Urban-rural mining: waste utilization in Guangdong, China

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Abstract. Attitudes towards waste have changed gradually in view of the environmental pollution created and the potential of waste as a resource. This has led to the city and countryside of China being viewed as a complete "urban-rural mine"; resources are extracted from what was once considered waste. Guangdong is a developed province and annual waste generation has recently exceeded 300 million tons. The waste distribution characteristics are as follows: most industrial solid waste is produced in the Pearl River Delta and Mountainous Region, waste associated with domestic activities is concentrated in the Pearl River Delta, and agricultural waste is found throughout the province. The ratios of material recycling and energy recovery are 58% and 11%, respectively, of collected waste. Recycled products include construction material, artificial boards, fuel, plastic, metal, chemicals, oil, and fibers. Energy is recovered by generating electricity from domestic waste, landfill gas, and forest and crop residue.

1. Introduction
Urban mining is an effective activity whose overall goals are resource conservation and environmental protection, as well as generating economic benefits by recovering potential resources contained in waste [1, 2]. The concept developed from an initial idea [3] to focus attention on recovery of valuable metals in old electronics [4] and was subsequently extended further to consider all products of urban catabolism [1, 5].

After nearly forty years of open development and high rates of economic growth, there are multiple problems in China that have arisen whilst striving to achieve social prosperity. These problems, which have seriously restricted sustainable development, include sharply increasing consumption of natural resources, constantly expanding volumes of waste generated during production and domestic processes, and excessive loading of the carrying capacity of the ecological environment. In order to encourage recycling and secondary resource extraction, the National Development and Reform Commission began construction of urban mining demonstration bases in 2010. However, as an agricultural country, the contradiction between urban and rural in China is prominent during rapid industrialization and urbanization. The anthropogenic boundary, including attitudes towards environmental pollution caused by waste discharge, is the key obstacle to integrated development. Waste in rural areas, which is a source of one third of all serious pollution in soil, water, and the atmosphere, could be a tremendous mineral resource if it was subjected to appropriate utilization [6, 7]. To facilitate an ecological civilization strategy and eliminate the urban-rural dual structure, activities
that recover materials and energy from waste should not be limited to within city borders but instead expanded to rural areas. The city and countryside are thus viewed holistically as a complete "urban-rural mine" and resources are extracted from what was once considered waste.

Guangdong province, the epitome of ecological civilization construction and sustainable development of China, maintains a high economic growth rate with less energy consumption, carbon intensity, and a more livable ecological environment. The positive activities of urban-rural mining is one of the important factors. This paper estimated nine categories of urban-rural waste generation and distribution and analyzed the status of material recycling and energy recovery from waste in Guangdong.

2. Waste generation and distribution

2.1. Waste generation
The amount of waste generated rose continuously from 2010 to 2014. The total quantity has exceeded 300 million tons annually since 2012. Forest residue, domestic waste, restaurant garbage, construction and demolition (C&D) waste, municipal sludge, and e-waste have increased annually. The general trend in crop residue is upward. Industrial solid waste and animal waste slightly decreased from 2012. In 2014, the categories generating the greatest volume of waste were C&D waste and forest residue, respectively accounting for 31% and 21% of total waste, followed by industrial solid waste and animal waste, respectively occupying 17% and 13%; the other categories were 18%.

![Figure 1. Quantity of waste generated in Guangdong.](image)

2.2. Waste distribution
Waste distribution possesses regional characteristics that are closely related to industrial structure, population distribution, and lifestyle. The Pearl River Delta, as one of the three urban agglomerations in China, accounts for 30.5% of the terrestrial area, 53.7% of the inhabitants (over 80% are urban populations) and 85% of the GDP of the whole province. The characteristics of the agglomeration, including small area, crowded cities, intensive industry, advanced economy, and frequent human activity, mean that most waste is concentrated in this place. Volumes of domestic waste, municipal sludge, C&D waste, restaurant garbage, e-waste, and industrial solid waste are greater than in other regions. The Western and Mountainous Regions have vast land areas coupled with a sparse population, more than half of which live in rural areas. Waste in these two regions is primarily generated from agriculture, forestry, and animal husbandry. The Eastern Region has minimum area and high
population density and nearly 60% of its population is urban. It has the least amount of waste per category, except domestic waste, municipal sludge and restaurant garbage, which are slightly higher than in the Western and Mountainous Regions.

Figure 2 shows nine categories of urban-rural waste distribution in Guangdong 2014. The amount of domestic waste in Shenzhen reached 5.41 million tons. The most restaurant garbage produced in Guangzhou, where it exceeded 700 thousand tons. The top seven municipal sludge producers were Pearl River Delta cities, of which both Shenzhen and Guangzhou exceeded one million tons. C&D waste in Guangzhou exceeded 30 million tons, and was nearly three times higher than in Shenzhen and Zhanjiang. The highest quantity of e-waste was generated in Guangzhou, which produced more than twice as much as any other city. The largest volume of industrial solid waste, exceeding 7 million tons, was generated in the heavy industrial base Shaoguan. The second highest volume was produced in Dongguan, and was 5.49 million tons. The highest quantity of forest residue was generated in Zhaoqing (over eight million tons). Qingyuan and Maoming were the second largest producers, exceeding seven million tons. Zhanjiang and Shaoguan were third, producing five million tons. The cities with the highest volumes of both animal waste and crop residue were Zhanjiang, Maoming, Zhaoqing, and Meizhou. Animal waste in both Zhanjiang and Maoming exceeded six million tons, which is about 1.5 times higher than that of Zhaoqing and twice that of Meizhou. Crop residue in Zhanjiang was 5.65 million tons, nearly three times that in Maoming.

![Figure 2. Waste distribution for each category in Guangdong 2014: (a) Domestic waste, (b) Restaurant garbage, (c) Municipal sludge, (d) C&D waste, (e) E-waste, (f) Industrial solid waste, (g) Forest residue, (h) Animal waste, (i) Crop residue.](image_url)

3. Resource recovery

3.1. Overview
Material recycling and energy recovery are the two main approaches to secondary resource utilization. The provincial ratio of material recycling and energy recovery was 58% and 11%, respectively, of collected waste; the rest was disposed of or discarded. Every city has material recycling, and energy recovery is concentrated in the Pearl River Delta. Up to the end of 2015, there were 278 comprehensive resource utilization enterprises and 52 circular economy industrial parks including eight urban mining demonstration bases.

3.2. Material recycling

Recycled products manufactured from secondary resources in Guangdong include construction material, artificial boards, fuel, plastic, metal, chemicals, oil and fibers. Industrial solid waste such as fly ash, desulfurization gypsum, phosphogypsum, coal gangue, furnace slag, mullock, and C&D waste are used to produce construction materials including autoclaved aerated concrete blocks, concrete bricks, retaining walls, and composite Portland cement. Forest residues such as tree branches, offcuts, bark, saw powder, and shavings are used to produce artificial board (fiber board, chipboard, and block board) or solid fuel. A few crop processing residues (rice husks, corn cobs, tea-oil seed shells, and peanut shells) are blended with forest residues to produce biomass pellets and briquettes. Municipal sludge is desiccated for land use or fuel fabrication. Waste plastics are used as a special material for polyester fibers, automobiles, appliances, and pipes by modified regeneration or for recycled products such as bags, trays, and polyester film. E-waste is generally used for metal (copper, aluminum, iron) and plastic recycling. Ferroalloys like blister copper, matte, and low nickel matte are recycled from electroplating waste and dust ash. Chemical waste is used to produce alkali, salt, and soil conditioner. Waste oil from restaurant garbage is used for biodiesel, feed grade blended oil and industrial oil refining.

Recycling technologies focused on construction material manufacture from industrial solid waste and artificial board processing from forest residues are present in almost all areas of the province. Fuel reproduction technologies for forest and crop residues are applied in every section except the Eastern Region, which has the smallest quantity of available secondary resources. Recycled plastic producers are distributed in the Eastern Region and the Pearl River Delta. Metal recycling has not yet been extended to the Western Region. Chemical recycling processes are found in the Pearl River Delta and the Mountainous Region. Waste oil comprehensive utilization enterprises are distributed in Foshan, which is the state-level pilot city for restaurant garbage recycling. Regenerated fiber manufacture occurs in the Eastern Region and the Pearl River Delta.
3.3. Energy recovery
The main approach of energy recovery from secondary resources in Guangdong is biomass power generation, which refers to waste incineration, landfill gas, and direct combustion of forest and crop residues. Total installed capacity, grid-connected capacity, and contract on-grid energy was 711.4 MW, 620 MW and $4.667 \times 10^9$ kWh respectively in 2014 [8]. All 23 waste incineration power plants—almost all except those at Shantou and Maoming are in the Pearl River Delta—have a daily disposal capacity of 25 thousand tons. The annual generating capacity of Shenzhen Xiaping 10MW landfill gas power generation project is 50 million kilowatt hours. Shaoguan biomass power plant is the first forest and crop residue to energy by direct combustion project in Guangdong. Zhanjiang has the world’s biggest agriculture and forestry biomass power plant in terms of both unit capacity and total installed capacity. In 2015, it made use of more than 900 000 tons of forest and crop residues, with on-grid energy of 643 million kWh and emission reductions of carbon dioxide totaling 506 400 tons [9].

Figure 4. Manufacturers of recycled products in Guangdong 2015.

Figure 5. Biomass power plants in Guangdong 2015.

Pearl River Delta: 1-Guangzhou, 2-Shenzhen, 3-Zhuhai, 4-Foshan, 5-Huizhou, 6-Dongguan, 7-Zhongshan, 8-Jiangmen, 9-Zhaoqing; Eastern
Region: 10-Shantou, 11-Shanwei, 12-Chaozhou, 13-Jieyang; Western Region: 14-Yangjiang, 15-Zhanjiang, 16-Maoming; Mountainous Region: 17-Shaoguan, 18-Heyuan, 19-Meizhou, 20-Qingyuan, 21-Yunfu.

4. Conclusions
Guangdong has fertile farmland, developed urban agglomerations, and luxuriant forest. Huge volumes of waste generated in economic production and domestic life are a latent urban-rural mineral resource. The government has already started to actively encourage waste exploitation based on distribution characteristics. Heretofore, material recycling of industrial solid waste and forest residues has been popularized across the province, waste incineration power plants cover the Pearl River Delta, and the main area of production of forest and crop residue has the world’s largest biomass power plant. Although urban-rural mining activities have obtained some benefits for the environment, economy, and society, most secondary resources have yet to be exploited. A technology roadmap is necessary in order to optimize resource recovery according to waste distribution, following the rule of utilization in situ.

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