

ORIGINAL ARTICLE

An Urban Metabolism and Ecological Footprint Assessment of Shah Alam, Malaysia

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ABSTRACT

Introduction: Uncontrolled and unplanned urban development lead to various detrimental impacts; the situation has worsened in the 4th industrial revolution. This study aimed to assess urban metabolism and sustainability of the city of Shah Alam, Selangor using Material Flow Analysis (MFA) and Ecological Footprint Analysis (EFA). **Methods:** The MFA and EFA were used to assess the metabolic flow, ecological footprint and biocapacity of Shah Alam. The input and output data were obtained from various government departments and organizations. When there was no available local data, national data were downscaled to simulate the study area. **Results:** MFA estimated the average individual consumption of food in Shah Alam at 0.24 kg/cap/day which later generates waste of 0.65 kg/cap/day. For water consumption, Shah Alam residents used about 222 kg/cap/day and released 288 kg/cap/day of wastewater. Rapid urban development in Shah Alam has influenced electricity consumption and production of carbon dioxide with 0.383 koe/cap/day and 9.2 kg/cap/day respectively. EFA showed that Shah Alam encounters ecological deficit for food as the ecological footprint value is higher than biocapacity value with 44,041 gha and 5,167 gha respectively. As for carbon dioxide output, biocapacity value is higher than carbon footprint value with 2,763 gha and 1,435 gha respectively, which indicates that Shah Alam has the capability to sequester carbon dioxide with the remain ecological reserve of 1328 gha. **Conclusion:** Integration of different analysis on urban metabolism and sustainability can provide insights on the city performance and can be used to formulate strategies and policies to oversee the consumption and carbon footprint in the city of Shah Alam.

Keywords: Urban Metabolism, Ecological Footprint, Urbanization

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INTRODUCTION

Cities can be seen as a focal point for most communities with various economic, social and cultural activities being held on daily basis. Cities will require vast quantities of material resources and energy in order to maintain their economic, social and cultural activities (1,2). Improper development planning of urban area will make the cities grow inexorably and cause various environmental impact such as climate change, excessive energy consumption, resource depletion and other ecological impacts (3,4). The unsustainable development of cities will lead to overpopulation which increases the

demand of material resources and energy that overloads the capacity of the city and could indirectly disrupt the ecosystem balance (5,6).

‘Urban metabolism’ concept was introduced by Karl Marx in 1883 to describe his industrialization critique on energy and material exchanges between nature and society (7). In 1965, Abel Wolman re-launched this concept to explain deteriorating air and water quality in American cities. Urban metabolism can be defined as the collection of complex socio-technical and socio-ecological processes which include the flows of materials, energy, people, and information of the city which cater to the needs of its populace and the effect to the surrounding hinterland (8). Urban metabolism can assess the impact from urbanization through various approach like Material Flow Analysis (MFA), input and output analysis, and Ecological Footprint Analysis (EFA).

This study assessed the urban metabolism and sustainability of the city of Shah Alam in Selangor, Malaysia, using MFA and EFA as Shah Alam strives to become a low carbon city by 2030. The urban metabolism assessment from this study can also determine the capability of Shah Alam to cater to city consumption and the urbanization pressure.

MATERIALS AND METHODS

Study Location and Study Design

Shah Alam is the capital state of Selangor. Shah Alam municipality's coverage is about 290.3 km² and consists of 3 parts: north, central and south. The municipality is divided into 56 sections. The total population of Shah Alam is estimated at 650,000 people (9). Generally, this study depicted the previous year's numerical data on several variables which was used to conduct Material Flow Analysis (MFA) to study the urban metabolism of Shah Alam. The data on material flow analysis were also used in analysis of ecological footprint in order to determine ecological carrying capacity of Shah Alam.

Data Collection and Data Analysis

The secondary data for determining the material flow analysis and ecological footprint were provided by published national, state, and district data. Secondary data on input and output variables were obtained from various departments whether government or governmental liaise companies (GLCs); the data is downscaled to per capita per day by dividing the data with population of Shah Alam to work out the consumption and production per capita per day (10). The input and output data are converted into the same unit of kg/cap/day. The data and their sources are summarized in Table I.

Ecological Footprint Analysis

Ecological footprint (EF) is a method to assess the sustainability of specific location by measuring the biologically productive land, sea area, river area or ecological asset which is required by a population to produce and sustain the renewable resources and ecological services (11,12). In other word, ecological footprint is a tool to calculate the combined demand of human for ecological resources, wherever they are located. Hence, several formulas such as ecological footprint equation and biocapacity equation is used in ecological footprint analysis. The ecological footprint equation is in Equation 1.

$$EF = D/Y \quad \text{Equation 1}$$

Where:

D: Annual of product

Y: Annual yield of the same product (expressed in gha*)

*Gha = global hectare

Table I: Sources of secondary data

Data	Sources
Solid waste generation	Shah Alam City Council (MBSA) (2018)
Carbon dioxide emission	International Energy Agency (IEA) (2017)
Food consumption	Food and Agriculture Organisation of the United Nations (2019)
Energy consumption	Malaysia Energy Commission (2018)
Wastewater generation	Azman, Shaari, & How (2013)
Water usage	National Water Service Commission (SPAN) (2019)

Global hectare is often estimated by using yield factors to compare national average yield per hectare to world average yield in the same land category. Global hectare also uses equivalence factor to get relative productivity among various biologically productive land. Hence, integration of yield factors is necessary for more detailed ecological footprint formula following the previous equation is in Equation 2.

$$EF = (P/YN) * YF * EQF \quad \text{Equation 2}$$

Where:

P: Amount of the product harvested or emitted (equal to D)

N: National average yield of P

YF: Respective yield factor

EQF: Equivalence factor for country and land use type in question

Other than that, biocapacity measurement is used by measuring the total area available which is weighted by the productivity of that area and the result of the measurement will represent the ability of a biosphere to produce crops, livestock and the ability to sequester carbon dioxide (12). The biocapacity formula is in Equation 3.

$$BC = A * YF * EQF \quad \text{Equation 3}$$

Where:

BC: Biocapacity

A: Available area given land use type

YF: Yield Factor

EQF : Equivalence factor

RESULTS

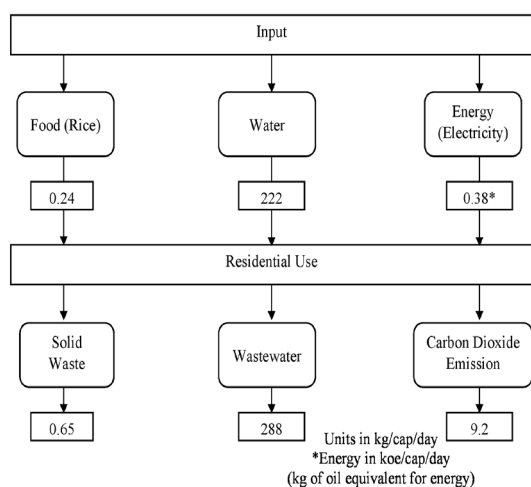
MFA was used to determine the sustainability of Shah Alam. After data were analysed and downscaled, daily consumption in Shah Alam is depicted in Table II. Resource consumption and waste generation per day showed that the output of urban metabolism being released by population is lower than the input being consumed. The lower output flow than the input of

Table II: Daily consumption/production in Shah Alam

Component	Unit	Shah Alam Consumption / Production (Population: 650 000)
Input		
Food (Rice)	kg/day	156000
Water	Million liters/day	144.3
Energy (elec- tricity)	Ktoe/day	248.95
Output		
Solid Waste	kg/day	422500
Wastewater	m ³ /day	187200
Carbon diox- ide emission	kg/day	5980000

consumption may be caused by several factors. Authors would like to highlight that the discussion on this study can only be compared with the similar urban metabolism and ecological footprint using the same method. Comparisons cannot be made loosely with other ecological footprint studies. Major comparison was made based on a study on urban metabolism which was conducted in Greater Kuala Lumpur, the resource and waste flow of Greater Kuala Lumpur for solid waste and water consumed 0.38 kg/cap/day of food and generated 4.5 kg/cap/day of solid waste and the usage of water about 236.1 kg/cap/day to produce 225.0 of wastewater. For energy, Greater Kuala Lumpur consumed 0.188 koe/cap/day of energy which indirectly emit 0.455 kg/cap/day of carbon dioxide (13). These figures were rather identical with individual resource consumption and waste generation of Shah Alam per day.

Material Flow Analysis flow chart in Fig. 1 represents the metabolic flow of material and energy across Shah Alam which results in the release of waste. It means that

**Fig 1: Material Flow Analysis flow chart**

when residents consume the resources like food, water and energy, subsequently the resources will undergo metabolic process which indirectly produce solid waste, wastewater and carbon dioxide emission respectively. Based on Fig. 1, the input and output of the material balance nearly achieve the state of balance where the input and output are almost similar in value.

DISCUSSION

The food component being assessed in this study was rice as it is the staple food for Asian countries including Malaysia. The data on food supply is obtained from Food and Agriculture Organization of the United Nations (FAO) which stated about 2840 thousand tonnes of rice being harvested in Malaysia for the year 2017 for 31.11 millions of people (14). The total harvested rice was divided by the number of Malaysian population in 2017 and were further downscaled by 650,000 residents of Shah Alam which resulted about 156,000 kg/day or 0.24 kg/cap/day in 2017. Meanwhile, the total rice consumption for Klang Valley is 624,028 kg/day which is about 0.24 kg/cap/day (13). It is worth noting that Shah Alam is also part of the Klang Valley or the Greater Kuala Lumpur as it is also called. The total consumption of rice for Klang Valley was higher than total rice consumption for Shah Alam which is about 624,028 kg/day and 156,000 kg/day respectively but it is worth noting that the average daily consumption of rice was similar which is 0.24 kg/cap/day. These numbers depict that socio-demographic and eating pattern across Klang Valley is similar. Shah Alam urban population consist of workers and students who may tend to eat out due to unavailability of food at home and time constraint due to work (15).

To put into perspective, Metro Vancouver, Canada residents consumed about 1,753,000 tonnes of food with 2.29 kg/cap/day where it can be seen that food consumption in Metro Vancouver is higher than Shah Alam (2). The higher number of populations of Vancouver with approximately 2.1 million people and being a high-income population is reflected in their affordability to buy and waste more food. This inference is proven as there is estimated about 372.7 thousand of plate waste in Metro Vancouver (2).

In 2017, the daily production of solid waste for 650,000 residents in Shah Alam is 422,500 kg/day where the average individual production a day was about 0.65 kg/cap/day. The total solid waste output for Klang Valley in a day is 10,700,539 kg/day or 4.5 kg/cap/day which is higher than average individual production of waste per day in Shah Alam (15). Klang Valley is the centre of Selangor with urban development rapidly occurring and contributing to the high rate of economic and commercial activities and evidently resulting in high production of solid waste. Besides, lack of awareness among residents in Klang Valley on 'Reduce, Reuse, and

Recycle' (3R) campaign was also a contributing factor to the high generation of solid waste. Currently, the rate of recycling in Malaysia is only about 3-5% from the total solid waste generated (16). Malaysia generates 33,000 tonnes of solid waste per day, mostly from households and at least 22% of this waste can be extracted and recycled. With the increasing rate of urbanization, the rate of waste generation for the year 2020 is being expected to be about 30,000 tonnes per day which consist 45% of food waste, 24% of plastic waste, 7% of paper, and 6% of glass and others (16, 17).

For Metro Vancouver, the residents consumed about 2,399,900 tonnes of materials a year which approximate about more than one tonne per capita per year, which is higher than Shah Alam (2). Besides, total solid waste output a year from Metro Vancouver was also higher than total solid waste output a year in Shah Alam for about 1,139,560 tonnes and 154,236.81 tonnes respectively. These differences in total output of solid waste may be due to high population in Metro Vancouver. Even though Metro Vancouver residents generate more solid waste than Shah Alam residents, the rate of recycle of the waste among Metro Vancouver residents is higher than Shah Alam; Metro Vancouver residents approximately recycled about 50% of their waste (2). The Metro Vancouver residents are highly aware of, and practice, the waste minimization concept in segregation and recycling of the waste materials.

According to National Water Service Commission (SPAN), (2019), the Selangor water consumption for year 2017 is about 3,243 MLD (million litre per day) with domestic and non-domestic usage of about 1,870 MLD and 1,373 MLD respectively. In Selangor, about 99.8% of the population received the distribution coverage for water supply with domestic consumption per capita per day in the year 2017 about 222 litres per capita per day (l/cap/day) or kg/cap/day (17).

In light with similarly conducted study, the average individual consumption per day in Klang Valley is slightly higher than Shah Alam with 236.06 kg/cap/day and 222 kg/cap/day. The high usage of water in Selangor is very alarming as it is higher than national average household consumption which is 201 kg/cap/day. The high consumption of water may be due to special tariff rate in the Selangor state which provides a significant amount of free water supply to their residents. As a result, people have a tendency to use more water than they should. Occasional water disruption across Selangor due to water pollution shows that no one resource is finite, and the water and environment authority need to see the opportunities that cities can provide for more integrated and sustainable water use management.

On comparison, Metro Vancouver water consumption was 424,860,000 m³ with 554.29 kg/cap/day. These figures are higher than water consumption of Shah

Alam. The residents in Metro Vancouver use more water than Shah Alam's residents and seem to concur with the statement that a highly urbanized city tend to use more water (18).

Selangor wastewater management is maintained by the company Indah Water Konsortium (IWK) that has been awarded concession for nationwide sewerage service except for the Pasir Gudang City Council, Johor Bharu City Council, States of Kelantan, Sarawak and Sabah. Because of inability to get the data from IWK, the data on wastewater production was obtained from a secondary source which stated that about 2.97 billion cubic meters per year of wastewater was generated in 2010 (1). After being downscaled, it is estimated that Shah Alam produced about 187,200 m³/day which was about 288 kg/cap/day. In contrast, Klang Valley produced more wastewater than Shah Alam with total production in a day about 585.027 million cubic meters but with lower average individual per day with 225 kg/cap/day (15). The difference in average individual production of wastewater per day between Shah Alam and Klang Valley may be due to the sprawl of economic growth in Shah Alam which indirectly affect the generation of wastewater (19).

In 2006, Metro Vancouver generated about 462,053 500 m³ of wastewater which was about 602.8 kg/cap/day. Both Shah Alam and Metro Vancouver wastewater output are higher than water input that may be due to infiltration and inflow of storm water (8). In developed countries, wastewater pollution is considered as outdated issue because the wastewater is efficiently managed to prevent environmental pollution arising from it. But, for developing nations, the wastewater pollution become a growing concern as reported by United Nations that more than 80% of wastewater being discharged into the water body without any treatment which can degrade the quality of water course (20). About 72% of 473 rivers in Malaysia has been found to be polluted with 25 of them considered as highly polluted in 2013; one of the sources of pollution is caused by inefficient sewage treatment system (20).

Residential sector in Malaysia has consumed about 2678 ktoe per day in year 2016 and downscaled to 6,989,968 consumers, it resulted in about 0.38 ktoe/cap/day (9). For Klang Valley, the total energy consumption per day is 488.82 ktoe/day with an average daily per capita about 0.19 (15). Comparison of Klang Valley and Shah Alam with Metro Vancouver for total domestic electricity consumption showed that the domestic electricity consumption for Metro Vancouver was higher than electricity consumption for Klang Valley and Shah Alam, as Metro Vancouver need about 1,732.97 ktoe/day and 0.83 koe/cap/day to meet the population demand (8). The rate of energy consumption is usually affected by population density, rate of urban development and living standard of the population. Standard of lifestyle

and increasing income among residents will result in increasing energy demand (21).

Carbon dioxide emission released to natural surrounding originates from many sources either natural or anthropogenic especially from energy generation. Malaysia has generated about 103.1 million tonnes or 9.2 kg/cap/day of carbon dioxide for electricity and heating sector in year 2015 (22). This means that Shah Alam electricity consumption was about 248.95 ktoe of energy per day that will generate about 5,980,000 kg/cap/day of carbon dioxide per day. So, for every 0.383 koe of energy consumed by people, 9.2 kg of carbon dioxide will be produced and released into the surrounding.

In discussion for situation in Klang Valley, the total release of carbon dioxide is 1,183,054.61 kg/day with the average individual per day is 0.46 kg/cap/day (15). It means that average per capita per day generation of carbon dioxide in Shah Alam is higher compared to Klang Valley with 9.2 kg/cap/day and 0.46 kg/cap/day respectively. This increasing trend of carbon dioxide was due to the increasing demand of electricity which directly and indirectly release carbon dioxide into the atmosphere. The greenhouse gases especially carbon dioxide is released to the environment because of the burning of fossil fuel to generate electricity (23).

In the 1990s, the 'ecological footprint' concept was established by William Rees and Mathis Wackernagel (22). Environmental pressures from processes and activities in the studied area can be identified. Since the formulation, the method has undergone modification and improvement leading to comparisons of sustainability among populations of the world rather meaningless due to difference in mathematical model used. As for this study, due to lack of available data and calculation method for those waste stream components, only food and carbon dioxide can be used to determine ecological footprint. The waste flow in ecological footprint is not thoroughly explored as carbon dioxide is the only waste stream in which calculation for ecological footprint is available (8). Fig. 2 shows ecological footprint and biocapacity of Shah Alam.

Based on Fig. 2, the value of food footprint which is higher than the value of biocapacity indicates that Shah Alam is facing ecological deficit or biocapacity deficit. The deficit is about -38,874 gha, due to scarce agriculture land that sustain population demand on food because crops usually need a large area to grow (8,21). As urbanized area, it is common for Shah Alam to only have small proportion of agriculture land because many agriculture lands have been converted into industrial, commercial and residential area as required by the urban development policy. Hence, Shah Alam must import the food and crop from nearby districts which have high production of food in order to meet the population

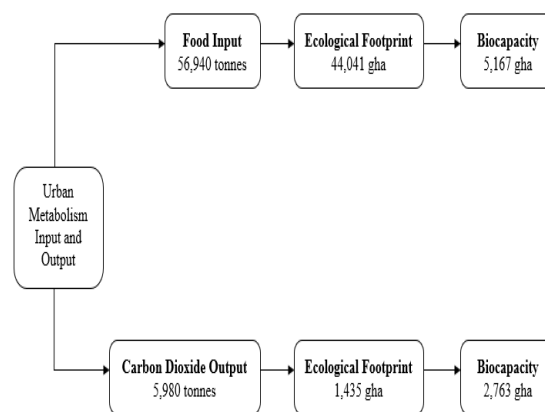


Fig 2: Ecological footprint and biocapacity of Shah Alam.

demand. For carbon footprint, the value obtained through analysis is 1,435 gha and its biocapacity is 2,763 gha. The biocapacity value is higher than carbon footprint value which indicates that Shah Alam has the capability to sequester carbon dioxide with the remain ecological reserve of about 1,327 gha.

Malaysia recorded about 3.92 gha per capita of ecological footprint and 2.26 gha of biocapacity in the year 2016 (24). Apparently Shah Alam's ecological footprint and biocapacity per capita are lower than national ecological footprint and biocapacity per capita due to lesser number of ecological footprint components which are being calculated in this study. Apart from that, ecological footprint and biocapacity for both Malaysia and Shah Alam indicated that ecological deficit is encountered nationally and locally. Hence, federal and state governments should work together to establish policy on sustainability to reduce human pressure on earth's biocapacity and promote sustainable lifestyle.

CONCLUSIONS

The finding of this study on urban metabolism found that the input and output of the material flow analysis for Shah Alam city is nearly reaching the state of equilibrium. Overall findings on input and output of Shah Alam expressed in per capita per day is higher than input and output of Klang Valley. The ecological footprint for food has undergone ecological deficit whereas carbon footprint shows ability of ecological reserve to sequester carbon dioxide. The integration of different analyses on sustainability would be useful as each analysis can capture different perspective that may benefit our country in the future.

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