Global land use of diets in a small island community: a case study of Palau in the Pacific

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Abstract
Modern dietary habits in communities are linked and are part of the global food supply chain. To achieve sustainable food production and consumption, communicating the impact associated with food production and dietary choices at community level to consumers is important. However, previous footprint studies have primarily focussed on food consumption at the national level and neglected community-level consumption activities. This study surveyed the diets of a small island community and linked the results with multi-region land footprint analysis in Ollei Village, Republic of Palau. The analysis was used to determine the extent to which the dietary lifestyles of communities depend on external land use through the global supply chain. We showed that the global food supply chain has reached this corner of the world, and the dietary habits of the community are already heavily dependent on processed and imported foods. The community and country are highly dependent on large land use in some major producer/exporting countries through the global food supply chain. In addition, the amount of external land used for food production exceeds the biocapacity of the agricultural land in the community and country. This study bridges the gap between community-level consumption activities and national-scale footprint analysis, and quantitatively assesses the impact of consumption activities at the community level on the global environment. The results and approach of this study could contribute to the development and implementation of vertically integrated food policies between the national and community level in Palau.

1. Introduction
Modern dietary habits are linked and are part of the global food supply chain. This global system has contributed to improving living standards by redistributing nutrients and increasing resilience to local shocks [1, 2]. However, the increasing food production associated with the international food trade and the demand for natural resources are placing an enormous strain on the planet. The multiple steps associated with food processing and exchange within the supply chain make it difficult to understand the environmental impact of traded food [3]. Both producers and consumers are required to participate in efforts to reduce food-related environmental impact. Communicating the impact associated with food production and dietary choices to consumers could enable a higher uptake of sustainable diets [4]. The need for people to have information, and awareness regarding sustainable consumption and lifestyles has been...
articulated in Goal 12 of the Sustainable Development Goals [5].

Even in rural communities on some islands, where subsistence fishing and farming are still practiced, traditional diets are changing to import-based diets [6]. Specifically, in the Pacific Islands, dependence on imported foods from other countries is higher than in many other regions [7, 8]. The diets of these communities have shifted from diets high in locally sourced fresh fruits, vegetables and seafood to diets high in processed and imported foods [9]. As a result, the region is experiencing growing health problems and has become vulnerable to shocks and an impact on food production, distribution, and procurement that may occur as a result of climate change and other factors [10]; this is a trend that has recently been emphasized by the coronavirus (COVID-19) pandemic [11, 12]. With shifting dependence in different regions and commodities, there is little information available on the implication of this change in terms of the environmental impact of diets in small island countries and communities [13].

Previous studies on environmental footprint have highlighted differences in the environmental impact of foods and highlighted the importance of more sustainable consumption [14]. They play an important role in increasing consumer awareness of sustainable consumption activities [4, 15–18]. Recent studies evaluating carbon, energy, water and land footprints associated with diets in countries and regions, such as China [19, 20], Europe [21, 22], Australia [23] and others [24] have demonstrated that consumption patterns are associated with environmental pressures abroad through the import of various products. In particular, terrestrially sourced food products have a dominant impact on the land and water footprint [25–27]. However, previous footprint studies evaluating domestic sustainability and risks associated with land have primarily focussed on food consumption at the national level; the footprint studies that are limited to several island countries [28] have neglected community-level consumption activities. This information gap on the environmental impact of food between the national, individual or community level is a barrier to increasing the awareness of food-related risks and sustainable consumption by individuals and communities [2].

To address this gap, we estimate the global environmental footprint on community-scale food consumption; this enables linking of community-scale behavior with global environmental impact. We had initially performed a survey to explore the dietary habits of a small island community. Subsequently, we estimated the global land use related to these habits by linking the results of the survey with a multi-region footprint analysis. Finally, we compared the global land-use area with the internal biocapacity of resources available to the community to discuss the environmental impact and its scale.

2. Methods

2.1. Target area

The target community was Ollei Village in Ngarchelong State, located at the northern end of Babeldaob Island in the Republic of Palau. Palau is an island country in the western Pacific Ocean with a rich natural environment. The country comprises approximately 340 islands, including Babeldaob Island, the largest, and Koror, the economic center. The population of Palau was 17 661 in 2016 [29], and there are no major food-related industries. The GDP values for agriculture/forestry and fishing were 2.2 and 3.9 million USD in 2015, respectively, accounting for 1% and 2% of the total GDP, respectively; these activities are much smaller than the import of food/beverages, which amounted to 40.7 million USD in 2015 [29]. Ollei Village is a rural community 65 km away from Koror; it comprises 21 households and 86 residents (figure 1). Traditionally, the diets of these residents have been based on self-sufficiency and the sharing food, such as taro and fish [30]. A fishing port is located at the west end of the village and most local seafood consumed in the village arrives through this port. Several well-maintained traditional croplands, known as meseti, are located along the river and coast, where the traditional staple food (taro) is planted [30]. Three local stores sell commodities purchased from Koror.

2.2. Local survey for food ingredient consumption

We stayed in the village from 24–30 September 2015 and distributed a food frequency questionnaire (table S1 (available online at stacks.iop.org/ERL/16/065016/mmedia)) to all households. This questionnaire included the following questions: (a) ‘which meal was eaten?’; (b) ‘which ingredients were used?’; (c) ‘how and where was each ingredient obtained (purchased, locally shared or through subsistence)?’ and (d) ‘how many family members did the meal serve?’. We visited all the households, recalled the questionnaire in person daily, and asked the participants to fill out the form directly if anything was unclear. In addition, we distributed a camera to each household to record and identify all meals. This survey was conducted in accordance with the research guidelines of the Japan Sociological Society Code and the ethical policy of Nagoya University. The state governor and all subjects provided consent prior to participating in the anonymous dietary survey.

We calculated the quantity of consumed ingredients based on the average per capita consumption of ingredients in each dish, the number of dishes and family members. The types of dishes were identified from the names and photos of dishes provided in the survey. The average number of ingredients per capita in dishes was estimated by referring to typical (standardized) local recipes that were provided by
local residents. We adopted similar recipes in other Pacific Islands, Japan and the United States (USA) if the local recipe was unavailable; this was because the culinary practices in Palau were strongly affected by these recipes. For grains, such as rice and taro, we estimated the average per capita consumption of each grain based on the average caloric consumption of grain (650 kcal\(\text{capita}^{-1}\text{d}^{-1}\)) in Palau \[31\]. The condiments were not considered in the calculation because their small percentage varied among individuals and families. Imported foods were identified among purchased ingredients, based on the food production and import situation in Palau. Specifically, purchased fish, pounded taro, tapioca and certain vegetables, such as cucumbers, aubergines and spinach, were considered to have been domestically produced. Other foods, primarily consisting of grains, meat, eggs and dairy products were regarded to have been imported (see table S2 in the supplementary material). When necessary, we confirmed the production of each ingredient by consulting local residents and researchers.

2.3. Estimation for global land use

To reveal the link between local food consumption and external land use, we adopted globally normalized land-use areas, measured in global hectares (gha), as an indicator of agricultural land appropriated as a resource. The gha was used for the National Footprint Accounts \[32\] to represent the amount of land (in ha) required to produce agricultural products under the world average yield of each product. Land-use areas associated with the annual consumption of imported food in Ollei Village were determined by food category, trading partner, land user and land category. A trading partner is a country/region that directly exports primary or processed food products to Palau. By contrast, a land user represents a country/region from where agricultural land is appropriated to cultivate primary products. These are either directly exported to Palau or used as raw materials for food products (including livestock feed) that are exported to Palau in the global supply chain. A country/region that cultivates primary products and exports primary or processed food products to
Palau can be both a land user and trade partner (see figure S1 in the supplementary material for a schematic of the trading relationship among land users, trading partners, Palau and Ollei Village).

Land-use areas in land-user country/region \(i\) (gha) associated with the annual import of product \(k'\) (USD) from the country/region (trading partner) \(j\) to Palau, \(L_{ij}^\text{pl}(k')\), were determined using equation (1) where \(l\) is the land category. Global land-use areas were calculated by multiplying the import values for each food category (USD) by the land footprint intensities (gha USD\(^{-1}\)) of the trading partners. Subsequently, land-use areas (gha) associated with the annual consumption of imported foods in Ollei Village, \(L_{jl}^\text{ol}(k)\), were determined using equation (2),

\[
L_{ij}^\text{pl}(k') = \sum_{k'} Q^j_{kl}(k') \cdot \frac{1}{1 + T_j(k')} \cdot C_{k'k} \cdot M_j(k'),
\]

(1)

\[
L_{jl}^\text{ol}(k) = \sum_{k'} L_{ij}^\text{pl}(k') \cdot \frac{1}{\tilde{M}(k')} \cdot C_{k'k} \cdot X(k),
\]

(2)

where \(M_j(k')\) is the annual import value (USD) of product \(k'\) from country/region \(j\) to Palau; and \(\tilde{M}(k')\) is the annual import quantity (kg) of product \(k'\). \(X(k)\) is the annual equivalent quantity of the weekly consumption of imported food \(k\) in Ollei Village (kg). \(Q^j_{kl}(k')\) represents the land footprint intensity of land category \(l\) in the land-user country/region \(i\) (gha USD\(^{-1}\)) associated with the production in sector \(k'\) in the country/region (trading partner) \(j\). \(Q^j_{kl}(k')\) describes the linkage through trade between countries/regions \(j\) that produce (and partly export) food products and the countries/regions \(i\) where agricultural land is appropriated to produce primary products, including feed and food crops used as raw materials for food products. \(T_j(k')\) indicates the trade margin rate of imports from countries/regions \(j\). Product category \(k'\) corresponds to the four-digit harmonized commodity description and coding system (HS) code, and \(k\) denotes the land category adopted in the field survey. The land footprint intensities were linked to the four-digit HS codes using the binary variable, \(C_{k'k}\). This variable allows the conversion of the sector in the land footprint database \(k'\) into product category \(k\). Similarly, we linked each imported food to a single four-digit HS code using the binary variable, \(C_{k'k}\), which coordinates the food category \(k\) with the corresponding product category \(k'\).

In equation (1), global land-use areas were calculated by multiplying the import values for each food category (USD) by the land footprint intensities (gha USD\(^{-1}\)) of the trading partners. Equations (1) and (2) assume that the breakdown of trading partners \((j)\) of Palauan food imports in each food category \((k)\) was reflected in the imported food consumption in Ollei Village. The survey results confirm that households in Ollei Village purchased food from the economic capital, Koror, partially through local stores.

We used the annual equivalent quantity of the weekly consumption of imported foods obtained from the survey in Ollei Village \(X(k)\). For \(M_j(k')\) and \(\tilde{M}(k')\), the annual values and quantities in 2015 were obtained from the International Trade Centre (ITC) Trade Map [33]. We used land footprint intensities provided by the Eora database (as of 2012) for \(Q^j_{kl}(k')\). The largest multi-region input-output (MRIO) table in the world consists of 14 839 industrial sectors that trade within and among 190 countries/regions [34, 35]. Based on the Leontief inverse matrix calculated from the MRIO table, Lenzen et al [34, 35] analyzed the environmental emissions and resource consumption directly and indirectly induced by the production in each of the 14 839 sectors. This included agricultural land use directly and indirectly induced in the 190 countries/regions through trade, including domestic and international transactions. We cited cropland and grazing land areas (gha) appropriated in countries/regions \(i\) induced by 1 USD of production in sector \(k'\) in country/region \(j\), and used them for \(Q^j_{kl}(k')\). The food-related sectors in some Palauan trading partners in the Eora database were coarse; therefore, some of the imported foods linked to broadly classified sectors, such as ‘other food products,’ were sources of uncertainty. This database includes land footprint intensities as components of the ecological footprint of the five land categories (cropland, grazing land, fishing grounds, built-up land and forest land), according to the National Footprint Accounts [32]. This paper presents the results for agricultural land use, including cropland and grazing land, which accounts for approximately 76% and 83% of the total global land use associated with food imports to Palau and Ollei Village in 2015, respectively. Based on critical debate [36], we excluded land used for carbon dioxide (CO\(_2\)) sequestration. Examples of how global land-use areas were calculated are presented in tables S3 and S4 in the supplementary material. Trade flows between Ollei, Palau, trading partners and land users were illustrated on a world map using ArcGIS. Trade flows were also illustrated in a Sankey diagram using the web-based software, ‘Sankey diagrams from Excel’ (http://ramblings.mchper.com; currently unavailable). All calculations were conducted using Microsoft Excel.

### 2.4. Biocapacity calculation

We calculated the biocapacity of agricultural land in Ollei Village \((B^0)\) using equation (3), according to the formula for the country-level biocapacity in the National Footprint Accounts [32]. Biocapacity is a measure of the biologically productive land area available to provide ecosystem services in gha. As such, it
is comparable to land-use areas demanded for food consumption in Ollei Village and Palau.

\[ B^D = A_{WK} \cdot EQF = A_{NK} \cdot \frac{Y_{WK}}{Y_{WK}} \cdot EQF. \quad (3) \]

First, we divided the agricultural land areas in Ollei Village measured by a field survey in 2014 (taro patch, 1.16 ha; home garden, 1.73 ha; and farmland, 1.30 ha) into bio-productive areas used to produce each product \( k \), \( A_{NK} \); this was based on the current production share of Palau cropland. Then, \( A_{NK} \) was converted into the equivalent area of world-average cropland yielding each product \( k \), \( A_{WK} \), by multiplying the ratio of the yield in Micronesia \( Y_{NK} \) to the world yield \( Y_{WK} \) available in the ProdSTAT database provided by the Food and Agriculture Organization [37]. The cropland equivalence factor, \( EQF = 2.52 \) [26], was multiplied by the agricultural land area in Ollei Village to determine the agricultural land biocapacity. Similarly, we determined the biocapacity of agricultural land in Palau, \( B^P \), based on the cropland areas surveyed in 2011 (agroforestry, including taro patches and home gardens, 1,570 ha; and farmland, 317 ha).

### 3. Results

#### 3.1. Community-scale food consumption

Weekly diets were compiled from 724 ingredients in the 208 meals consumed by 38 people in the 11 households of Ollei Village during the survey period. The results of the survey (figure 2 and table S2) show that local residents largely depend on grains (e.g. rice, bread, ramen, pasta) and meat (e.g. beef, pork, chicken) more than traditional taro and fish-based diets. However, traditional foods, such as bats (upper middle picture in figure 3) and bird meat were still consumed by some villagers (figure 2). Subsistence foods from the ocean and agricultural products, such as taros and fruits, have contributed to self-sufficiency in Ollei Village. However, nearly 100% of the animal-husbandry products (meat, eggs and dairy) and grains were imported from other countries and obtained by purchase; Palau has no large livestock industry. The survey revealed that dietary habits in Ollei have shifted towards an imported food-oriented lifestyle dependent on the global supply chain; this is despite Ollei being a small and remote island community.

#### 3.2. Global land use in the community

The estimated global agricultural land-use area associated with the annual equivalent consumption of imported foods in Ollei Village reached 10.9 gha (0.29 gha capita\(^{-1}\)). This area is 37% larger than the biocapacity of agricultural land in Ollei Village, which is estimated at 7.94 gha (figure 4(a) and table S2). By contrast, the global agricultural land-use area associated with the annual Palauan food imports was 14 508 gha (0.82 gha capita\(^{-1}\)) in 2015. This was four times larger than the biocapacity of the agricultural land in Palau, estimated at 3663 gha (figure 4(b)). This difference in global agricultural land-use area between Ollei Village and the country of Palau can be considered as traditional diets based on ingredients from traditional croplands and inshore fishing remain in Ollei Village and all imported and processed foods consumed in Ollei Village were transported through Koror, resulting in high transportation and purchasing costs.

For Ollei and Palau, most global agricultural land-use areas were occupied by meat and grain products; the USA accounted for the largest share in cropland and grazing land (pie charts in figures 4(a) and (b)). The large difference in the share of Australia between grazing land and cropland use is explained by the large import value of processed meat products from the country. Similarly, the comparably large share of Thailand’s cropland use is associated with the second largest import value of rice, following the USA.

Trade flows and consequent agricultural land-use areas associated with imported food consumption in Ollei Village (figure 5) indicate that the rural village is strongly connected to countries worldwide, particularly to the USA, Australia and Asian countries. In addition to direct trading partners, the analysis highlighted the countries where agricultural land use was induced by imported food consumption in Ollei through the global food supply chain (land users in figure 5). For instance, Japan accounted for 23% of the Palauan import value of bakery products and noodles in 2015 (figure 6). However, Japan used little domestic cropland to produce grains as raw materials and used foreign land through the import of grains from major agricultural countries, such as Australia and the USA.

### 4. Discussion and conclusion

This study has surveyed the diets of a small island community and linked the results with a multi-region land footprint analysis in Ollei Village, Republic of Palau. This analysis has determined the extent to which the dietary lifestyles of communities depend on external land use through the global supply chain. Previous footprint studies have focussed on food consumption at the national level and have neglected community-level consumption activities. This study successfully bridged the gap between community-level consumption activities and national-scale footprint analysis and led to the following new findings.

First, the community and country have connections with a limited number of major partners through the global food supply chain; this includes the direct import of food from land users and indirect links with multiple countries that supply ingredients to trading partners. The community and Palau have
strong relations with Asian countries, such as Japan and Taiwan, and are connected to major agricultural countries, such as the USA and Australia. Notably, Palau is significantly dependent on land resources in the USA. This phenomenon is a manifestation of geopolitical relationships as Palau was part of the United Nations Trust Territory of the Pacific Islands. This was administered by the USA from the end of World War II to Palau’s independence in 1994. Since then, Palau has had a Compact of Free Association with the USA, under which the two countries cooperate on a broad range of issues. These existing connections through global supply chains help overcome shocks in local food supply in Palau.
Figure 4. Area of global agricultural land use including cropland and grazing land use associated with imported foods in Ollei Village from 24–30 September 2015. (a) Annual equivalent consumption of annual food imports by Palau in 2015; (b) by trading partner. Breakdown of trading partners for cropland and grazing land use is shown in the pie charts.

Figure 5. Trading partners of Palau for imported foods consumed in Ollei Village and consequent agricultural land-user countries/regions. Direct trading partners are connected to Palau by solid lines that represent the agricultural land-use area associated with foods exported from each trading partner to Palau and consumed in Ollei Village (the agricultural land-use area associated with foods exported from the USA is 9.23 gha). Color depth of the country/region indicates the agricultural land-use area appropriated in each country/region (land user) for the cultivation of primary products directly exported to Palau or used as raw materials of food products (including livestock feed) exported to Palau and consumed in Ollei Village (the agricultural land-use area appropriated in the USA is 9.08 gha). Trading partners and land-user countries/regions that account for less than an annual equivalent of 0.01 gha (approximately 0.1% of the total agricultural land-use areas associated with food imports for Ollei Village) are excluded.
However, they also increase exposure to risks from external perturbations, including climatic disasters, wars and pandemics [38–40]. The uneven distribution of trade partners is considered a risk factor [41, 42]. As such, to avoid risks associated with a dependence on the global supply chain, a good national/producer strategy involves the distribution of imports among different import partners and the selection of partners with low land resource risks [42, 43].

Second, the domestic production of all food consumed in Palau is impossible because of the lack of current and potential agricultural land. Overuse of the limited land resources on the island for food production at scales commensurate with current consumption would result in environmental degradation. This includes reduced sustainability and increased environmental burden on aquatic ecosystems due to soil erosion [44]. Environmental degradation also has a negative impact on the ecotourism industry, a major industry in Palau. The abundant forests in Palau, its ocean resources and the present economy are conserved through food imports. Therefore, it is important to connect food security and environmental strategies in Palau to balance food imports, food production and environmental protection [45]. Palau does not have a clear national/producer strategy due to a chronic lack of data and statistics to guide the development of strategies on food security and the environment [13]. The results and approach of this study can contribute to developing or justifying governmental food policies, such as import food taxation, agricultural subsidies and domestic land-use regulation [46–48].

Furthermore, this study showed that, as in other countries [9, 48], the dietary habits of the community in the Pacific are increasingly shifting towards higher dependence on processed and imported foods, particularly foods based on grains and meat. These grain- and meat-based diets significantly affect individual health [18, 46]. Many previous studies have also revealed that the consumption of meat and meat-based foods, and grains in some instances, has major footprints, including carbon emissions [24, 28], energy and water consumption [21], eutrophication [24], nutrient (nitrogen and phosphorus) use/emissions [49, 50] and land use [24]. Therefore, diets high in imported grain- and meat-based foods are likely to have a significant negative environmental impact outside Palau. Although some of the findings of this study have already been described in previous national studies, this study provides quantitative evidence to support these existing findings. The approaches and methods of this study, which link community-scale activities with their impact on the global environment, could contribute to the development and implementation of vertically integrated food policies between national and community level. Finally, this study has limitations, such as measuring the amount of food ingredients in each meal, identifying the import partners of foods consumed by the community and accounting for weather and seasonal variations in dietary choices. A viable and regular monitoring framework and system at the community level is necessary to overcome these limitations.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).
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References

[1] Wood S A, Smith M R, Fanzo J, Remans R and Defries R S 2018 Nat. Sustain. 1 34–7
[2] Halpern B S et al 2019 Proc. Natl Acad. Sci. USA 116 18152–6
[3] Wilde B, Mervis J and Wigginton N S 2014 Science 344 1100–3
[4] Poore J and Nenecek T 2018 Science 360 987–92
[5] United Nations The Sustainable Development Agenda SDGs (available at: www.un.org/sustainabledevelopment/)
[6] Kraussmann F, Richter R and Eisenmenger N 2014 J. Ind. Ecol. 18 294–305
[7] McGregor A, Michael Bourke R M, Manley M, Tubuna S and Deo R 2009 Pac. Econ. Bull. (available at: https://core.ac.uk/download/pdf/156561824.pdf)
[8] Parks W and Abbot D 2009 UNICEF Pacific and UNDP Pacific Centre (available at: https://www.asia-pacific.undp.org/content/rbap/en/home/library/sustainable-development/protecting-pacific-island-children-women-during-economic-and-fihml)
[9] Thow A M, Heywood P, Schultz J, Quested C, Jan S and Colagiuri S 2011 Ecol. Food Nutr. 50 18–42
[10] Cvitanovic C, Crimp S, Fleming A, Bell J, Howden M, Hobday A J, Taylor M and Cunningham R 2016 Clim. Risk Manag. 11 53–62
[11] Farrell P et al 2020 Food Secur. 12 783–91
[12] Love D C et al 2021 Glob. Food Secur. 28 100494
[13] FAO 2020 Pacific Multi-Country CPR Document 2013–2017 (available at: www.fao.org/3/a-as134e.pdf)
[14] Wiedmann T and Lenzen M 2018 Nat. Geosci. 11 314–21
[15] Hookstra A Y and Wiedmann T O 2014 Science 344 1114–7
[16] Kikuchi-Uehara E, Nakatani J and Hirao M 2016 J. Clean. Prod. 125 216–26
[17] Hillborn R, Banobi J, Hall S J, Pucykowski T and Walsworth T E 2018 Front. Ecol. Environ. 16 329–35
[18] Godfray H C J, Aveyard P, Garnett T, Hall J W, Key T J, Lorimer J, Pirethromb R T, Scarborough P, Springmann M and Jebb S A 2018 Science 361 eaam5324
[19] He P, Baiocchi G, Hubacek K, Feng K and Yu Y 2018 Nat. Sustain. 1 122–7
[20] Song G, Li M, Semakula H M and Zhang S 2015 Sci. Total Environ. 529 191–7
[21] Salmoral G and Yan X 2018 Resour. Conserv. Recycl. 133 320–30
[22] Chaudhary A, Pfister S and Hellweg S 2016 Environ. Sci. Technol. 50 3928–36
[23] Farmery A K, Gardner C, Green B S, Jennings S and Watson R A 2015 Environ. Sci. Policy 54 35–43
[24] Behrens P, Jong J C K, Bosker T, Rodrigues J F D, De Koning A and Tukker A 2017 Proc. Natl Acad. Sci. USA 114 13412–7
[25] Han M Y, Chen G Q and Dunford M 2019 Land Use Policy 83 325–33
[26] Chen B et al 2018 Sci. Total Environ. 613–614 931–43
[27] Steen-Olsen K, Weitzelt J, Cranston G, Erzin A E and Hertwich E G 2012 Environ. Sci. Technol. 46 10883–91
[28] Shirley R, Jones C and Kammen D 2012 Ecol. Econ. 80 8–14
[29] Palau National Government 2015 Statistical Yearbook (available at: www.palaugov.pw/executive-branch/ministries/finance/budgetandplanning/rop-statistical-yearbooks/)
[30] Ida A 2012 A study on watershed-based landscape planning on Babeldab Island in the Republic of Palau, Micronesia PhD Thesis The University of Tokyo, Tokyo
[31] Bennett A 2015 Public Health Convention (available at: www.slideshare.net/AmandaBennett4/public-health-convention)
[32] Borucke M, Moore D, Cranston G, Gracey K, Iha K, Larson J, Lazarus E, Morales J C, Wackernagel M and Galli A 2013 Ecol. Indic. 24 518–33
[33] International Trade Centre 2018 Trade Map (available at: www.trademap.org/)
[34] Lenzen M, Kanemoto K, Morán D and Geschke A 2012 Environ. Sci. Technol. 46 8374–81
[35] Lenzen M, Morán D, Kanemoto K and Geschke A 2013 Econ. Syst. Res. 25 20–49
[36] van den Bergh J C M and Grazi F 2014 J. Ind. Ecol. 18 10–25
[37] Food and Agriculture Organization FAOSTAT (available at: www.fao.org/faostat/en/)
[38] Graedel T E, Harper E M, Nassar N T and Rock B K 2015 Proc. Natl Acad. Sci. USA 112 6295–300
[39] Graedel T E et al 2012 Sci. Technol. 46 1063–70
[40] Cimprich A, Bach V, Helbig C, Thorenz A, Schriever D, Sonnemann G, Young S B, Sonderegger T and Berger M 2019 J. Ind. Ecol. 23 1226–36
[41] Nakatani J et al 2018 Omega 75 165–81
[42] Genechev E D, Sonnemann G and Young S B 2017 Int. J. Life Cycle Assess. 22 31–9
[43] Puma M J, Bose S, Chon S Y and Cook B I 2015 Environ. Res. Lett. 10 024007
[44] Noda K, Iida A, Watanabe S and Osaka K 2019 Environ. Res. Lett. 14 054004
[45] Palau International Coral Reef Center and the Stanford Center for Ocean Solutions 2019 Palau’s National Marine Sanctuary: Managing Ocean Change and Supporting Food Security (available at: http://picrc.org/picrcpage/palau-national-marine-sanctuary and https://oceansolutions.stanford.edu/pnms-report/)
[46] Mytton O T, Clarke D and Rayner M 2012 BMJ 344 c2931
[47] Wirensius S, Hedenus F and Mohlin K 2011 Clim. Change 108 159–84
[48] Mobeg E et al 2021 Nat. Food 2 282–90
[49] Oita A, Malik A, Kanemoto K, Geschke A, Nishijima S and Lenzen M 2016 Nat. Geosci. 9 111–5
[50] Joenseh K, Pulikkein H, Karups S, Ypä J and Virtanen Y 2019 Int. J. Life Cycle Assess. 24 26–36