



Urban-Scale Material Flow Analysis: Malaysian Cities Case Study

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Abstract. Urban metabolism studies highlight the consumption of input resources, the process within the system together from the source, use phase and recycling of wastes. The aim of this study was to assess urban metabolism in three cities in Malaysia; Kuala Lumpur, Ampang Jaya and Selayang by using Material Flow Analysis (MFA). The data that was analysed included electricity inputs, water inputs, food (rice, eggs and sugar) inputs, carbon dioxide outputs, wastewater outputs and solid waste outputs. The national data were down-scaled to provide regional data where deemed necessary. The electricity consumption of 0.188 koe/cap/day in Klang Valley contributed to carbon dioxide of 0.455 kg/cap/day, while 95.32% of water consumption became wastewater. Consumption of 0.38 kg/cap/day of 'rice, eggs and sugar' contributed in the production of 4.5 kg/cap/day of solid wastes. The urban metabolism approach provides information on urban management at city level such as material cycling, energy efficiency and waste management and may also assist in decision making for future urban development planning as well as providing an informed and rapid assessment on the environmental performance of urban area.

Keywords. *Urban metabolism, urban-scale material flow analysis, city management*

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1. Background

The study of urban metabolism was first introduced by Abel Wolman who identified that a city is comparable to an ecosystem (Wolman, 1965). Materials and energy flowed into the system is similar with consumption of resources by organisms in an ecosystem. As a result of the intake of resources, wastes and products are created within the system. The urban metabolism study quantifies the inputs such as water, food and fuel and the outputs such as sewage, solid refuse and air pollutants by tracking their respective transformations and flows. Through the study of urban metabolism, researchers are able to understand a variety of systems occurring in cities, regions and neighbourhoods worldwide (Pincetl et al., 2012). The overview

of an urban metabolism in an urban system is shown in Figure 1.

Environmental impacts emerge as Greater Kuala Lumpur expands in terms of economic growth and becomes a global liveable metropolis. Since Greater Kuala Lumpur is one of the main economic zones in Malaysia, the authorities take the initiative to control and mitigate the environmental impacts. The rapid transformation of Kuala Lumpur into a wide urban area during the last decade of the twentieth century has contributed to many of the environmental issues (Abdullah et al., 2012; Zhang, 2013). The authorities as well as the public should work together to uphold the sustainable development of the cities in Greater Kuala Lumpur. In light of the idea to achieve the goal

as well as to introduce a more sustainable city policy, the study of urban metabolism of Greater Kuala Lumpur is deemed essential.

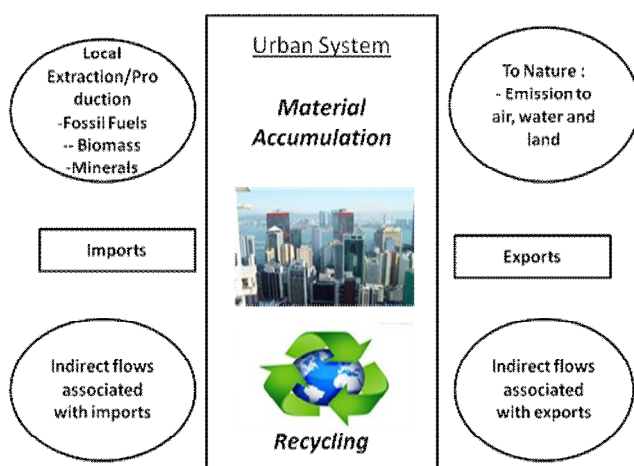


Figure 1: Urban Metabolism Concept in an Urban System(Minx et al., 2011)

2. Materials and Methods

2.1 Methodology

Material Flow Analysis (MFA) is a rapid representation of the interrelation between the economy, a subsystem of the environment with the environment and the living things that rely on a continuous process of materials and energy (Hinterberger et al., 2003; Kestemont & Kerkhove, 2010; Kennedy et al., 2011).

MFA can be the initial step towards a broader study of social, economic and environmental aspects of local supply chains (Courtonne et al., 2015), as the material flow that can be examined includes energy inputs, water inputs, food and drink inputs, gas outputs, wastewater outputs and solid waste outputs.

In order to understand more about material consumption and sustainability levels, trends need to be observed for a period of several years. Proper comparisons can be made by undertaking studies using the same methodology in other developing cities (Zhang, 2009; Hoekman, 2015).

2.2 Study Location and Variables

Three thriving cities in the Greater Kuala Lumpur masterplan were selected: Ampang Jaya, Selayang and the heart of Kuala Lumpur itself within the authority of their respective local governments (Figure 2). The Greater Kuala Lumpur comprises the area under the administration of ten local governments. The independent variables in this study were residential activities in the area of Kuala Lumpur, Ampang Jaya and Selayang. The dependent variables against the independent variables are energy (electricity) inputs, water inputs, food (rice, eggs and sugar) inputs, gas (carbon dioxide) outputs, wastewater outputs and solid waste outputs.

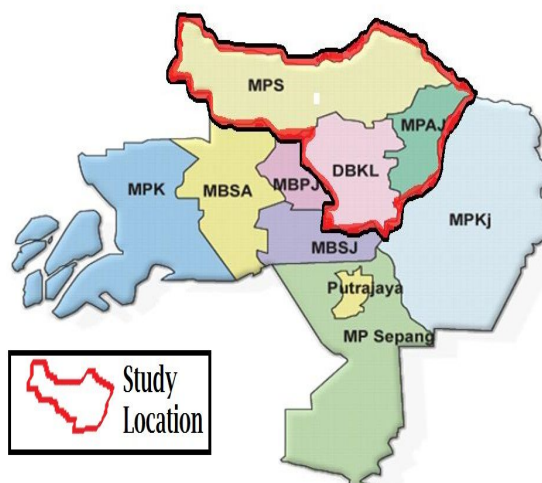


Figure 2: Map of Study Areas (Official Website of Greater Kuala Lumpur/Klang Valley, 2014)

2.3 Data Collection and Analysis

Data of materials input and output were obtained from utilities providers as well as from the local government of the cities. The national figures were divided with population of Malaysia and number of days in a year to obtain consumption and production per capita per day. The national data were downscaled to city levels in instances where the available data was not available. Table 1 summarized the materials, their respective units and source of data from desktop literature.

Table 1

Sources of secondary information

Material	Unit	Source & Year
Electricity	ktoe	Energy Commission (2011)
Water	million litres/day	National Water Services Commission (2011)
Rice, eggs and sugars	tonnes	Food and Agriculture Organization of the United Nations (FAOSTAT) (2014)
Carbon dioxide	billion kg	Ahmad (2004)
Wastewater	litres/day	Kling (2007)
Solid Waste	kg/cap/day	Sakawi (2011)

3. Results and Discussion

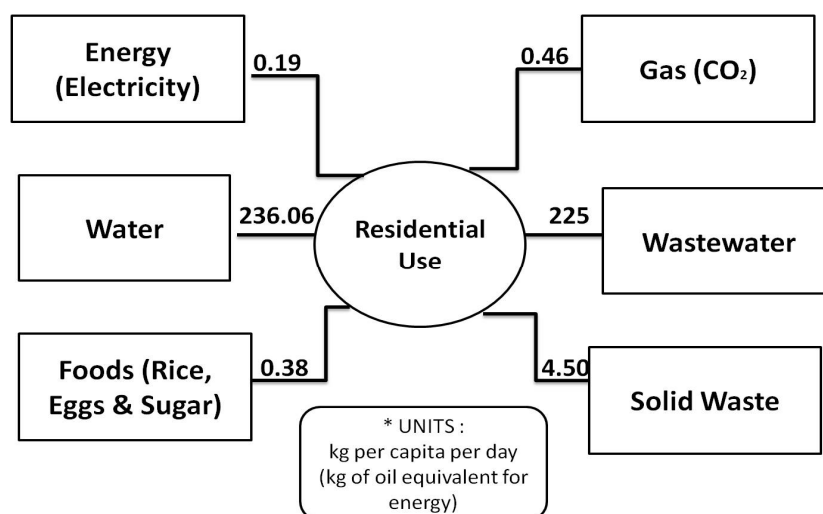
From the data collection and analysis, an overview of the material flow resources and output was established (Figure 3). The overall material balance reveals that the system is in a near steady state where the total input almost equals total output. This section presents the results and discussion of the material flows in the three cities with a total population of 2.6 million people. Table 2 presents the outline for the average individual consumption for all the input and output for the three localities. Table 3 demonstrates the total consumption of each

input and output according to localities and in comparison with Aveiro, Portugal. The following sections discuss the respective material flows in Table 2 and Table 3 with supporting explanation.

3.1 Energy Input

Energy inputs are expressed in kilogram of oil equivalent. The highest electricity input was in Kuala Lumpur for the year 2010 with 298 685 koe/day. The second highest input of electricity is Selayang with 101 972.89 koe/day, followed by Ampang Jaya with 88 164.67 koe/day. The total electricity consumption was 488 822.56 koe/day and agrees with the number of population in the three cities.

The consumption of electricity depends on the development and population in the cities. Kuala Lumpur is one of the most urbanised states in Malaysia, hence, massive economic activities as well as other residential and commercial activities are undertaken to meet the demands of the country and its inhabitants. Although Selayang is less developed compared to Ampang Jaya, the high electrical consumption was mostly because of individual use in the population.



Note: 1 tonne is equal to 1,000 kg, 1 liter is equal to 1 kg, 1 ktoe is equal to 1,000,000 koe and 1 koe is equal to 1 kg.

Figure 3: Schematic outline of Material Flow Analysis for Greater Kuala Lumpur

Table 2

Input Output outline for Kuala Lumpur, Ampang Jaya and Selayang

Input / Output	Unit	Average Individual Consumption/Production in a Day Kuala Lumpur, Ampang Jaya and Selangor
INPUT		
Energy	koe/cap/day	0.19
Water	kg/cap/day	236.06
Foods	kg/cap/day	0.38
Rice		0.24
Eggs		0.06
Sugar		0.08
OUTPUT		
Gas (CO ₂)	kg/cap/day	0.46
Wastewater	kg/cap/day	225
Solid Waste	kg/cap/day	4.5

When the total consumption of electricity of each city in a day is compared with the city of Aveiro in Portugal where this methodology was adopted, the consumption of the three cities was higher. One of the reasons is due to the high population density. However, when compared with crude individual consumption, the con-

sumption of electricity in Aveiro according to Lemos (2011) is higher, which is 0.347 koe/cap/day. Meanwhile, the individual consumption in Klang Valley is 0.188 koe/cap/day. Aveiro has winter months in which the population may consume more electricity to warm their habitation.

3.2 Water Input

The total inputs of water was 613 773 926.7 m³/day for the year 2010 in Kuala Lumpur is 375 033 970 m³/day (61.1%), 110 701 057.82 m³/day (18%) in Ampang Jaya and 128 038 898.90 m³/day (20.9%) in Selayang. The major differences were due to the variations in population density. A high population will lead to higher demand of water consumption inputs. The water input in Kuala Lumpur was the highest (61.1%) compared to the other two cities combined (38.9%).

The individual consumption in Aveiro in a day according to Lemos (2011) is 112.60 kg/cap/day, which is lower than the individual consumption in Klang Valley in a day (236.056 kg/cap/day). It is seen that individuals in Klang Valley tend to use more water compared to individuals in Aveiro.

Table 3

Schematic comparison between Kuala Lumpur, Ampang Jaya, Selayang and Aveiro

Input / Output	Unit	Total Consumption / Production in a Day			
		Ampang Jaya Population: 468 961	Kuala Lumpur Population: 1 588 750	Selayang Population: 542 409	Aveiro Portugal Population: 73 335
INPUT					
Energy (Electricity)	koe/day	88 164	298 685	101 972	25 447
Water	m ³ /day	110 701 057	375 033 970	128 038 898	8 257 521
Foods	kg/day	178 205	603 725	206 115	38 134
Rice		112 550	381 300	130 178	30 067
Eggs		28 137	95 325	32 544	1 467
Sugar		37 516	127 100	43 392	6 600
OUTPUT					
Gas (CO ₂)	kg/day	213 377	722 881	246 796	233 205
Wastewater	m ³ /day	105 516 225	357 468 750	122 042 025	6 995 426
Solid Waste	kg/day	2 110 324	7 149 375	1 440 840	113 669

The higher consumption of water in Klang Valley (part of Greater Kuala Lumpur master-plan) may be due to the weather and commercial activities. In Aveiro, there are winter months, while in Malaysia the weather is hot and humid. Water consumption from drinking and cleaning are more frequent to accommodate to the sanitary requirements along with physiological needs and comfort. Restrooms and toilets in Malaysia are mostly equipped with faucets and bidets to meet the religious and cultural needs of the population who clean themselves with water after relieving themselves (Gilli, 2004; Jurattanasan & Jaroenwisan, 2014).

3.3 Food Input

As for the food inputs rice, eggs and sugar, Kuala Lumpur has the highest total input, which was 603 725 kg/day due to the large population. Selayang had the second highest input at 206 115.42 kg/day followed by Ampang Jaya with 178 205.18 kg/day.

The total consumption of rice, eggs and sugar in Aveiro was only 38 134.2 kg/day. The individual consumption was at 0.52 kg/cap/day in Aveiro according to Lemos (2011), and when compared to the Klang Valley area, it was 0.38 kg/cap/day. The consumption of rice in Aveiro is higher than in the Klang Valley since rice is one of the staple foods for the Portuguese, which is similar to Malaysia. The sugar input for Aveiro is 0.01 kg higher, and as for the eggs input, the population in Malaysia tends to eat more.

3.4 Gas (CO₂) Output

The total emission of CO₂ was 1,183 054.61 kg/day. It was 722 881.25 kg/day (61.1%), 213 377.26 kg/day (18%) and 246 796.10 kg/day (20.9%) for Kuala Lumpur, Ampang Jaya and Selayang, respectively. The high difference between Kuala Lumpur, Ampang Jaya and Selayang could be due to a lack of carbon sinks, which are the green trees, and due to diverse activities taking place in the city, such as respiration, transportation, building construction, electrical consumption and commercial activities (Moore et al., 2013).

In the city of Aveiro, the total production in a day is 233 205.3 kg/day. The individual production of CO₂ in Aveiro is 3.18 kg/cap/day as reported by Lemos (2011), which is higher than individual production in Klang Valley, which is only 0.455 kg/cap/day. The higher production in Aveiro was due to higher consumption of electricity and other anthropogenic activities that cause the emission of CO₂. This could be due to the weather patterns and commercial activities conducted there.

Emission of gases due to the natural and anthropogenic activities will lead to greenhouse effects and cause the global temperature to increase. In Kuala Lumpur, about 100,000 large-cover trees will be planted as one of the measures by the Kuala Lumpur City Hall to make it into a more sustainable city by 2020. This measure can directly help to reduce the amount of CO₂ emissions into the atmosphere, which may also decrease the amount of CO₂ in the area of GKL/KV (Holmes & Pincetl, 2012; Economic Transformation Programme, 2013).

3.5 Wastewater Outputs

For wastewater outputs, the total (585 027 000 m³/day) in a day for Kuala Lumpur, Ampang Jaya and Selayang are 357 468 750m³/day (61.1%), 105 516 225 m³/day (18%) and 122 042 025 m³/day ((20.9%). Kuala Lumpur produced the highest amount of wastewater in a day due to the high number in population compared to the other two cities.

In Aveiro, the total production of wastewater is 6 995 425.65 m³/day. As reported by Lemos 2011, the individual production of wastewater in Aveiro is 95.39 kg/cap/day, and it is 225 kg/cap/day for the individual production in Klang Valley. The high production of wastewater in Klang Valley is due to high consumption of water.

Nowadays, the technology in treating the wastewater has developed. The technologies are more efficient and reliable in treating the wastewater. Hence, it is hoped that with advanced technology, it can ensure the sustainability of environment during the treatment works. In order to reduce the amount of greenhouse gas emissions, technical advancements of the high-

class treatment should be accompanied by technological substitution. As for the output of wastewater treatment, when dewatered sludge is incinerated rather than landfilled, both the CO₂-equivalent emissions and landfill volume decreases (Lin, 2009).

3.6 Solid Wastes Outputs

Total solid wastes output for the area of Kuala Lumpur, Ampang Jaya and Selayang in a day are 7, 149 375 kg/day, 2, 110 324.5 kg/day and 2, 440 840.5 kg/day, respectively. The high difference between the city of Kuala Lumpur compared to Ampang Jaya and Selayang is due to the diverse human activities. The economic and commercial activities in the area contribute to the high production of solid wastes, and the high generation in Kuala Lumpur is due to the urban development (Chandrappa & Das, 2012).

When compared with the total production of solid wastes in a day in Aveiro, which is 113 669.25 kg/day, it is significantly lower than the three cities. Individual production in Aveiro is 1.55 kg/cap/day. The high production of wastes in Klang Valley may be due to a lack of awareness on Reduce, Reuse, Recycle (3R) measures. Enforcing the segregation of household waste at the source has been implemented by the Solid Waste Management and Public Cleansing Corporation since September 2015 (SWCorp Malaysia, 2016), and the outcome is yet to be assessed. The corporation was established to complement and ensure the successful implementation of the National Solid Waste Management Policy. Municipal solid waste generation in Malaysia has increased significantly in recent years, ranging between 0.5 - 2.5 kg/cap/day (or a total of 25000 - 30000 tons per day) (Johari et.al, 2014; Badgie et al., 2012; Fauziah & Agamuthu, 2012).

According to the official website of the Economic Transformation Programme (2013), one of the transformation plans is to come out with an orderly and well-planned solid waste management system. The first measure is to inspire the implementation of the 3R programme, fol-

lowed by expanding the waste treatment capacity. The design for urban planning and waste management should be integrated to motivate positive attitudes towards sustainability (Shafie et al, 2013). Besides, the management of solid waste and public cleaning services will be upgraded and new technological improvements such as automatic waste collection and its potential will be evaluated.

These measures will lead to a more sustainable urban solid waste management system of Greater Kuala Lumpur, which includes the area of Ampang Jaya and Selayang, and most importantly, Kuala Lumpur, since it occupies about 5.14 % of Malaysia's population compared to Ampang Jaya and Selayang, which is only 1.66 % and 1.92 % respectively, thus contributing to more solid wastes.

4. Conclusion

Sustainability is a state of total balance in the intake of energy and other consumptions while emitting waste in a balanced manner. The electricity consumption of 0.19 koe/cap/day in Klang Valley contributes to CO₂ of 0.46 kg/cap/day; 95.32 % of water consumption will be the share of wastewater production in the area of Klang Valley, and the consumption of 0.38 kg/cap/day of rice, eggs and sugar in Klang Valley will contribute to the production of 4.5 kg/cap/day of solid wastes (Figure 4).

The difference between the total inputs and outputs of each areas being studied were due to the difference in the population. The difference of the total inputs and outputs in Klang Valley is 6.67 kg/cap/day and this is because some of the balancing items, such as other types of foods and products that contribute to waste generations are not taken into account due to some limitations. Between the three cities, Kuala Lumpur has the highest total consumption of inputs and production of outputs due to high density population.

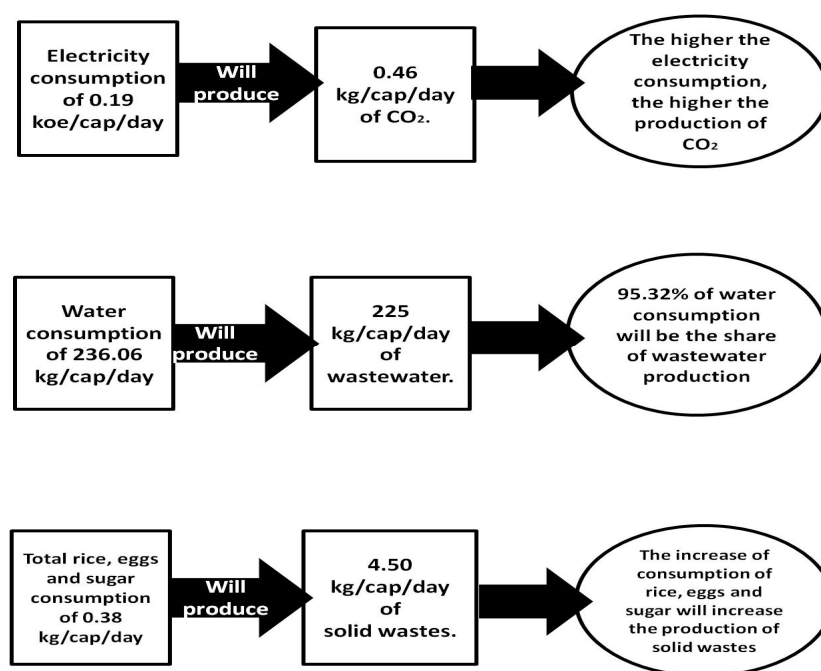


Figure 4: Schematic representation of Input and Output Flow for Greater Kuala Lumpur

In order to cope with the consumption of electricity in Malaysia, information and education on energy-efficiency as well as creating public awareness on energy-saving methods and energy conservation can be undertaken. Industrial ecology approaches, such as rain-water harvesting and green technology, may

also assist in the goal of sustainable development for the accounted inputs and outputs. It would appear that the material flow analysis will further improve the practicality in managing urban system and is economically feasible for urban managers.

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