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# The use of green waste from tourist attractions for renewable energy production: The potential and policy implications

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## HIGHLIGHTS

- Green waste from tourist attractions could help offset the tourist′s fossil fuel consumption.
- Economic, technical, and social feasibility analysis of green waste for energy production.
- Puts forward policy recommendations, from management regulations, public support etc.

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## ABSTRACT

Quantifying potential renewable energy sources from tourist attractions is a pivotal initial step in developing energy policies and strategies for low-carbon tourist industry development. Although solar energy and wind power have been in use for providing power for tourist attractions, the value of using waste biomass for energy production is still poorly understood. Here we advocate a promising approach that produces energy from green waste created by tourism attractions currently existing in large numbers and is still increasing dramatically. Using the Yangtze River Delta (YRD) of China as an example, we evaluated the potential of utilizing green waste to produce energy from 385 tourist attractions in 16 cities of this region. Our results showed that the total potential energy production using the green waste biomass was estimated at 6740 TJ/yr (1 TJ $=10^{12}$ J) with an average of 137 GJ/ha/yr (1 GJ $=10^{9}$ J), accounting for 6% (the average of the Yangtze River Delta, some scenic areas up to 93%) of YRD′s tourism industry′s energy consumption in 2008. The use of green waste for energy production is possible using current technology and could result in a win–win approach by reducing waste and increasing the renewable energy yields.

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## 1. Introduction

A low-carbon economy is an approach to resolving the sharp conflict between rapid economic growth and high $CO_2$ emission and it has attracted much attention from many governments (Moloney et al., 2010; Kei et al., 2010). Tourism is an energy-intense economic sector that emissions are growing rapidly (Gössling, 2013). In 2009, the World Economic Forum released a report entitled "Towards a low carbon travel and tourism", which officially proposed the concept of "low-carbon tourism" and thus the carbon emissions from the tourism industry gained increased attention (Chiesa and Gautam, 2009). A new study found that tourism causes 5% of global $CO_2$ emissions and these emissions are predicted to increase at an average rate of 3% per year up to 2035 (Peeters and Dubois, 2010). This increase is problematic as a global reduction of emissions by 3–6% is required to avoid climate change (Peeters and Dubois, 2010). Interest in the use of renewable biomass energy for tourist attractions has increased recently, in response to a need to reduce greenhouse gas (GHG) emissions Tang et al., 2011; Xu et al., 2011).

Wood-based energy is the simplest and oldest renewable energy that is a potentially-underutilized low-carbon fuel (Aguilar, 2009; Andress et al., 2010; Rogers et al., 2012). Waste biomass is a renewable energy feedstock that is unlikely to compete with food crops, cause and increased carbon debt or negative environmental impacts (Tilman et al., 2009). Due to aesthetic and safety factors (to prevent dead branches from injuring tourists or creating a greater fire hazard), the management of plant landscaping includes the need to prune plants, replace dead trees and clean up fallen leaves. A large amount of

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green waste is generated annually from tourist attractions. Green waste (also called garden waste or yard waste) biomass is ligneous in nature and is produced from various plant structures, including large tree branches from pruning, hedge cuttings, grass clippings, small branches, leaves, and other plant debris etc. (Boldrin et al., 2011). The cost of landfilling green waste is great due to the large volume. If left in situ, green waste will produce methane and other greenhouse gases as well as potentially providing breeding grounds for pathogenic bacteria. This can affect the health of tourists and staff, especially during hot weather. Green waste recycling is an attractive concept and has been implemented primarily through composting (Boldrin and Christensen, 2010; Haaren et al., 2010). However, composting has a limited market demand (Pfister et al., 2011). Therefore, the effective management of green waste has become an important issue for the managers of tourist attractions.

With tourist arrivals growing, as well as the level of facilities and services improving, the dilemma lies with an increasing energy demand, with the need for energy savings and to attain emissions reduction targets. The use of environmentally friendly and recyclable resources in landscape projects is a prerequisite for the sustainable development of tourism (Tang et al., 2011). Moreover, tourists are willing to pay for renewable energy (Kostakis and Sardianou, 2012; Tsagarakis et al., 2011). With technological advancements (such as lignocelluloses-to-ethanol conversions, advanced wood combustion, especially small-scale equipment energy conversion), there are increasing opportunities for generating biofuel energy from green waste biomass (Field et al., 2008; Amidon et al., 2008; Gupta et al., 2012). Utilization of increasing amounts of waste biomass for biofuels cannot only reduce waste disposal costs, but also increase renewable energy yields.

The idea of using green waste biomass to produce bioenergy has been promoted in recent years. A study estimates that green waste biomass from plant trimmings in Singapore could help offset 1.6% to 6.5% of the nation′s fossil fuel consumption (Koh et al., 2008). The potential of waste biomass in green space for biofuels production has been confirmed in China (Shi et al., 2013). The net greenhouse gas (GHG) emissions for green wastes from biochar production are negative and only half of that for switchgrass biofuel production (Roberts, et al., 2009). Based on the assessment of efficient $CO_2$ saving, the $CO_2$ saving potential of green waste for energy utilization can reach 126–1040 kg $CO_2$/Mg biomass (Kranert et al., 2010). A life cycle assessment (LCA) for green waste management scenarios suggested that the incineration of green wastes with specific characteristics (e.g. high LHV and low ash content) showed potential environmental benefits (Boldrin et al., 2011). Generally, the green waste were scattered in space and differed in quantity. Green waste from tourist attractions, which can be centrally collected, is more suitable for bioenergy production. To our knowledge, this is the first study to address the potential of green waste from tourist attractions for energy production. In this study, using the Yangtze River Delta (YRD) as a test case, we: (1) examined the potential for biofuel production using green waste; (2) conducted a comprehensive feasibility analysis of green waste for energy production; and (3) discussed the challenges and policy implications for developing energy using green waste. The conclusion is that this approach could provide a potential win-win resulting in waste biomass treatment and increasing renewable energy yields.

## 2. Study area

The Yangtze River Delta agglomeration, located in east China (120°29′35″E–122°38′50″E, 29°8′50″N–32°6′26″N), is comprised of the Shanghai municipality and 15 cities in the neighboring provinces of Jiangsu and Zhejiang. With its powerful economy and rapid development, the YRD region has become the sixth largest metropolitan area in the world and plays an important role in China′s economic and social development. Comprising 10% of the total population in China, it contributes to about 20% of the national Gross Domestic Product (Gu, et al., 2011). The YRD urban area is 3439 $km^2$ and accounts for 11.7% of China′s total urban area (NBSC, 2009). With 2% of the land supporting 10% of China′s population, urbanized to regional land area ratio (3.3%) was much higher than China′s average (0.6%). This specific study region was chosen because it was a key area for energy savings and carbon reduction. Moreover, according to the World Tourism Organization, China ranks third in arrivals in the world (UNWTO, 2012). The YRD is known as the “golden triangle” in the Chinese tourism industry (Zhang et al., 2011). The number of tourists reached 471.4 million person-times in 2008 (Fig. 1).

Tourist attractions of the Yangtze River Delta provide a tourism core area in which to promote the development of renewable energy, and in turn, will have a positive effect nationally and worldwide. Furthermore, the plant-based landscapes in YRD (especially in Suzhou and Hangzhou city) were considered world-class for their superior natural environment as well as their economic and cultural atmosphere. Plant-based landscapes, as the main components of attractions, accounted for 96% of the 400 A-class tourist attractions of the Yangtze River Delta region (Table 1). The quantity of green wastes produced was large, continues to increase, and has focused specific attention on the issue of green waste management. Furthermore, the YRD region relies heavily on imports of fossil fuels to meet its enormous energy demands due to a lack of local energy resources. Green waste is a renewable source of energy that is acquired locally. Urbanization and tourism industry development in the YRD could reflect China′s future development trends. Therefore, the YRD was chosen as an ideal case study to demonstrate the potential of green waste to supply a region′s renewable and sustainable energy demands.

## 3. Methods

### 3.1. Field measurements and questionnaires/surveys

The method for quantifying green waste in this study was adapted from urban tree residues research (Nkambwe and Sekhwela, 2006). Field surveys and interviews were conducted from February 2009 to December 2011. We established 100–200 random plots (400 $m^2$) for each city′s tourist attractions in the YRD. To estimate biofuel production potential, we selected the tourist attractions with high-quality greenspace. Within each plot, data were collected on plant species, numbers of trees and shrubs and the areas of hedges and herbs.

The composition of the green waste was determined by collecting waste samples eight times during the year, twice per season, using all the green waste received during the day of sampling. After pruning and collecting, bundles of green waste were weighed using a dynamometer. Mass was determined in the field on the moist materials. Samples of wood were put into plastic containers to determine moisture content (MC).

Face-to-face surveys were conducted within randomly selected management departments to determine the quantity and characteristics of the green wastes. A management department was comprised of tree care firms, landscape maintenance personnel and waste removal staff. Survey data consisted of the yearly records for 2009–2011 and the following survey information was recorded.

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