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Ecological Footprint and Water Footprint of Taipei

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Abstract: Taiwan suffers from many natural disasters and is vulnerable to climate change. A continuous increase in its ecological footprint (EF) would pose numerous threats to the city. Taipei is Taiwan's most densely populated city. Whether its citizens are consuming more resources because of their high income and high degree of urbanization, thereby burdening the environment, warrants study. In contrast to most top-down EF analyses, in this study, 445 residents were surveyed to calculate their carbon, built-up land and water footprints. Gender, occupation, age, education level and personal annual income do not influence water footprint or EF. Moreover, an individual's water footprint is not correlated with his or her EF. The built-up land footprint that is obtained in this bottom-up study is similar to that in Taiwan's top-down national footprint account. However, the personal carbon footprint found herein is smaller than that in the national footprint account, because this study asked respondents only about consumption related to everyday activities. Since Taipei residents have a high income and high daily consumption, the water footprint herein is larger than the top-down water footprint. This bottom-up EF analysis reflects residents' daily consumption patterns and can be used in future urban decision-making.

Keywords: ecological footprint; carbon footprint; built-up land footprint; water footprint; Taipei

1. Introduction

For decades, environmental pressures that are imposed by human activities have caused major changes to the planet, putting global warming and climate change at the heart of the global environmental debate [1]. One of the main causes of these environmental problems is the greenhouse effect, which is believed by scientists to be dominated by carbon dioxide (CO_2) emissions. The increase in greenhouse gases in the atmosphere is caused mostly by economic growth and the burning of fossil fuels such as coal, oil and natural gas [2].

Major shifts in the planet that are caused by environmental pressures, including climate change, can cause disaster if not properly addressed. Such disasters (such as drought, (excess inland water, wind erosion and others) can cause further environmental, social and economic sustainability issues [3]. To measure sustainability accurately, relevant and reliable data are required. Therefore, numerous indices have been developed to advance policies and to evaluate the sustainability [4–6]. Restated, tools are required to quantify systematically the effect of human activities on the environment. Even though no single index can alone capture complex concepts such as sustainability [7,8], it can feasibly be used to quantify and monitor various aspects of sustainability (such as environmental orientation). Therefore, a systematic method is required to analyze consistently multiple pressures on the environment that are generated by human beings [9–11].

Most of the relevant environmental economics literature takes carbon dioxide emissions as a proxy for environmental degradation because of the ease with which large samples of data can be obtained and the importance of these emissions to the greenhouse effect. However, in addressing environmental degradation, considering only a single indicator (or type of pollution) is unreasonable. Therefore, the ecological footprint (EF) was proposed [12] to capture the degradation of various stocks, such as soil, forests, mining and oil [13]. Although it has some weaknesses [14,15], the ecological footprint account (EFA) is regarded as a first approximation to the overall pressure on the earth's ecosystem that is imposed by human activities [9].

Taiwan, an island state, has been suffering from earthquakes, typhoons and various disasters that have geographical, geological and climatic causes. Areas that are prone to such disasters, which include debris flow and flooding, are spread throughout the island, making Taiwan highly vulnerable to climate change. Exacerbated by a continued increase in EF (increased pressure on the ecosystem), such disasters pose numerous threats.

Taipei, the capital of Taiwan, is located in the Taipei Basin, and is particularly vulnerable to climate change. With a population of almost 2.7 million, Taipei has the largest population density of any city in Taiwan. Hence, whether associations exist between the EFs of Taipei and environmental vulnerabilities is an important topic in relation to the urbanization of Taiwan, an island state, and elsewhere. Using a bottom-up method, this study asked respondents about their daily footprints of carbon emissions (carbon footprint), built-up lands (built-up land footprint) and water consumption (water footprint).

This study further analyzes whether any variation exists among the EFs of districts in Taipei to identify correlations between environmental characteristics and ecological loads. The implications of the analytical results for environmental education and urban governance in Taipei are elucidated. Specific policies for managing key aspects of consumption in the districts of Taipei and targeting important United Nations Sustainable Development Goals (SDGs) are discussed.

2. Ecological Footprint

William Rees and Mathis Wackernagel co-developed the concept of the EF in 1996 [12]. Although it has been criticized as being insufficiently precise, the EF has for decades been one of the most commonly used sustainability indices [16]. The ecological footprint is an interesting measure of consumption as it effectively converts the consumption of all biological resources—from food, beef cattle and fish to peat and wood—into a measure of the amount of land and water that is required to support this consumption and the disposal of its related waste [17].

The Global Footprint Network (GFN) defines the EF as the amount of biologically productive lands and water that are required to produce all of the resources that an individual, population or activity consumes and to absorb all of the waste that they generate, given current technologies and resource management. The six components of EFs are cropland, grazing land, fishing ground, forest land, land for fixing carbon and built-up land. Since the EF involves various resource stocks, policies that are implied by its use may be more effective than those supported by consideration of a single ecological indicator [18].

The EFA sums the demand for ecological services for people in terms of bioproductive land, allowing it to be compared with the amount of bioproductive land (biocapacity) that is available for providing these services [4,14]. Bioproductive lands provide such services as resource regeneration, carbon sequestration or urban infrastructure, and consumption to meet human needs may be associated with a single activity, individuals, a city, a nation or a population. The main value of this metric is that it supports an understanding of local resource needs and of the relationship between resources and global sustainability challenges [4,9,19].

To monitor environmental pressures, many countries have begun to investigate the land, water and other goods and services that are required to meet the human demand for water, energy, food, shelter and transportation [20–22]. Most of these flows are related to basic infrastructure and are critical to economic productivity, and so are associated with a footprint of basic infrastructure [20]. However, researchers are increasingly concerned with a consumption-based footprint, which does not allocate the greenhouse gas emissions by residential and commercial sectors to producers, rather, they are allocated to the end consumer.

For example, the ISO 14,060 series provide clarity and reliability for quantifying, monitoring, reporting and verifying greenhouse gas emissions and removal. Through a low-carbon economy, the

ISO 14060 series support sustainable development, thus helping organizations, project sponsors and stakeholders to benefit [23].

To ensure reliability in the assessment and reporting of water footprints, water footprint assessments based on the International Standard are based on life cycle assessments (in accordance with ISO 14044) and include geographical and temporal dimensions. Water footprints at different life cycle stages can be added to represent the size of the water footprint and identify potential water-related environmental impacts [24].

The EFA is obtained using two main approaches—top-down (composite) and bottom-up (component) [10,25,26]. The top-down method uses national data (including production, import and export data) to calculate a national footprint, which is then, through the multi-regional input-output (MRIO) table in the national currency [27] or actual material and energy flows, broken down using various consumption categories, and divided among various cities using household expenditure survey data. This method compares the EFs of cities in various countries, but is only used to assess consumption levels of cities. A top-down method supports a more consistent comparison of urban and national footprints, and does not suffer from the time and cost limitations of extensive local data compilation and/or lifecycle analyses [10].

The bottom-up method, which does not calculate a national footprint, uses urban data (local currency input–output tables or physical flows of goods and energies) to calculate the EFs and it commonly requires extensive data collection [10,21]. The bottom-up method has been used in cities such as Cardiff, Kawasaki, Shenyang, Vancouver and York [9] and the metropolitan areas of 15 Canadian cities [28].

The EFA aggregates all human activities that require bioproductive land and therefore cannot be used to reflect how society develops [29]. Defining the EF as a system for accounting, rather than a normative indicator of progress, makes it applicable to a wide range of contexts, which are essential elements of sustainability assessment frameworks, allowing it to be applied to a wide range of sectoral and socio-political entities, which all have their own cultures and sustainability solutions [4].

Bioproductive lands vary in their capacity to produce biological flows (biological resources and services that are used by humans). Therefore, in the EFA, their areas are scaled in proportion to their bioproductivity. Accordingly, the unit of measurement of the EFA (global hectare, gha) is the ratio of the rate of bioregeneration to the world's mean bioproductivity [30]. The EFA tracks the supply (biocapacity) and demand (ecological footprint) of renewable resources and ecosystem services. Using global hectares to express ecological flows supports a direct comparison of EFs and the quantification of human demand for the biosphere [4].

Researchers can calculate EFs using questionnaires. For example, the mean EF of residents in Steward Community Woodland in Devon, England, was 2.06 gha per person, which is 39% of the UK's per capita EF. The corresponding carbon footprint was 3.75 tons, or 34% of the UK average of 10.92 tons. Interactions among residents' transportation, land-use practices, community activities, and moderately low-impact homes significantly reduced their footprint [31].

Burman et al. reviewed the literature on carbon footprints, water footprints and life-cycle analyses in Portugal, and thus identified six carbon footprint studies and seven water footprint investigations. However, all of those studies were concerned with industry [32]. The highest-consumption countries unsurprisingly have the highest EFs, and despite recent economic crises, the United States is one of the global leaders in both mean and absolute consumption [17].

The first study to estimate EFs in Taiwan was performed in 1997. Since that study did not include "equivalence factors", the EF values differed from their current values. Wang et al. examined Taiwan's EF from 1994 to 2007, and found that in 2007, the mean EF per person in Taiwan was 6.54 gha, and the total EF was equivalent to an area of 42 times the area of the country [33].

Lee [34] calculated Taiwan's EF accounts using data in a 2000–2011 study that was published by the GFN. A comparison between the EF trends of Taiwan and those of neighboring Asian countries revealed that Taiwan's EFs were increasing steadily in 2014 [34]. In 2014, Taiwan's total population was

23.43 million people and its per capita EF was 9.00 gha; its total EF was 210.87 million hectares, which is 58 times the area of Taiwan. Restated, 58 times the land area of Taiwan was required to provide all of the resources required by the Taiwanese in 2014, revealing that the country's consumption and production far exceeded its land load.

Chung-Hua Institution for Economic Research (CIER) [35] downscaled the EF account to Taiwan's counties and cities. The expenditure ratios of sub-items in Taiwan's household income and expenditure table was multiplied by the national EF to calculate EFs for each county and city. This method was similar to that of Isman et al. [34]. The results thus obtained reveal that EF is proportional to household income, and that per capita EF is also higher in counties and cities with a higher average income per household (such as Taipei). Most studies of city EFs calculate the EF from the top down and most consider large cities in metropolitan regions [13]. This study, in contrast, aims to measure personal EFs using a bottom-up method with a stratified random sampling questionnaire in 12 districts in Taipei, Taiwan.

3. Research Design

3.1. Research Method

The personal footprint accounts in this consist of three items—a carbon footprint, a built-up land footprint and a water footprint. The personal EFA herein is the sum of the carbon footprint and the footprint of the built-up land, and it differs from the personal EFA that is obtained using national statistical data (and includes a cropland footprint, a grazing footprint, a forest footprint, a fishing ground footprint, a carbon footprint and a built-up land footprint).

The questionnaire in this study was focused on the respondents' daily consumption of food, clothing, accommodation and transportation (please refer to the Supplementary Materials). For example, the water footprint calculator (How Large is Your Water Footprint?) in Taiwan's Environmental Quality Culture and Education Foundation's guidelines was used and the respondents' daily consumption was determined using four classes (food, clothing, accommodation and transportation).

Respondents were asked to provide information about "food" consumption (daily food intake, daily beverage intake, number of days on which they cook at home, washing methods and so on), "clothing" consumption (number of times laundry is done weekly, type of washing machine, number of baths had weekly), "accommodation" consumption (type of water tap, number of daily showers, how many times baths are taken weekly, type of toilet) and "transportation" (means of washing car, number of times monthly their motorcycle is steam-washed).

With respect to "food", the investigator asked respondents to specify their diets for the previous week. Respondents who could remember in detail their food consumption during the preceding week were asked to answer each question in the questionnaire. Respondents who could not remember their diet in detail were asked to provide their average weekly or daily intake of each type of food. Daily intakes were subsequently multiplied by seven to obtain a weekly intake. (Please refer to the supplementary questionnaire for the detailed questions and answers.)

The questions on individual carbon footprint in the questionnaire were based on the "Carbon Reduction Behavior Calculator" of Taiwan's Environmental Protection Administration (EPA). The built-up land footprint was calculated using the floor area of the building in which the person lives.

3.2. Sampling Methods

A stratified random sampling method was used and a sampling formula [36] was applied to determine the size of the sample. The questionnaire survey was distributed in 12 districts of Taipei. Two investigators were recruited to conduct personal EF surveys for almost five months from December 2016 to April 2017. To obtain valid and accurate survey results, investigators had to participate in training courses during which the topics and purpose of the study were explained to them. A total of 445 valid samples were collected.

Two investigators were hired to conduct face-to-face household surveys in 12 districts, based on stratified random sampling. The investigators gave each interviewee a US$5 gift. When the interviewees were not at home at the time of the first survey, the investigators left their contact information, including a telephone number, a letter explaining the reasons for the survey and scheduling a subsequent visit. When a face-to-face household survey was conducted, the investigator explained the content of the questionnaire and helped the interviewee to answer his/her questions. All of the respondents in the original sample list responded to the face-to-face questionnaires, except for 55 who could not be contacted after three attempts.

4. Results

4.1. Descriptive Statistic

The sample included females (57.95%) and males (42.05%) and so differed slightly from the overall population, which comprised 52.88% females and 47.12% males in 2017. The largest fraction of respondents by occupation, 21.41%, worked in the service sector; the second largest fraction, 19.82%, worked in the business sector. The largest group by age was 21–30 years (35.23%), followed by those aged 51 years old and above (22.50%) and those aged 31–40 years (20.68%). The most common educational level was tertiary education (58.18%), followed by post-graduate (19.55%). The largest group by annual personal income (24.49%) had an income of NTD350,000–499,999. The household sizes followed the order three (25.23%), four (23.41%), two (19.77%) and one (17.05%).

4.2. EF for Districts

4.2.1. Carbon Footprint

The questionnaire covered individual daily consumption (food, drink, clothing, housing, transportation, leisure and other consumables). Using the Carbon Reduction Behavior Calculator of Taiwan's EPA, the mean individual carbon emissions for each district were obtained (Table 1). Xinyi District had the highest personal carbon emissions (129.00 kg) while Songshan had the lowest (93.58 kg).

Table 1. Personal carbon emissions in 12 districts.

Ranking	District	Mean Personal Carbon Emissions (kg)
1	Xinyi	129.00
2	Wanhua	126.02
3	Beitou	125.29
4	Nangang	115.97
5	Shilin	114.10
6	Neihu	110.73
7	Da'an	110.01
8	Wenshan	101.47
9	Zhongshan	99.16
10	Datong	95.98
11	Zhongzheng	94.62
12	Songshan	93.58
Average		109.66

According to the GFN [37], the equivalence factor for CO_2 absorption is 1.26. In calculating how much CO_2 is absorbed by the land, CO_2 emissions that are absorbed by the oceans (a quarter) must be considered [38]. The carbon absorption rate of the land is 1.8 tons per hectare [12]. Using Equation (1), carbon emissions were converted into a carbon footprint, as shown in Table 2. Xinyi District had the largest personal carbon footprint (0.0677 gha) and Songshan District had the smallest (0.0491 gha).

Table 2. Personal carbon footprint in 12 districts.

Ranking	Districts	Mean Personal Carbon Footprint (gha)
1	Xinyi	0.0677
2	Wanhua	0.0662
3	Beitou	0.0658
4	Nangang	0.0609
5	Shilin	0.0599
6	Neihu	0.0581
7	Da'an	0.0578
8	Wenshan	0.0533
9	Zhongshan	0.0521
10	Datong	0.0504
11	Zhongzheng	0.0497
12	Songshan	0.0491
Average		0.0576

$$\text{Carbon footprint (gha)} = CO_2 \text{ emissions (kg)}/1000 \times (1\text{-}1/4)/1.8 \text{ (ton/hectare)} \times 1.26 \text{ (equivalence factor)} \quad (1)$$

4.2.2. Built-Up Land Footprint

Equation (2) was used to obtain the personal built-up land footprint (hectare) and then Equation (3) (which includes the equivalence factor) was used to obtain the modified built-up land footprint (gha). According to Table 3, Shilin District had the largest built-up land footprint (0.0105 gha) and Nangang District had the smallest (0.0074 gha).

Table 3. Personal built-up land footprint in 12 districts.

Ranking	Districts	Mean Personal Built-up Land Footprint (gha)
1	Shilin	0.0105
2	Zhongshan	0.0103
3	Wanhua	0.0097
4	Xinyi	0.0094
5	Da'an	0.0094
6	Wenshan	0.0092
7	Beitou	0.0090
8	Datong	0.0089
9	Zhongzheng	0.0088
10	Neihu	0.0084
11	Songshan	0.0082
12	Nangang	0.0074
Average		0.0091

$$\text{Built-up area (hectare)/number of residents} = \text{personal built-up land area (hectare)} \quad (2)$$

$$\text{Personal built-up land footprint (gha)} = \text{personal built-up land area (hectare)} \times 2.51 \text{ (equivalence factor)} \quad (3)$$

4.2.3. Personal EF

Using Equation (4), the mean personal carbon footprint was added to the mean personal built-up land footprint to yield the mean personal EF in each district (Table 4). Xinyi District had the highest personal EF (0.0771 gha) while Songshan had the lowest (0.0573 gha).

Table 4. Personal ecological footprint (EF) in 12 districts.

Ranking	Districts	Mean Personal EF (gha)
1	Xinyi	0.0771
2	Wanhua	0.0759
3	Beitou	0.0747
4	Shilin	0.0704
5	Nangang	0.0683
6	Da'an	0.0671
7	Neihu	0.0665
8	Wenshan	0.0624
9	Zhongshan	0.0624
10	Datong	0.0593
11	Zhongzheng	0.0585
12	Songshan	0.0573
Average		0.0667

$$\text{Mean personal EF} = \text{mean personal carbon footprint} + \text{average personal built-up land footprint} \quad (4)$$

4.2.4. Water Footprint

The respondents were asked about their daily water use, which was classified as domestic water use (direct water use) or virtual water use (indirect water use). Domestic water use (direct water use) is the use of water in everyday life, including for bathing, cooking, car washing, vegetable washing and other tasks. Virtual water use (indirect water use) is the use of water that is consumed in the production of goods, including for growing rice and manufacturing industrial products. The Water Footprint Calculator is used to convert these values into water footprints.

Wenshan had the largest mean personal monthly direct water use (24,540.26 L) and Zhongshan had the smallest (14,042.21 L) (Table 5). Songshan had the largest mean personal monthly virtual water use (indirect water use) (66,590.97 L) and Zhongshan had the smallest (75,573.42 L) (Table 6).

Table 5. Personal monthly direct water use in 12 districts.

Ranking	Districts	Mean Personal Monthly Direct Water Use (Liters/Month)
1	Wenshan	24540.26
2	Da'an	22337.90
3	Songshan	21866.25
4	Wanhua	21403.59
5	Xinyi	21147.68
6	Nangang	20771.20
7	Beitou	19781.42
8	Zhongzheng	17449.81
9	Neihu	17267.65
10	Datong	15380.23
11	Shilin	14753.77
12	Zhongshan	14042.21
Average		19228.50

Table 6. Personal monthly indirect water use in 12 districts.

Ranking	Districts	Mean Personal Monthly Virtual Water Use (Liters/Month)
1	Songshan	66590.97
2	Nangang	122855.2
3	Wanhua	120916.9
4	Neihu	114968.8
5	Beitou	102317.7
6	Shilin	102157.5
7	Xinyi	97366.37
8	Zhongzheng	88075.7
9	Datong	83574.68
10	Wenshan	82465.46
11	Da'an	79956.85
12	Zhongshan	75573.42
Average		94734.95

Adding direct water footprints to indirect water footprints yields the total water footprint for a district. Songshan had the largest total personal monthly water footprint (24,540.26 L) and Beitou had the smallest (14,042.21 L) (Table 7).

Table 7. Total personal monthly water footprint in 12 districts.

Ranking	Districts	Total Personal Monthly Water Footprint (Liters/Month)
1	Nangang	143626.4
2	Wanhua	142320.5
3	Neihu	132236.4
4	Beitou	122099.1
5	Xinyi	118514.1
6	Shilin	116911.3
7	Wenshan	107005.7
8	Zhongzheng	105525.5
9	Da'an	102294.8
10	Datong	98954.91
11	Zhongshan	89615.63
12	Songshan	88457.22
Average		20830.87

Equation (5) yielded the personal daily water footprint. Songshan had the highest daily water footprint (6271.66 L) and Zhongshan had the lowest (2986.16 L) (Table 8).

Table 8. Personal daily water footprint in 12 districts.

Ranking	Districts	Mean Personal Daily Water Footprint (Liters/Day)
1	Nangang	4787.55
2	Wanhua	4744.02
3	Neihu	4407.88
4	Beitou	4069.97
5	Xinyi	3950.47
6	Shilin	3897.04
7	Wenshan	3566.86
8	Zhongzheng	3517.52
9	Da'an	3409.83
10	Datong	3298.50
11	Zhongshan	2987.19
12	Songshan	2948.57
Average		3798.782

Total personal monthly water footprint (liters/month)/30 = personal daily water footprint (liters/day) (5)

Xinyi District had the highest personal carbon emission (129 kg) and Songshan District had the smallest (93.58 kg). Converting carbon emissions into personal carbon footprints revealed that Xinyi had the largest personal carbon footprint (0.0677 gha) and Songshan had the smallest (0.0491 gha). Shilin had the largest personal built-up land footprint (0.0105 gha). The carbon footprint was added to the built-up land footprint to obtain the EF. Xinyi had the largest personal EF (0.0771 gha) and Songshan had the smallest (0.0573 gha). The mean personal daily water footprint in Taipei was 3,798.782 L. Nangang had the highest water footprint (4,787.55 L) and Songshan had the lowest (2948.57 L) (Table 9).

Table 9. Carbon footprint, built-up land footprint, EF and water footprint in Taipei.

	Carbon Footprint (gha)	Built-up Land Footprint (gha)	EF (gha)	Water Footprint (Liters)
Average	0.0576	0.0091	0.0667	3,798.782
Highest District	Xinyi (0.0677)	Shilin (0.0105)	Xinyi (0.0771)	Nangang (4,787.55)
Smallest District	Songshan (0.0491)	Nangang (0.0074)	Songshan (0.0573)	Songshan (2,948.57)

4.3. ANOVA of Carbon Footprint, Built-Up Land Footprint and Water Footprint

4.3.1. One-Way ANOVA of Carbon Footprint and EF

One-way ANOVA was applied to the environmental footprints (water footprint, carbon footprint, built-up land footprint and EF) of the 12 districts. The null hypothesis is that these footprints do not vary among the 12 districts. The results reveal that the variations of the carbon footprint and EF among districts were significant ($p < 0.05$) at the levels of $p = 0.031$, so the null hypothesis was rejected. Restated, the personal carbon footprint and EF vary among districts (Table 10) so a post hoc test was performed. However, the water footprint and the built-up land footprint do not vary significantly, so no corresponding post hoc test was performed.

Table 10. One-way ANOVA of carbon footprint and EF.

	ANOVA		HOV Test	Robust Test (Brown-Forsythe)	Games-Howell Test
	F	*p*	Significance		
Water footprint (liters/person)	0.965	0.477			
Carbon footprint (gha/person)	1.955	0.031 *	0.000	0.031	No significance
Built-up land footprint (gha/person)	0.925	0.515			
EF (gha/person)	1.955	0.031 *	0.000	0.031	No significance

* $p < 0.05$.

The homogeneity of variance (HOV) test yields significant results (0.001) so the districts exhibit no homogeneity. Therefore, only the Games-Howell test was conducted.

The Game-Howell's post hoc test revealed that the personal daily carbon footprint and the personal daily EF did not vary significantly among districts. Therefore, although variations existed among the districts with respect to personal daily carbon footprint and personal daily EF, these two variables were not significantly related, so the personal daily carbon footprint of Taipei residents was not correlated with the daily EF.

4.3.2. One-Way ANOVA of Socio-Economic Background, Water Footprint and EF

Gender

One-way ANOVA of the water footprint, EF and gender reveals that the relationships between gender and personal water footprint, personal carbon footprint, personal built-up land footprint and personal EF were not significant, so in Taipei, gender does not affect water footprint and EF (Table 11).

Table 11. One-way ANOVA of gender, water footprint and EF.

Gender	ANOVA	
	F	p
Water footprint (liter/person)	1.234	0.267
Carbon footprint (gha/person)	1.919	0.167
Built-up land footprint (gha/person)	1.172	0.280
EF (gha/person)	1.919	0.167

Occupation

One-way ANOVA of water footprint, EF and occupation reveal that the relationship between occupation and personal water footprint, and that between personal carbon footprint and personal EF were not significant, so no post hoc test was required. For the personal built-up land footprint, a significant relationship was identified ($p < 0.05$). The Scheffe post hoc tests revealed no significant variation among occupational groups. Therefore, the relationships between the various occupations and personal carbon footprint or EF (Table 12) did not have to be compared with each other.

Table 12. One-way ANOVA of occupation, water footprint and EF.

Occupation	ANOVA		HOV Test	Scheffe Post Hoc Tests
	F	p	Significance	
Water footprint (liter/person)	0.479	0.889		
Carbon footprint (gha/person)	1.154	0.323		
Built-up land footprint (gha/person)	2.231	0.019*	0.101	No difference among groups
EF (gha/person)	1.154	0.323		

* $p < 0.05$.

Age

One-way ANOVA of water footprint, EF and age revealed that the relationships between age and water footprint, carbon footprint, and EF were not significant, so no post hoc test was conducted. The one-way ANOVA results of the built-up land footprint yielded a significant relationship with age, at $p = 0.029$, so the null hypothesis was rejected and age affects an individual's built-up land footprint. The HOV test of the built-up land footprint revealed a significant variation with age; therefore, the Games-Howell test was conducted. No significant differences among age groups were found. Therefore, the relationships of age with water footprint and EF did not have to be compared with each other (Table 13).

Table 13. One-way ANOVA of age, water footprint and EF.

Age	ANOVA		HOV Test	Robust Test (Brown-Forsythe)	Games-Howell Test
	F	Significance	Significance		
Water footprint (liter/person)	0.544	0.703			
Carbon footprint (gha/person)	1.103	0.355			
Built-up land footprint (gha/person)	2.725	0.029 *	0.000	0.012	No significance
EF (gha/person)	1.103	0.355			

* $p < 0.05$.

Education

One-way ANOVA of education, water footprint and EF revealed that educational level did not significantly influence personal water footprint, carbon footprint, built-up land footprint or EF. Therefore, no post hoc test was performed. Restated, the level of education of Taipei residents does not affect their water footprint or EF (Table 14).

Table 14. One-way ANOVA of education, water footprint and EF.

Education	ANOVA	
	F	*p*
Water footprint (liter/person)	1.026	0.381
Carbon footprint (gha/person)	2.254	0.081
Built-up land footprint (gha/person)	2.210	0.086
EF (gha/person)	2.254	0.081

Annual Income

One-way ANOVA of personal annual income, water footprint and EF revealed that personal annual income did not significantly affect personal water footprint, carbon footprint, built-up land footprint or EF, so no post hoc test was conducted. Annual income did not affect the water footprint or EF (Table 15).

Table 15. One-way ANOVA of annual income, water footprint and EF.

Annual Income	ANOVA	
	F	*p*
Personal water footprint (liter/person)	0.663	0.680
Personal carbon footprint (gha/person)	1.261	0.274
Personal built-up land footprint (gha/person)	0.907	0.490
Personal ecological footprint (gha/person)	1.261	0.274

In Taipei, socio-economic background (gender, occupation, age, educational level and personal annual income) did not affect the water footprint or EF.

4.4. ANOVA of Water Footprint and Ecological Footprint

One-way ANOVA of personal water footprint and personal EF revealed that the correlation coefficient between the personal water footprint and the personal EF was 0.086 ($p > 0.01$), so these two variables were not correlated (Table 16).

Table 16. ANOVA of personal water footprint and EF.

Water Footprint and Ecological Footprint		Personal Daily Water Footprint (Liter/Person)	Personal Daily EF (gha/Person)
Personal daily water footprint (liter/person)	Number of Pearson Significance (two-tail)	1	0.086
	Significance (two-tail)		0.069
	Number	446	446
Personal daily ecological footprint (gha/person)	Number of Pearson Significance (two-tail)	0.086	1
	Significance (two-tail)	0.069	
	Number	446	446

5. Conclusions and Suggestions

EF is typically analyzed using top-down methods. In this study, bottom-up questionnaire surveys were used to evaluate the footprints of residents of various districts of Taipei.

5.1. Conclusions

The EFA that was used in this study differs from most EFAs, which are obtained using a top-down approach, with six categories of bioproductive land—cropland, grazing land, fishing ground, forest land, land for fixing carbon and built-up land. Environmental footprints are summed, considering equivalence factors, [39,40] to calculate food, forest, carbon and other footprints. In this study, only the carbon footprint and built-up land footprint, which are two of the six components of the EF, are estimated.

The built-up land footprints in this study do not differ significantly from Taiwan's EFs that were considered by Lee and Peng [39]. However, the carbon footprint differs significantly from that considered by Lee and Peng. According to the IEA, Taiwan's per capita carbon emission in 2015 was 10.65 metric tons. A transformation formula was used to convert this value to 4.43 gha/person. Lee and Peng [39] followed the IEA's top-down guidelines, so their carbon footprints (carbon emissions) included carbon dioxide that was emitted in the generation of the electricity for national development and in national public works. In contrast, in this study, only personal carbon footprints, associated with personal consumption, were calculated. The individual carbon footprint in Taipei was 0.0576 gha.

One-way ANOVA was performed to determine the relationships among the footprints in the 12 districts. The results revealed significant variations of the carbon footprint and the EF among the districts of Taipei. In contrast, the Game-Howell's post hoc test revealed that the variations of the water footprint and the built-up land footprint were insignificant. The relationship between individual carbon footprint and EF was not significant.

Gender, occupation, age, educational level and personal annual income were unrelated to water footprint and EF. One-way ANOVA revealed no correlation between the water footprint and the EF. The absence of a significant relationship between urbanization and EF was indirectly verified. Urbanization is a long-term process and its damage to the environment is difficult to measure in the short term [41].

5.2. Suggestions

In this study, 445 valid questionnaires were collected following stratified random sampling to estimate the EF of residents in the 12 districts of Taipei. Most of the surveys were conducted during the day, so heads of households, retirees and seniors were more likely to be surveyed than lower-age and working-class residents. Although relatively few young respondents were sampled the proportions of other classes of respondents were broadly representative of the residents of Taipei. The unrepresentative age distribution of the respondents could be overcome in the future by distributing the questionnaires on both weekday mornings and holiday mornings.

To ensure that an excessive burden was not imposed on the respondents, the questionnaire asked respondents to provide their consumption for the preceding day or week. Some respondents could not easily and clearly remember the sought consumption data. Case studies or in-depth interviews could be conducted in the future to obtain thorough and accurate consumption data for EF accounts.

The results in this study reveal that Taipei has a per capita built-up land footprint of 0.0091 gha, which is close to the average values obtained by a top-down calculation for Taipei (0.01 gha) [35], and is close to the built-up land footprint of six cities in Portugal (0.02 gha) [10]. This result shows that the bottom-up method in this study supports, and is supported by, the top-down national EF account. This favorable finding may arise from the fact that the question items concerning built-up land involve the respondents' dwelling space, and the relevant data are easy to obtain. This finding suggests that the built-up land footprints in various countries or cities can be calculated using either a top-down approach or a bottom-up approach and that the results obtained in either case reasonably reflect the built-up land areas of the respondents.

The difference between this study and that of Lee [34] is that the carbon footprint herein is small because industrial and commercial services and industrial development are not considered. A policy that is based on carbon footprints must consider industrial and commercial services and the industrial footprint. The water footprint in this study is relatively large. Taipei is the capital city of Taiwan and has a high level of consumption, yielding a high water footprint. Additionally, a high level of water consumption may have been obtained because of the use of interval scale of answers in the questionnaire rather than actual water consumption. In the future, residents' water bills could be used to calculate their water footprints.

The case study in Taipei indirectly revealed the absence of a significant relationship between urbanization and EFs, but only carbon footprint, built-up footprint and water footprint were considered. If more EF categories had been calculated, then the determination of any relationship would have been more accurate. Other cities and countries should be studied to determine whether any statistical correlation exists between urbanization and EF.

The results herein indicate that although the residents of the various districts of Taipei have different EFs, no statistical correlation exists between the district or social background of a respondent and his or her EF or water footprint. Appropriate environmental education programs can be designed to encourage residents to achieve environmental education objectives (awareness, knowledge, attitudes, skills and actions) and modify their daily consumption patterns to reduce their EFs.

This study concerned only the carbon footprint, the built-up land footprint and the water footprint. To compare more comprehensively personal footprints with the six components of the EF, follow-up studies should address cropland, grazing land, forests and fishing grounds using a bottom-up questionnaire survey. This study involved only surveys of the EFs of residents of the 12 districts in Taipei. Future studies could make cross-boundary comparisons (cities vs. towns, towns vs. rural areas and so on).

Since the EF is a nonstationary series, policies such as imposing a carbon tax, subsidizing clean energy and imposing appropriate land-use controls have a permanent effect on the EF [42]. Government departments should, therefore, review amendments to existing statutory regulations, and the competent authorities should implement regulations to protect environmental health to reduce the EF in its jurisdiction [41]. Government departments must also effectively plan land uses and improve the ecological intelligence of communities to reduce their EFs.

As the world moves toward a sustainable, resilient and carbon-free future, cities have been identified as the heart of evolutionary change. They are the best places to rapidly develop more efficient systems, and to implement policies that mitigate climate change. In this context, future works should encourage the use of the EF in cities to meet climate change mitigation goals [10]. This study focuses only on the carbon footprint, built-up land footprint and water footprint, and further compares the size of EFs in various districts of Taipei. A better understanding of urban planning and urban governance and the promotion of local consumption will improve carbon mitigation and the long-term sustainability of Taipei and other cities.

This study provides the EFs of various types for use by urban managers and analyzes the pressures that are imposed by urban residents on their urban environments. In September 2019, Taipei became the tenth city in the world to submit a Voluntary Local Review (VLR) to the Institute for Global Environmental Strategies (IGES) (https://iges.or.jp/en/projects/vlr (accessed on 2019/10/12)). However, the VLR cannot clearly identify the trade-offs that Taipei residents make in pursuit of various urban activities. The EF provides information about the trade-offs made by citizens and city decision-makers with respect to numerous human activities. Future studies should examine the links between SDGs and EF and policy implications can thus be pursued.

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