGS from 4.5 $m^2{\cdot}cap^{-1}$ in 2011 up to 5.6 $m^2{\cdot}cap^{-1}$ at present.

Some of the public green space development strategies have been implemented by the BMA government. These include: increase green space and urban landscape; decorate roadside areas

Please cite this article in press as: Thitanuwat, B., et al. Green residues from Bangkok green space for renewable energy recovery, phosphorus recycling and greenhouse gases emission reduction. Waste Management (2016), http://dx.doi.org/10.1016/j.wasman.2016.12.012