Taiwan’s Ecological Footprint, 2012-2018

Yung-Jaan Lee*, Po-Shu Wu1, and Lei Chai1

1Chung-hua Institution for Economic Research, Taiwan

Abstract. The Ecological Footprint (EF) is a measurement broadly adopted by the international community to measure the progress toward sustainability. Taiwan’s EF methods refer to the annual reports of the Global Footprint Network (GFN). Therefore, the calculation method closely follows international trends and is updated accordingly. Since the first calculation of Taiwan’s EF in 1998, Taiwan’s EF has been revised several times. At present, the EF from 1994 to 2011 can be obtained. The purpose of this study is to update Taiwan’s EF from 2012 to 2018. This study divides the biologically productive lands into six categories. Since there are two different data sources for fishing grounds and carbon emissions, Taiwan’s EF can be calculated with four different results. Overall, Taiwan’s EF shows a slow downward trend from 2012 to 2018. Furthermore, Taiwan’s carbon footprint accounted for about 70% of the EF, followed by the cropland footprint, which accounted for about 20% of the EF. Compared with global trends, Taiwan’s carbon footprint is about 10% higher than the global carbon footprint, indicating that Taiwan’s carbon emissions are higher than the global average. With the global emphasis on carbon reduction, Taiwan needs to focus on improving carbon emissions.

1 Introduction

In 2020, the COVID-19 swept the world. Cities around the world, in the face of the pandemic, adopted shutdown strategies, including restrictions on going out, working from home, self-control and other outbreak control strategies. For the human society, the COVID-19 is an unprecedented disaster. However, from the perspective of nature, it is a rare respite. For example, the water quality of Venice's Grand Canal becomes clear and fish swims freely [1]. Many wild animals suddenly appeared in cities. Because of the shutdown of cities, it is not humans who walk down the street, but a variety of wild animals leaving their footprints and asking: where have humans gone?

When the COVID-19 arrived, there was a dead silence. Economic activities have slowed down as a result of human dormant. According to the latest report of the Global Footprint Network [2], as a result of the COVID-19 outbreak, the ecological footprint (EF) of human activities declined significantly in 2020, with data showing an 8.4% decline in forest footprints and a significant 14.5% decline in carbon footprints. This is the first time since the global financial crisis in 2008 that the carbon footprint has declined. Does this mean that the pandemic is the Earth's febrifuge?

Using the Ecological Footprint (EF) as a measurement, we can find that the world's greenhouse gas emissions have declined due to the pandemic. Meanwhile, slowing production of forest products due to slowing economic activities indicates that the carbon sequestration rate of forest increases. The above-mentioned EF data suggest that the pandemic helps make the environment move toward sustainability, which is a rare opportunity. Looking back at Taiwan's response to the 2020 pandemic, the performance was positive and optimistic. As a result, the measurement of Taiwan's EF becomes an important research agenda, which is the main purpose of this study.

Since Taiwan is not included in the Global Footprint Network (GFN), Taiwan's EF has long been calculated by Taiwan’s Forestry Bureau and the Chung-Hua Institution for Economic Research [3-5]. At present, Taiwan’s EF had been calculated from 1994 to 2011. After 2012, Taiwan's EF has not been studied for systematic calculation, which is the main research goal of this study. First, this study introduces the concept of EF, the trend of research on EFs abroad and the study of Taiwan’s EF in the past. Second, this study presents the results of Taiwan's EF from 2012 to 2018. This study then discusses the differences between Taiwan’s EF trends and global trends, and puts forward suggestions for Taiwan’s future research and related policy applications.

2 Literature Review

2.1 Ecological Footprint: Concept and Calculation

2.1.1 Concept of EF: measurement of sustainability

The ecological footprint is a sustainability measurement widely adopted by the international community in recent years, and its novelty lies in the transformation of sustainable development from a narrative definition to a computable indicator. The characteristics of this indicator transform complex statistical items into a clear single value - global hectares (gha) - which makes sustainability...
a comprehensive environmental measurement that can be tracked over a long period of time and can be communicated in dialogue with other indicators.

The term ecological footprint consists of "ecological" and "footprint". Ecology refers to the ecological environment with the ability to survive and maintain (i.e., biological productivity). The survival and maintenance capacity refers to the ability of ecological environment to contain assignment and self-purification. Footprints are traces left by human activities and can be referred to as a portion of the lands occupied by humans. Thus, combining these two words, the ecological footprint can be understood as the areas occupied by humans for their survival [6]. In practice, the EF is based on the "occupied areas" perspective to calculate the sum of human consumption in a particular region (usually a country). The sum is then divided by the total population and the "environmental areas occupied per capita" can be obtained - that is, the "ecological footprint".

The EF is an operational tool for measuring sustainable development. The most widely cited definition of sustainable development is the Brundtland Report's "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [7]. In order to develop sustainably, Daly [8] argued that the concept should be a transition from sustainable "growth" of quantitative expansion to sustainable "development" of qualitative improvement. Growth is a quantitative increase in scale, and development is a qualitative improvement or a release of potential.

Daly [8] suggested the need to establish an operational principle of sustainable development, which is the establishment of an "environmental carrying capacity" - "the maximum number of populations that the habitat can support without permanently detracting from the productivity of the ecosystem of a particular habitat". Furthermore, the Agenda 21, issued by the United Nations at the Earth Summit in Rio in 1992, advocated that "data-based information improves the quality of decision-making" provided a strong basis for the establishment of environmental monitoring indicators.

The EF can be regarded as a paradigm shift in the concept of "environmental carrying capacity". In the past, "environmental carrying capacity" was regarded as the feeding capacity of a piece of land (including food, water, energy, social welfare, etc.). The calculation of carrying capacity needed to consider regional characteristics and the vague definition of computation. Thus, Rees [9] responded to Daly's [8] viewpoint and proposed the ecological footprint concept.

Subsequently, Wackernagel and Rees [6] transformed the carrying capacity concept into the EF concept and proposed four types of biologically productive land, establishing the methodology of the EF as an indicator for measuring sustainable development. This set of calculations seeks to be comparable and traceable, and has the potential to correct comprehensive metrics. As data permit, the Global Footprint Network (GFN), a cross-border EF database, was established. On a two-year base, the National Footprint Account (NFA) was published, with a reference manual on trends and calculation methods for EF changes in 232 regions/countries worldwide.

2.1.2 Basic Formula for Calculating the EF

The purpose of calculating the EF is to respond to the following question: How much biosphere's regenerative capacity is needed to support human activities? More precisely, how much regenerative capacity does a particular human activity (food, forestry, etc.) require? In response to the above questions, the following assumptions are proposed for the calculation of the EF (Wackernagel and Rees, 1996):

(1). The earth's biological productivity to support the survival of all living things is limited, and human activities can be absorbed and assimilated by the regenerative capacity of the biosphere.

(2). The regenerative capacity is measured as ecological capacity. It is assumed that biological productivity is sustainable.

In practice, only the basic services of human activities need to be calculated, without double counting more than two services (the finer it is, the more natural functions it contains). A total of six biologically productive lands can be obtained (Table 1) (NFA, 2018).

Table 1. Six types of biologically productive lands.

| Cropland: | Grazing land: | Forest land: |
|-----------|--------------|-------------|
| Cereals, nuts, potatoes, etc. | Meat. | Wood. |
| Fishing ground: Aquatic. | Land for housing and facilities. | Land for converting carbon dioxide. |

Source: [10]

According to the latest reference manual published by the NFA [10], the six biologically productive lands include: cropland, grazing land, forest land, fishing ground, built-up land and carbon footprint. Each type of land is calculated based on a classified item, i.e., grazing land calculates the total consumption of meat. Therefore, this method of calculation is called the enumeration calculation.

The EF calculates the average consumption per person (Ci) for the six consumption items (i). To convert the six types of footprints into a uniform value, the per capita consumption (Ci) is divided by the average productivity (Pi) of that item (i), and the six values are added up to obtain the EF:

\[
EF \text{ (gha/per capita)} = \frac{C_i}{P_i} \tag{1}
\]

where,

- Annual consumption per capita (Ci): total regional or national consumption divided by the population for a particular item.
- Average biological productivity for a specific item (Pi): regional production divided by global average yield (i.e., conversion value).

The biologically productive lands can be simplified to global hectares (gha).
The above EF value is the most basic calculation concept. In practice, the EF should be justified through the correction of international trade and equivalent productivity, reflecting: (1) The international trades (import and export of consumer goods) are frequent and there is a need to consider the international trade correction. (2) The land productivity of different consumer goods is not the same. For example, croplands are highly intensively operated and therefore highly productive; and grazing lands are highly extensively operated and therefore less productive. Consequently, data correction through the "equivalent factor (EQF)" is required. The calculation formula for the actual consumer goods (i) is as follows.

\[
EF(i) = \frac{(Production + Imports - Exports) \times (Total population X Equivalent Factor (EQF))}{Import + Export}
\]

(2)

The above formula reflects the concept of EF, which is calculated considering: (1) the adjustment of the enumerated items, (2) the relevant parameters containing corrections to the equivalent factors, and (3) changes in the way global production is calculated. Changes in these factors are detailed in the NFA's annual report.

2.2 Previous Research on Taiwan's EF

Since the Global Footprint Network (GFN) does not include Taiwan as an area for calculating EFs, the calculation of scholars in Taiwan. The EF research is divided into two parts: First, the national EF account is carried out with a specific period of time as the target of long-term tracking. Second, relevant urban/regional development research and economic externality research use the EF as an assessment indicator of sustainable development, because of its mature, stable and traceable characteristics. Taiwan's EF accounts mainly refer to the annual reports of the Global Footprint Network (GFN) and the National Footprint Account (NFA), which detail the calculation of EF and include algorithmic changes, such as the adjustments of enumerated items and updates to balance parameters. Therefore, Taiwan's EF is calculated in keeping with international trends and updated simultaneously during major algorithmic changes. Taiwan's EF accounts are mainly conducted by Lee and his colleagues [3-5, 11]. Since the first calculation of Taiwan's EF in 1998, Taiwan's EF has been recalculated several times and the previous footprint data have been updated simultaneously. At present, there are studies covering Taiwan's EFs from 1994 to 2011. Therefore, the main purpose of this study is to update Taiwan's EF accounts from 2012 to 2018.

Taiwan's first EF account in 1998, referred to Wackernagel and Rees [6], divided the bioproductive land into six categories (cropland, grazing land, fishing ground, forest land, energy land and built-up land) and calculated that Taiwan's EF in 1996 was 4.67 hectares per person [4]. However, the EF value did not consider the equivalent factor (EQF) and would significantly underestimate the footprint.

Lee and his colleagues were commissioned by the Council of Agriculture in 2005-2006 to recalculate the EF after including equivalent factors, and to calculate the change in EFs over a 10-year period from 1994 to 2003. Their research found that the EF increased from 5.07 global hectares per person in 1994 to 5.14 global hectares per person in 2003 [3]. It can be found that after the inclusion of equivalent factors, the EF value grew from 4.67 to 5.07 global hectares/person, which accurately reflected the differences in biological productivity of different types of land. Moreover, it showed that the previous research underestimated Taiwan's EF, the difference between the two account is about 1.25 times.

As the global warming effect from increased greenhouse gas emissions threatens global sustainable development, the Global Footprint Network (GFN) and the National Footprint Account (NFA) replaced the "energy land" with the "carbon footprint" to address that the increase in carbon emissions will significantly enlarge the EF account. Lee [3] then recalculated Taiwan's EF in 2004 and found that Taiwan's EF had grown significantly from 5.14 global hectares/person to 6.72 global hectares/person (of which the carbon footprint accounted for 2.23 global hectares/person), which is equivalent to 42 Taiwans. The amount of CO2 emitted requires 14 Taiwans to absorb. The change of enumerated items allowed Taiwan's EF to grow by about 1.3 times.

The EF is an important indicator for measuring sustainable development. Its innovative enumerated calculation methods can estimate national scale footprint account and local scale footprint account. Lee [3] adopted a local-scale approach to analyze Taiwan’s EF at the county and city level. The results found that consumption patterns and regional characteristics exhibit a significant relationship with Taiwan’s EF. Through the comparison of EF, we can see that good-quality public services and effective land use are important pathway to reduce the footprint.

Wang et al. [11] referred to the research methods of Lee [6] and carried out a retrospective calculation of Taiwan's EF from 1994 to 2007. Their study results show that the EF of 2007 was 6.54 global hectares/person. The most important algorithmic changes are mainly in the built-up land and energy land. First, because hydropower data are not easy to obtain, so they are excluded from the calculation, the built-up land footprint only calculated the built-up area. The energy land was originally divided into "consumer goods" and "carbon footprint." However, because of the complexity of the item of consumer goods and calculation difficulties of data variation, the item of consumer goods was excluded from the calculation of energy lands. The energy lands only calculated the carbon footprint.

In response to the global trends in EF calculation and to continuously track changes in Taiwan's EF, Lee and Peng [5] recalculated Taiwan's EF. According to their research findings, Taiwan's EF in 2011 was 9.43 global hectares per person, of which carbon emissions amounted to 5.94 global hectares per person, accounting for more than 60%. The significant growth in footprint caused by carbon emissions is in line with global trends.
3 Results

Using the classification method of NFA [10], this study divides the EF into six categories of bioproductive lands: cropland, grazing land, fishing ground, forest land, built-up land and carbon footprint. There are two sources of data for fishing ground, with differences in production, imports and exports from different sources. In addition, the sources of carbon emissions are divided into domestic statistics and IEA statistics. Since there are two sources of fishing ground and carbon emissions, four different results can be calculated for Taiwan’s EF (Fig. 1). Although Taiwan’s EF fluctuated from 2012 to 2018, there was a slow downward trend. The four different colored lines represent the EF of the different data source combinations, with the differences caused by different sources of fishing ground data less than 0.1 gha. Conversely, different sources of carbon emissions data have a larger impact, with differences between about 0.1 gha and 0.2 gha.

In the changing trend of various footprints (Fig. 3), carbon footprint accounted for most of the proportion, followed by the cropland footprint. Taiwan's EF remained stable to a slow decline from 2012 to 2018, with no significant change in footprints during that period, with cropland footprint ranging from about 1.5 to 2.0 gha and carbon footprint falling around 4.5 gha. In terms of the proportion of footprints, the proportion of cropland footprint remained at 20%, while the carbon footprint accounted for 70% of Taiwan's EF. As for the other four footprints, their proportions were low and had no significant changes.

4 Conclusions and Suggestions

This study calculates the changes of Taiwan's EF from 2012 to 2018, and revises Taiwan's research methods according to the latest global EF research, of which the calculation of carbon footprint is the most important change.

Although Taiwan's EF fluctuated from 2012 to 2018, it showed a slow downward trend overall, indicating that the per capita consumption of resources decreased but not
significantly. In addition, Taiwan's carbon footprint accounted for about 70% of the EF, while the global carbon footprint accounted for about 60%. At present, carbon reduction is a global goal. Taiwan's carbon footprint continues to increase, and the proportion is gradually rising. In order to be in line with international standards, with the global carbon reduction as the goal, and continue to reduce Taiwan's EF, carbon footprint reduction is one of the key items in urgent need of review and improvement.

Compared with the trend of global EF, the trend of Taiwan’s EF is consistent with that of the world. Whether the trend of Taiwan’s EF is caused by population growth still needs more studies to confirm. Furthermore, influenced by domestic land use patterns and forestry policies, Taiwan's grazelands are small and the forest products are low, therefore the footprints of both items as a proportion of the EF are lower than the global average.

This study only calculates Taiwan’s EF of 2012-2018. The follow-up studies are encouraged to calculate Taiwan’s ecological benchmark to examine whether there is an ecological deficit in Taiwan. Furthermore, it is recommended to use the latest calculation methods to trace back Taiwan's EF over the years to examine whether Taiwan is moving toward or away from sustainability.

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