

A Small-Scale Study in Urban Metabolism for Developing Countries: from Theory to Practice

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Abstract

The study of urban metabolism in developing countries often faces many challenges, with the primary reason being the lack of available data. This study aimed to practically apply a suitable method to calculate the material and energy flows from households' consumption in the extended Ho Chi Minh City area. After a literature review of small-scale urban material studies, a method of Material Input Per Service (MIPS) was selected to proceed further household consumption calculations. The consumption aspects included electricity, water, food, shopping, leisure, transport and travel. We combined face-to-face interviews with households and the random online surveys to the research subjects. A total of 293 responses were collected during April to August, 2025. The overall MIPS results indicated that household resource consumption in the area was significantly higher than established sustainability thresholds. The use of the MIPS method helped to quantify material and energy flows in household consumption, thereby enabling the identification of aspects and behaviors that can be changed towards more sustainable consumption.

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Keywords

MIPS; material intensity; energy intensity; household consumption; urban area.

1 Introduction

Urban metabolism (UM) is defined as “the sum total of the technical and socioeconomic processes that occur in cities, resulting in growth, production of energy, and elimination of waste” [1]. Urban metabolism studies allow for an understanding of the direction and distribution of material and energy flows through an urban system that is essential for the sustainable development of cities. Urban metabolic studies can be conducted at different scales, ranging from the micro level to the macro level. Small-scale UM encompasses

both the micro level, which focuses on households and individual buildings, and the aggregated level, which extends to groups of building and neighborhoods [2]. Previously, numerous studies on UM at the neighborhood scale, where groups of households are considered collectively to analyze resource and energy flows, e.g., [3, 4].

The household-level UM studies provide detailed insights into consumption patterns of energy, water, materials, and food, allowing the identification of specific inefficiencies in energy and material

utilization. According to [5], a sustainable and equitable threshold for material resource use has been estimated at 10,000 kg per capita annually, and the sustainable lifestyle material footprint is set at 8,000 kg per capita annually. Particularly, for abiotic resources, [6] suggested the acceptable level of (5,600-6,100) kg per capita per year in the context of the global extraction to be reduced by half for a projected population of 9 billion in 2050.

A study of [7] summarized three main approaches to measuring UM: production-based, consumption-based, and hybrid methods. Among these, consumption-based methods are particularly suitable for studies on urban metabolic processes at micro and aggregated levels, as they focus on end-user demand and resource use of households or neighborhoods. Environmentally-extended input-output model was also introduced as a tool within the consumption-based approach, while life cycle assessment (LCA), material flow analysis (MFA), and life-cycle accounting were employed as tools within hybrid approaches. Similarly, in a recent systematic review, [8] identified MFA and LCA as the most widely adopted methods across the 70 studies examined. However, one of the major challenges of urban metabolism research is the scarcity of comprehensive and standardized data on energy, material, and waste flows at the city level [8, 9], particularly in developing countries [10].

Material input per service unit (MIPS) was first introduced in the study of [11] and developed as a prevention indicator encompassing both measurable and unmeasurable effects on the ecological system. MIPS has been widely applied across various domains, including production, consumption, and business management. At household level, MIPS applications focuses on consumption patterns and demand in the consumption stage of the value chain. The MIPS concept focus on inputs within the human-made production and consumption system (technosphere), and then the material and energy inputs are ultimately transformed into outputs associated with environmental impacts such as climate change, eutrophication, and acidification. By accounting for material input flows, it

becomes possible to make preliminary evaluations of the environmental impact potential of products and services. Therefore, MIPS serves as a practical approach to simplify environmental assessments and to lessen the uncertainties inherent in output-oriented methods such as the ISO 14040/44 LCA [12]. In the context of limited data availability for UM research, particularly in developing countries, MIPS provides an appropriate and practical method for implementing small-scale UM analyses.

Currently, applications of the MIPS approach for assessing household consumption have primarily been carried out in developed countries, such as the Netherlands [13]. This highlights the need for comparable studies in developing countries, where the MIPS approach is particularly suitable due to its simplicity and applicability in contexts with limited data availability.

Thus, in this study, we preliminarily applied the MIPS method to assess the material and energy flows resulting from student household consumption in urban areas of Ho Chi Minh City, Viet Nam, and its surrounding regions (prior to the administrative mergers effective from July 1, 2025). A primary objective of this initial application is to test and demonstrate the feasibility of calculating urban metabolism in the context of a developing country. This assessment helps to identify the intensity of resource use as well as highlight aspects and behaviors that can be changed towards more sustainable consumption.

2 Material and Research Methodology

The research procedure followed the MIPS framework [14] and was structured as shown in Figure 1. First, the aims and scope of the study were defined to clarify the system boundaries. Next, the household consumption activities were identified, including electricity, gas and water consumption, food consumption behavior, shopping, leisure, transport and travel [13]. Data for these categories were collected through surveys conducted with random households from selected area. In parallel, the service unit was selected and relevant data of the activities

were collected. Subsequently, the amounts of material and energy associated with each activity were determined. A decision step was included to check whether the quantities were large enough for meaningful analysis; if not, the corresponding appliance or activity was excluded. After determining the appropriate data of material and energy, its corresponding material intensity (MIT) values were

obtained from relevant databases and literature sources. The material input (MI) for each activity was then calculated, followed by the computation of the MIPS value by dividing MI by the defined service unit (S). Finally, the results were subjected to discussion and recommendation, where findings were analyzed, compared with previous studies and the sustainable and equitable threshold.

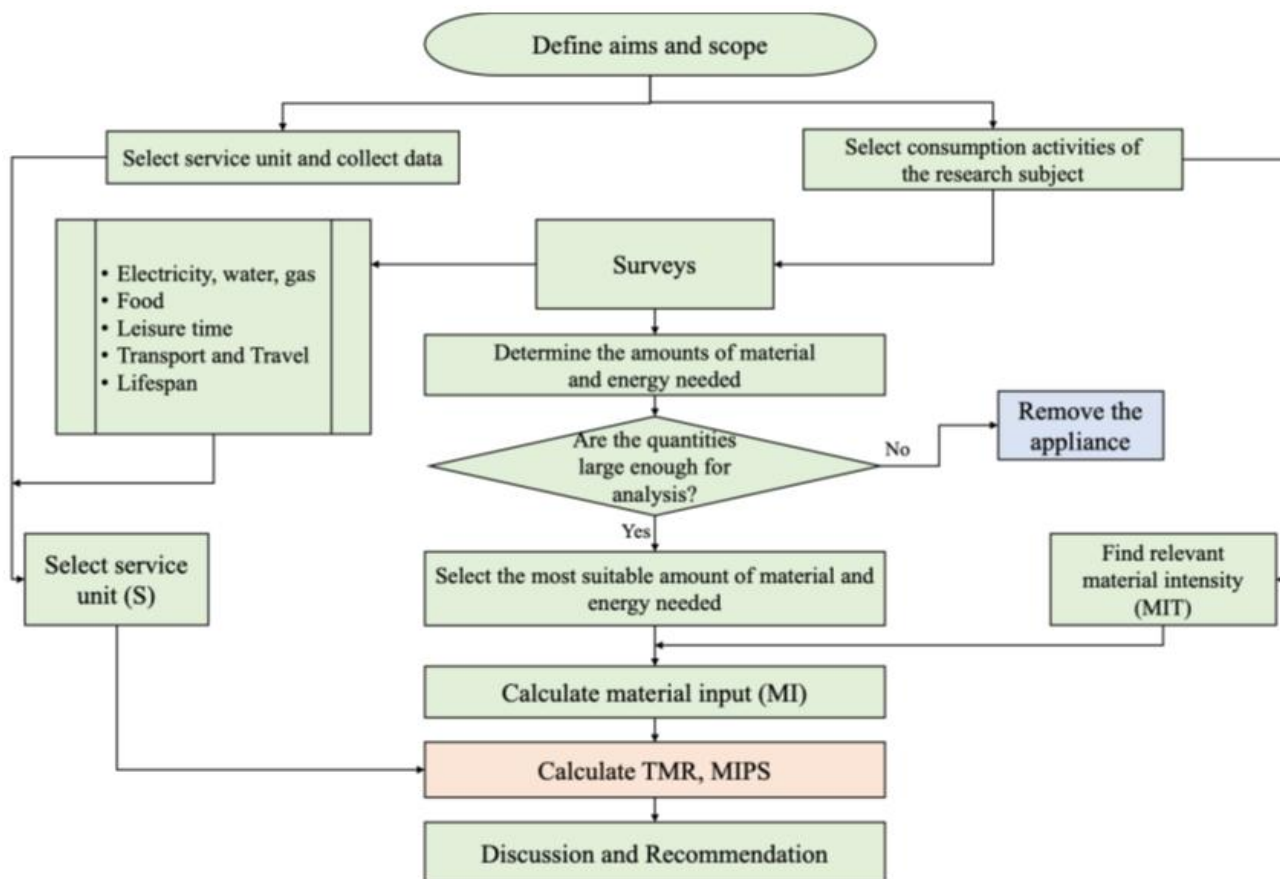


Figure 1 The study procedure

2.1 Data Collection

In the initial phase of the MIPS implementation process, the authors carried out surveys among students from several universities, with a primary focus on those from Nguyen Tat Thanh University, in the context of students living within household settings. The survey employed a combination of two methods, including in-person interviews and online structured questionnaires via Google Forms. A simple random sampling method was used. A total of 293 valid responses were recorded, including 199 from in-person interviews and 94 from the online survey.

2.2 Study Area

The study area is defined according to the respondents' places of residence, with 291 valid responses out of 293 collected. There was 91.9% of the participants live in Ho Chi Minh City, prior to the administrative mergers of July 1, 2025, followed by Binh Duong Province, and Dong Nai Province. Only one participant (residing in Dong Nai) lived in a different province from their university. Additionally, out of 276 valid district entries, a significant portion was observed in District 12 and Go Vap District, which accommodated 40.3% and 18.1% of the sample,

respectively, while the remaining respondents were widely dispersed across neighboring areas.

2.3 Data Analysis

Households' characteristics were characterized through their material consumption patterns across various selected categories. It included electricity, gas and water use, food consumption behavior, shopping, leisure time, transport, and travel, which served as empirical baseline for MIPS calculation. All data processing and MIPS calculation were carried out using Microsoft Office Excel and IBM SPSS version 27 software.

2.4 TMR and MIPS Calculations

The MIPS is defined as the ratio of cumulative material inputs required for a product or service to its corresponding service unit provided, formulated as: $MIPS = \frac{\sum MI}{S}$. Under the umbrella of MIPS concept, MI are categorized into five types: abiotic natural materials, biotic natural materials, water, air, and earth movement in agriculture and silviculture. The material input for each category is estimated by multiplying the amount of material input (in kilograms) by its material intensity coefficient [15]. The MIT values (expressed in kg/kg), are retrieved from well-known databases, e.g. [13]. The Total Material Requirement (TMR) was then quantified by aggregating the individual material inputs: the abiotic MI, biotic MI, and soil erosion MI. As a key metric in macro-level resource accounting, the TMR represents the "ecological rucksack", i.e., the cumulative, life-cycle material footprint of products and services [13]. We adopted this TMR metric, expressed as kg/person/year, to benchmark our findings against published international studies [5, 13].

3 Results and Discussion

3.1 Socio-demographic Statistics

Overall, the respondents represented 32 different academic majors across the survey. Out of a total of 293

surveyed individuals, the study recorded 263 valid responses (89.8%), while 30 cases (10.2%) were identified as missing data. To facilitate analysis, these majors were classified into five main disciplinary groups: Economics, management and social sciences; Engineering, technology and environment; Medical and health; Languages, culture, and tourism; and Information and Communication Technology. The largest proportion of respondents is Group 2 - Engineering, Technology & Environment - accounting for 112 cases or 38.2% of responses. This is followed by Group 1 (Economics, Management & Social Sciences) with 25.9%, and Group 4 (Languages, Culture & Tourism) with 13.7%. The remaining two groups, namely Group 5: Information and Communication Technology and Group 3: Medical and Health, account for 9.9% and 2.0%, respectively.

As for the year of study, juniors were the largest contribution group, accounting for 36.5%, followed closely by seniors at 34.1%. Sophomores constituted 12.6% of the cohort, while freshmen made up the smallest one at 6.8%. These varying rates of participation reflect different levels of experience with urban lifestyle routines among the year groups and their family.

Regarding residence status, Table 1 indicated a significant majority of respondents (68.7%) not living with their family, while the remaining of 31.3% were the people who are living with family. Considering on the valid responses, there has been a substantial difference in the average household size between the two groups. The average member of household size for those living with family was 4.2, while this value for those not living with family was 1.8, although both groups have the same range of 1 to 10 members. The average member of household size was 2.5, with an average of 2.3 adults per household. In later step, an average household size of 3 was adopted for MIPS calculations.

Table 1 Distribution of Household Size by Student Residence Status

		Count	Valid Count	Percent	Minimum	Maximum	Mean	Std.
Residence status	Living with family	91	84	31.3	1	10	4.2	1.3
	Not living with family	200	200	68.7	1	10	1.8	1.4
Household size	Household size	293	284	-	1	10	2.5	1.8
	Adult	293	284	-	1	10	2.3	1.5



3.2 Descriptive Statistics of Household Consumption

- Household Electrical Appliances and Devices Ownership
Cellphones (278), laptops (265), and electric fans (245) were the most frequently owned items in surveyed households. These devices also showed the highest average ownership (2 units), compared to the mean of 1 unit observed for all other appliances.

- Household cooking gas consumption

Nearly two-thirds of the participants (66.6%) reported not using gas for cooking or other household purposes. Among those who do use gas, 1-2 butane gas canisters per month was the highest usage category at 12.7%, followed by households using over 3 butane gas canisters per month (10.6%).

- Household electricity and water consumption

For electricity consumption, the mean value was 183.4 kWh with the large standard deviation. Similarly, water consumption was measured with the mean value of 9.5 m³ and a range from 3.3 m³ to 32.5 m³. A few outlier values have been removed.

- Household food consumption

The mean consumption values used for further MIPS calculations included 3.7 kg/week for pork, 1.5 kg/week for beef, 3.3 kg/week for chicken, and 2.3 kg/week for fish, 3.0 L/week of milk, 6.0 kg/week of vegetables, and 8.2 kg/month of rice.

- Household Leisure Activities

The distribution of weekly leisure time revealed that the largest proportion of households spend between 7 to 14 hours/week on leisure (36.4%), followed by

those spending over 20 hours/week (24.1%). In terms of the activities type performed, a strong preference for digital entertainment, with watching movies and playing games on personal devices is the most prevalent, accounting for 76.1% and 66.2% of cases, respectively. The study adopted 14.55 hour/week for an average value of leisure time for MIPS calculation.

- Household Transport and Travel

The travel mode of (ride-hailing) motorcycle was the most frequent choice, accounting for 73.5% of all observed transport activities and 90.6% of cases. The mean weekly distance traveled by (ride-hailing) motorcycle was the highest at 130.4 km. The mean values of each mode of travel were selected for MIPS calculation in further phase.

3.3 MIPS Calculations

Based on the survey results above, MIPS calculations have been performed for three outcome groups.

- MIPS of appliances and devices

Table 2 detailed the MI and MIPS calculation for various household appliances devices. Among the listed items, the air conditioner exhibited the highest MIPS at 133 kg/person/year, followed by the refrigerator (81 kg/person/year) and the electric stove (80 kg/person/year), primarily due to their high abiotic resource requirements and substantial water footprints. The total MIPS for all surveyed appliances and devices combined was 421 kg/person/year, providing a clear baseline for the material demand of modern household technologies in the study area.

Table 2 MIPS Calculation for Household Appliances and Devices

Appliance/Device	MI-abiotic (kg)	MI-biotic (kg)	MI-water (kg)	MI-air (kg)	TMR (kg)	Service (year)	MIPS (kg/person/year)
Television	1,349	1	271,383	345	1,350	6	75
Refrigerator	3,623	6	836,168	1,087	3,629	15	81
Air conditioner	5,977	5	1,102,695	1,392	5,982	15	133
Cellphone	10	0	193	3	10	6	1
Laptop	273	0	10,584	23	273	5	18
Microwave oven	339	0	6,928	21	339	19	6
Electric stove	2,163	1	592,086	717	2,164	9	80
Washing machine	1,036	0	19,386	179	1,036	12.5	28
Total					14,782		421

- MIPS of food consumption

Table 3 presented the TMR and MIPS for various food groups based on a 1-year service unit. Vegetables dominated the total material demand with the highest TMR of 9,858 kg/year and a MIPS value of 3,286 kg/person/year. This is due to the large share of the MI-water component and MI-erosion. Pork and beef followed as major contributors, with MIPS

values of 1,353 kg/person/year and 1,201 kg/person/year, respectively, primarily influenced by high MI-biotic and MI-soil requirements. Conversely, rice and milk represented smaller portions of the overall material intensity. The total TMR for household food consumption was calculated at 21,604 kg/year, resulting in an overall MIPS of 7,201 kg/person/year.

Table 3 MIPS Calculation for Household Food Consumption

Foodstuff category	MI-abiotic (kg/year)	MI-biotic (kg/year)	MI-water (kg/year)	MI-air (kg/year)	MI-erosion (kg/year)	MI-soil (kg/year)	TMR (kg/year)	MIPS (kg/person/year)
Pork	1,597	1,924	46,176	366	539	468,302	4,060	1,353
Beef	936	2,418	34,242	77	250	221,442	3,604	1,201
Chicken	1,201	789	39,125	257	206	186,701	2,196	732
Milk	172	468	4,836	15	48	42,744	688	229
Fish	335	562	32,412	99	20	17,701	917	306
Vegetable	2,285	398	303,888	1,171	7,176	37,440	9,858	3,286
Rice	0	426	0	0	789	0	280	93
Total							21,604	7,201

- MIPS of transport and travel

Table 4 calculated the MIPS for household transport methods over a 1-year service unit based on distance traveled in the survey aforementioned. The (ride-hailing) motorcycle showed the highest MIPS value at 3,471 kg/person/year and the highest TMR of 10,414 kg/year. This was followed closely by the (ride-

hailing) car with a MIPS of 3,277 kg/person/year, primarily due to its significant contribution to MI-water and MI-abiotic. In contrast, public bus and bicycle usage contributed much lower material intensities, at 346 and 316 kg/person/year, respectively. The total MIPS for household transport and travel was recorded at 7,410 kg/person/year.

Table 4 MIPS Calculation for Household Transport and Travel

Vehicle	MI-abiotic (kg/year)	MI-water (kg/year)	MI-air (kg/year)	TMR (kg/year)	MIPS (kg/person/year)
(Ride-hailing) Car	9,832	97,344	925	9,832	3,277
(Ride-hailing) Motorcycle	10,414	5,031	1,812	10,414	3,471
Bus	1,037	10,464	194	1,037	346
Bicycle	948	30,202	50	948	316
Total				22,231	7,410

- MIPS of leisure activity

Table 5 illustrated that among household leisure activities, going to the cinema or music shows had the highest TMR of 2,852 kg/year and a MIPS value of 951 kg/person/year. This significant material intensity was largely due to the massive MI-water requirement of 326,027 kg/year associated with these external

entertainment services. In contrast, digital-based activities such as watching movies or playing games on PCs/cellphones, as well as watching TV, contribute a lower and identical material intensity of 252 kg/person/year each. The total MIPS for household leisure activities was recorded at 2,060 kg/person/year.

Table 5 MIPS Calculation for Household Leisure Activity

Leisure Activity	MI-abiotic (kg/year)	MI-water (kg/year)	MI-air (kg/year)	TMR (kg/year)	MIPS (kg/person/year)
Watching movie on PC or cellphone	757	0	0	757	252
Playing game on PC or cellphone	757	0	0	757	252
Outdoor activities	1,059	24,968	0	1,059	353
Going to cinema, music show	2,852	326,027	942	2,852	951
Watching TV	757	0	0	757	252
Total				6,181	2,060

- MIPS of energy and water consumption

According to Table 6, electricity consumption stood out as the primary contributor to this category, with a TMR of 1,166 kg/year and a MIPS value of 389 kg/person/year. The production and distribution of electricity required a substantial amount of natural resources, particularly reflected in its high MI-water

component of 415,951 kg/year. Meanwhile, water and gas consumption showed much lower material intensities, with MIPS values of only 3 and 2 kg/person/year, respectively. The total MIPS for household energy and water consumption was calculated at 394 kg/person/year.

Table 6 MIPS Calculation for energy and water consumption.

Category	MI-abiotic (kg/year)	MI-water (kg/year)	MI-air (kg/year)	TMR ((kg/ year)	MIPS (kg/person/year)
Electricity consumption	1,166	415,951	484	1,166	389
Water consumption	10	517	4	10	3
Gas consumption	7	24	19	7	2
Total				1,183	394

Finally, the total MIPS calculated for the surveyed student households was 17,486 kg/person/year, primarily driven by high resource demands in daily transport and food consumption. To evaluate this metabolic profile, the result was benchmarked against international averages from CSCP and WBCSD [5]. According to the report, the theoretical sustainable lifestyle target was set at 8,000 kg/person/year, while the average material footprints for China, Europe, and Finland are reported as 15,200 kg, 29,000 kg, and 40,000 kg, respectively. The footprint calculated in this study (17,486 kg) exceeded the sustainable target (8,000 kg) and was slightly higher than the national average of China. However, it remained substantially lower than the material intensities observed in highly industrialized regions like Europe and Finland. Consequently, this comparison demonstrated that the

material footprint of the surveyed households aligns logically with the typical resource consumption patterns of a rapidly urbanizing region.

4 Conclusion

In conclusion, this study successfully applied the MIPS method to quantify the material and energy flows resulting from student household consumption in the extended Ho Chi Minh City area. Our findings revealed a total material footprint of 17,486 kg/person/year, which was predominantly driven by transport and travel (7,410 kg) and food consumption (7,201 kg), collectively accounting for over 83% of the total intensity. While this footprint exceeded the theoretical sustainable target, international benchmarking confirms it was entirely characteristic of a rapidly urbanizing environment. Importantly, this

successful preliminary application demonstrated the feasibility and value of the MIPS framework for Viet Nam and other developing nations. It offered a practical and reliable approach to assessing urban metabolism even in contexts where comprehensive data on material and energy flows are severely scarce. This assessment also helped to identify the intensity of resource use as well as highlight aspects and behaviors that can be changed towards more sustainable consumption.

Despite these promising insights, a primary limitation of this study is its exclusive focus on university student households, whose specific consumption

patterns may not fully represent the general urban population. Also, our model does not capture the socio-economic status of household cohorts in the study. Therefore, future research may expand the target demographic to include diverse family structures and income levels. A broader demographic will provide a more comprehensive understanding of the city's overall metabolism to better inform sustainable consumption policies.

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Nghiên cứu quy mô nhỏ về chuyển hóa đô thị cho các nước đang phát triển: từ lý thuyết đến thực tiễn

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Tóm tắt Nghiên cứu về chuyển hóa đô thị (Urban metabolism) ở các nước đang phát triển thường gặp nhiều thách thức với nguyên nhân chính là thiếu dữ liệu. Nghiên cứu này nhằm mục đích áp dụng thực tiễn một phương pháp phù hợp để tính toán dòng vật chất và năng lượng từ tiêu dùng hộ gia đình tại khu vực Thành phố Hồ Chí Minh mở rộng. Sau khi lược khảo tài liệu về các nghiên cứu chuyển hóa đô thị quy mô nhỏ, phương pháp Đầu vào vật chất trên mỗi dịch vụ (MIPS) đã được lựa chọn để tiến hành tính toán tiêu dùng hộ gia đình. Các khía cạnh tiêu dùng bao gồm điện, nước, thực phẩm, mua sắm, giải trí, giao thông và đi lại. Chúng tôi kết hợp phỏng vấn trực tiếp với các hộ gia đình và khảo sát trực tuyến ngẫu nhiên với các đối tượng nghiên cứu. Tổng cộng 293 phản hồi đã được thu thập trong khoảng thời gian từ tháng 4 đến tháng 8 năm 2025. Kết quả MIPS tổng thể cho thấy mức tiêu thụ tài nguyên hộ gia đình trong khu vực nghiên cứu cao hơn đáng kể so với ngưỡng bền vững quốc tế đã được thiết lập. Việc sử dụng phương pháp MIPS đã giúp định lượng dòng vật chất và năng lượng trong tiêu dùng hộ gia đình, từ đó xác định được các khía cạnh và hành vi cần cải thiện theo hướng tiêu dùng bền vững hơn.

Từ khóa MIPS; cường độ vật chất; cường độ năng lượng; tiêu dùng hộ gia đình; khu vực đô thị.