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Trading Spaces: Calculating Embodied Ecological Footprints in International Trade Using A Product Land Use Matrix (PLUM)

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ABSTRACT

Nations import and export biophysical resources. With many ecosystems worldwide under mounting stress, countries may be increasingly interested in knowing the extent and origin of their ecological imports and dependencies. In this paper the Ecological Footprint is used as a tool to measure the biophysical (as opposed to financial) value of international trade flows. This paper attempts to answer the following question: How large of an Ecological Footprint does a given country exert inside the borders of each of its trading partners? Records in the UN COMTRADE bilateral trade database are multiplied by a matrix of per-product footprint yield coefficients to translate from values in dollars and tonnes to units of hectares. This paper describes the methodology used to produce the findings presented at the 2007 BRASS Ecological Footprint Conference in Cardiff.

Conference Theme: Methodology

Keywords: Trade, Burden Shifting, Embodied Energy, Embodied Footprint

Overview

One of the transitions prescribed by the sustainable development agenda is toward dematerialization of human economies. In order to reconcile the goals of human development with the environmental capacities of the planet, the sustainable development agenda calls on nations to develop knowledge- and service-based economies which can provide increasing human welfare while holding steady or decreasing the amount of physical material metabolized to provide that welfare. The remarkable progress of development since WWII has come at a high cost to the biosphere. Numerous reports document the fact that ecosystems worldwide are under mounting stress (*1*-*3*). De-coupling economic growth from underlying biophysical flows is a goal of sustainable development for two reasons. First, de-coupling can help avoid the risk that ecological degradation will cause economic problems. And secondly, de-coupling creates the opportunity for human development to continue to progress without ecological constraints.

A first step toward de-coupling is to develop sound metrics for quantifying the biophysical flows underlying the economy. The broad project of natural resource accounting (a specialization within the emerging discipline of sustainability science) works to develop tools that measure the ecological, as opposed to the financial, balance of trade. As globalization accelerates, many nations depend on natural resources and ecological services from beyond their territorial borders. And as the global economy becomes more highly articulated and specializations deepen, many trade relationships will grow more asymmetrical in ecological terms while they remain close to parity in financial terms.

The specific question which this study attempts to answer is this: How large of an Ecological Footprint does a given country exert inside the borders of each of its trading partners?[1] This paper describes a method for calculating the embodied Ecological Footprint in trade flows. The UN COMTRADE international trade database is multiplied with a matrix of per-product Footprint yield coefficients (t/ha). This matrix, which we refer to as a Production Land Use Matrix or PLUM, is derived from Global Footprint Network's National Footprint and Biocapacity Accounts. (*4*, *5*). The result is the complete COMTRADE bilateral trade database translated into units of Footprint hectares. Countries can be classified as ecological creditors or debtors by their net trade balance of bioproductive area.

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[1] Nations also exert ecological impacts on not only on the territory of other nations, but also on the global commons. This is the case with deep sea fishing and atmospheric pollution. The methodology developed distinguishes Footprint impacts exerted on the global commons and on individual nations.

1.1. Description of methodology

The method for calculating the ecological weight of trade flows consists of combining national level EF accounts with the United Nations Statistics Department’s COMTRADE global trade database (*4*). Each of the products in the Harmonized System 2002 (HS02)[2] nomenclature (the product classification scheme used by COMTRADE) is associated with a Footprint yield coefficient (t/ha). These yield coefficients are derived from the National Footprint Accounts (*5*). The data year studied was 2002.

The National Accounts provide a robust, detailed accounting of the total Ecological Footprint and total imported and exported Footprints for the most populous 150 countries. The Footprints of raw and embodied resources are summed so that all major natural resource flows are captured. . The National Accounts also calculate, for each nation, the Footprint it needs to produce each of a variety of product types. The Accounts primarily track raw resources but offer conversion factors to convert between primary and secondary products (e.g. between oranges and orange juice), on a basis of weight or volume. (*6*)

These Footprint yield factors are gathered in a table we call a Product Land Use Matrix, or PLUM (Table 1). The PLUM contains for every country, year, and HS02 product code, a yield coefficient (t/ha), how large of a Footprint is exerted on each of the four major land use types (pasture, cropland, forest, and ocean/marine) in the production of that product.[3] Built-up land was assumed to not be ‘traded’ and was excluded from the analysis. Table 1 shows six representative entries from the PLUM.

1.2. Constructing a Product Land-Use Matrix (PLUM)

Ideally one output of the National Accounts would be a list of per-product Footprint intensities. These data would directly comprise the PLUM. However, the National Accounts 2006 Edition (the most current version at time of writing) offers these data in a different product nomenclature (SITC rev 3) than that used by COMTRADE (HS02). The forthcoming 2008 Edition of the Accounts will be recoded using HS02 nomenclature. Therefore, one challenge in the implementation, though not conceptualization, of this study was producing a PLUM in HS02 nomenclature. To build a complete, HS02-coded PLUM we utilized the same source data and applied similar methodology used in the National Accounts but tagged products by HS02 code rather than SITC code. Sections 1.4 through 1.8 detail the data and methodologies used to fill the PLUM.

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[2] At four digits of resolution, the level of detail used in this study, HS02 distinguishes 1,245 products.

[3] The National Accounts break down land use into 10 types, but for simplicity we have condensed them to four in this study. The PLUM could be extended to distinguish among the 10 land uses used in the Accounts.

1.3. Integrating COMTRADE and the PLUM

To arrive at Footprint flows, the trade flows in COMTRADE, recorded in tonnes, are cross multiplied by the Footprint yield coefficients. This results in a full bilateral trade dataset reporting the ecological value, in terms of hectares, traded between reporting countries. The National Accounts as published are trade-adjusted. The COMTRADE database is used along with FAO and other sources to calculate the trade adjustment. However the National Accounts report only total imports and exports, not disaggregated by trading partner. In this study we start with the non-trade-adjusted Footprint of production, as calculated by the National Accounts.

Table 1: PLUM Product Land Use Matrix (Footprint Yield Coefficients)

Country	Year	HS02 Code	Product Description	Pasture (t/ha)	Cropland (t/ha)	Forest (t/ha)	Marine (t/ha)
France	2002	H2-0104	Live sheep and goats.	0.18	0.24	0	0
France	2002	H2-0105	Live poultry	2.44	0	0	0
			…				
Germany	2002	H2-0104	Live sheep and goats.	0.25	0.13		
Germany	2002	H2-0105	Fish, frozen, excl. fish fillets	0	0	0	4.90
Germany	2002	H2-1001	Wheat and meslin	0	6.91	0	0
Germany	2002	H2-4701	Mechanical wood pulp	0	0	8.97	0

In the COMTRADE dataset 13% of records, representing 26% of total trade value, had no weight values reported. Since all the Footprint yield coefficients are in units of weight, the missing weights were filled, using price ($/t) estimates. For each commodity two reference prices were calculated. The World Price (WP) was calculated as the mean price paid by all nations at import or export of each commodity. (Transactions below 50kg were excluded from the calculation of the WP to filter reporting errors where a reporter filled in weight in tonnes instead of kilograms or in number of units rather than weight.) Secondly, an Average Reference Price (ARP) and Median Reference Price (MRP) were calculated as the mean and median prices paid at import/export by a reference group of eight major countries (France, Germany, Italy, Mexico, Spain, Sweden, UK, USA). Where the WP and the MRP differed by <50%, the World Price was used. If the WP and the MRP diverged by > 50%, but Reference Prices (ARP and MRP) differed by <50%, then the MRP was used. In 117 product categories (representing 11% of the total traded value), where <10% of the value of trade in those products had no weight data but the three price measures disagreed substantially, the WP was used. Finally, for the remaining 32 categories where the three price measures disagreed substantially and where >10% of the trade value required price-estimated weights, prices were manually estimated by comparing the WP and the prices paid by the eight countries comprising Reference Price group. Two commodity codes, Artworks (H2-97) and Commodities Not Specified According to Kind (H2-99) were assigned weights of 0 kg, omitting them from the calculations.

The following sections 1.4to 1.8 describe how the PLUM was filled. These calculations yield less accurate results than the National Accounts provide. These results should be used only as proxy values until a new edition of the Accounts using HS02 coding is available.

1.4. Forest Product Yield Coefficients

Forest yields are the basis for estimating how much forest area each country requires to produce a tonne of forest products. Three sets of national timber yields were available. The first is from the FAO Global Fibre Supply Model (GFSM) study (*7*). These data report each country's average forest increment, in m^3 roundwood / ha / yr. The second yield set is based on the IPCC recommended methodology for estimating national forest growth (*8*). GFN executed the IPCC methodology to calculate a second dataset of timber growth. The IPCC method suggested generally higher timber yields than did the GFSM. Both of these two yields estimate the annual timber increment. However forests may (and often are) harvested to produce a yield greater than their annual growth, causing deforestation. Using FAOSTAT ForestSTAT data (*9*) we estimated a third true 'production yield' by dividing the annual FAO-reported timber production (m^3) by the FAO-reported forest area (ha). The 'production yield' approach is the chosen approach, except in the cases of missing/unavailable values in which case the GFSM, or if unavailable, the IPCC, data were used. Overall the chosen approach agrees within reasonable limits to the GFSM results. 70% of the national data points differ by less than 33% and 95% differ by less than 66%. The chosen approach suggests more extensive forest use: for 73% of the countries, the chosen approach indicates more forest area is used to harvest timber products than is suggested by the GFSM. Three outlier countries (Brazil, Russia, and Canada) were set to use the GFSM estimate, since the Production Yield estimate was unreliable given their vast forested areas, leading to overestimates of deforestation To convert between timber products, reported in tonnes, and raw timber, counted in volume (m^3), a set of Technical Conversion Factors (TCFs) from an EU FAO study (*10*) were used as the basis for estimating the amount of roundwood (m^3) required to produce one tonne of each HS02 product. Countries with missing yield data were assumed to have world-average timber yield. Three filters were applied to the yield data. First, a check for erroneously low yields was performed: if the net yield was below 30% of the world average net yield, the world average figure was used. Second, a cap, set at 10x the world-average yield, was applied to constrain outliers. Finally, since HS02 nomenclature does not distinguish between natural and synthetic rubber, and natural rubber is a low-yield, area-intensive product, a manual filter was applied to set the areal footprint of rubber to 0 from countries which do not produce natural rubber.

1.5. Marine Product Yield Coefficients

Aquatic products are produced from aquaculture, fishing within a country's EEZ, and from deep sea fishing. The Footprint of fish caught in the open ocean is considered part of the production Footprint of the nation recording the landed catch. The HS02 nomenclature has only seven categories to distinguish marine products. Because of this low resolution it was not possible to determine the trophic level of exported fish products. As a proxy a world-average marine product yield was used. The global fish catch of 93 Mt was divided by an estimated fished area of 19 m. km^2 to arrive at a marine product yield of.4.9 t/ha. These data points are taken from the 2005 Edition National Accounts. The yields for three product codes of high-quality fish ready for human consumption[4] were adjusted downward by a factor of 2 to 2.5 t/ha to account for the high trophic level of these products. A factor two adjustment was considered a conservative estimate, since the yield of low trophic-level fish can be as much as 10x that of high trophic level fish. Repeating the calculations at six-digit HS02 resolution and adjusting for the trophic level of each species would improve the accuracy of the findings.

1.6. Cropland Product Yield Coefficients

Production yields (kg/ha) for each country and each crop product were taken from FAOSTAT (*9*). FAOSTAT product categories were mapped to HS02 categories. Where multiple FAOSTAT categories matched a single HS02 category (e.g. Apples and Pears are separated in FAOSTAT but a single category in 4-digit HS02 nomenclature), the average of the matching categories was used to estimate the yield for the HS02 product. A simple world-average yield was calculated for each product. HS02 categories with no directly matching FAOSTAT category were assigned averages of similar products. Daughter products (e.g. orange juice) were assigned the yield coefficient of their parent product (oranges), plus in some cases a dilution factor to increase the yield where the weight of the daughter product was augmented beyond the simple parent product. Countries with incomplete yield data were filled in with world yields. A check for erroneously low yields was performed: if the yield of a particular crop in a country was less than 30% of the world average yield, the world average figure was used.

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[4] The three products were: Live fish (HS02-0301), Fish, fresh or chilled, excluding fish fillets (HS02-0302), and Fish, frozen, excluding fish fillets (HS02-0303).

1.7. Pasture Product Yield Coefficients

The Footprints of animal products are among the most difficult to calculate, for a number of reasons. Animals are raised on a combination of open range grazing and fed harvested grasses as well as concentrate feed (primarily from grains such as corn but also from fishmeal and animal fats). Animals' diets vary dramatically by country: a cow raised in an industrialized nation could be fed entirely on concentrate feed and consume as much as 10x as much food over its lifetime than a cow eating grass and other foraged food in an less developed country. (*11*) Data on range productivity are scarcer than data on crop farming and forestry. Since pasture areas vary seasonally and blend in with light tree cover, different land use datasets vary dramatically in reporting how much pasture area a country has. Finally, there is an open methodological question which remains unsettled by the Footprint research community: In a given year, 100% of a pasture area may be available for grazing, and covered in cattle footprints, but less than 100% of the available grass is consumed. Should the Footprint calculation include just the grass consumed, or the entire area disturbed? Collectively, these difficulties are particularly relevant for countries with extensive grazing operations, such as Australia, Mongolia, South Africa, Brazil, New Zealand, Argentina, and the United States.

Global Footprint Network is in the process of re-evaluating the Footprints of animal products as part of the next edition of the National Accounts. For this study, estimates of pasture product yields were derived from the National Accounts 2005 Edition. These estimates are very likely accurate to within a factor of 5, and possibly accurate up to a factor of 2. They should be used as a placeholder and a basis of comparison only. Where estimates and assumptions were made they were intentionally biased toward under-estimating the true Footprint area. As a result, the pasture Footprints of most countries are visibly under-estimated. For example, with the yield coefficients used, Australia exports only 38 million hectares, or 5% of its total land area, while in fact sheep stations alone (not even counting cattle ranches) cover 12% of its total land area producing mutton and wool almost exclusively for export.

1.8. Energy Footprint Coefficients

One land use was calculated separately, namely, the energy footprint. Energy Footprints consist of the land area inundated by hydropower dams, a Footprint of nuclear power (currently set at par with fossil fuel energy, for lack of a consensus on an alternate methodology), and a CO_2 footprint used in generating energy used in a nation. The EF methodology presently accounts for CO_2 pollution by calculating the area of forest necessary to sequester the CO_2.[5]

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[5] This approach is chosen as the most conservative of reasonable approaches for calculating the Footprint of CO_2 pollution. For more on the rationale behind this, and summaries of the debate over the merits and flaws of this approach, the reader is referred to (Global Footprint Network 2005).

Nations which import embodied CO_2 in energy-intense products do not physically exert their carbon footprint on the providing nation but rather on the global commons. Thus the resulting Footprint cannot be said to be literally exerted on that nation.[6] Energy Footprints are reported separately from actual land uses (cropland, forest, etc.) so as to not exaggerate the land area used in a trading partner. This study assumed that all embodied energy came from a national-average fuel mix. The Footprints of fossil fuel and nuclear generated energy were not distinguished from hydropower and renewable sources.

Embodied energy estimates (GJ/t)[7] for each HS-02 product were gathered. The primary source for these figures was the embodied energy estimates, in SITC nomenclature, in the National Accounts. These data are maintained in an in-house library at GFN in turn based on data gathered by Stockholm Environment Institute-York (*12*) and the Centre for Energy and Environmental Studies (IVEM) at University of Groningen. Where the two nomenclatures did not have an exact correspondence, estimates based on similar products were used. In these cases two researchers[8] independently made estimates and agreement was reached on each figure. From the embodied energy estimate, in GJ, national carbon intensity data from IEA (g CO_2 / kWh) were used to translate energy into estimated CO_2 emissions (*13*). Estimating embodied energy and carbon in products remains a difficult exercise. The embodied energy estimates used are published herewith for peer review. Also, the findings of this study are not claimed to be authoritative - an approximate error range within +/- 50% is likely - but are intended to be used as a point of comparison for other estimates to move closer to accurate values.

Limitations

Footprint trade flows can be calculated either using a footprint coefficient approach or using I-O methodology. One drawback to a coefficient approach is that unless the coefficients are calculated very carefully the sum of the Export Footprint from the resulting dataset may not equal the Export Footprint as calculated in the National Accounts. (Conceptually if the complete PLUM is generated from National Accounts this risk is avoided but given that the Accounts are generated primarily from raw resource accounts and the PLUM entries code more processed child products this is difficult to ensure.) An I-O approach guarantees no sector of the studied economies is omitted. An I-O approach is also better suited to analysing international production

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[6] The exceptions are for hydropower and renewable energy, where the Footprint of energy production is physically in the producing nation. This study ignores these non-CO_2 energy footprints. Approximately 88% of global energy demand used to produce traded products is currently fossil-fuel based. Hydro, nuclear, and renewable sources were omitted for simplicity.

[7] Only energy expended in harvesting, processing, and transporting products are included. This differs from the eMergy approach in which embodied solar energy (in wheat, for example) is included. Including the embodied solar energy would be double counting in Footprint terms, since wheat would have a Footprint both for the cropland it grew on and again for the sun energy that fell on that cropland.

[8] DM and AP

chains where products are transformed. A coefficient approach determines the net export footprint by subtracting the total export footprint from the import footprint, but cannot disaggregate by individual products.

The advantages of a coefficient approach over an I-O approach are several: most I-O tables are available in only monetary and not physical units, so price estimates add margin for error; I-O tables are available for fewer countries than National Accounts cover so global trade analysis is currently not possible using I-O methods; and, I-O analysis can only be conducted when both trading partners have I-O tables whereas Footprint coefficients can be applied to movements of individual products at any scope from household to municipal to national.

The principle limitation constraining the accuracy of this study was that the PLUM should be filled using the National Accounts. Since the Accounts were not available in HS02 nomenclature compatible with COMTRADE at the time of this study, the Footprint yield coefficients in the PLUM had to be re-calculated following the data sources and methodology of the Accounts. The result is that the PLUM data used are less accurate than would be if produced by the National Accounts. Specific limitations are discussed in sections 1.4 through 1.8. This deficiency can be surpassed by repeating the study when an HS02-coded edition of the Accounts is available. Producing an HS02-coded National Accounts is itself a challenging project. The source data for the Accounts primarily report on raw natural resources. The HS02 classification is designed to record international trade flows and tends to utilize categories for more highly processed child products. Gathering robust per-nation extraction rates, to convert between primary and child products, is a significant undertaking but is a valuable contribution offered by the Accounts.

A future direction of study using the PLUM could be to produce a timeseries. Data in the National Accounts and COMTRADE are available as far back as 1962 (*14*), and a PLUM with a time dimension could be constructed. One major difficulty in executing this is that the dominant nomenclature in COMTRADE shifts over time, through three SITC and three HS revisions. Normalizing COMTRADE into a single-nomenclature timeseries would be challenging.

Results & Discussion

The summary tables in this section separate the energy Footprint and the land-area footprint. Footprint flows are reported in hectares (ha) and not units of global hectares (gha) as used in other Footprint studies. For this study the decision was made to keep results in actual hectares so they could be compared to actual land availability in exporting nations. Hectares can be trivially converted to gha using the National Accounts.

Table 3 summarizes the direct Footprint flows between regions.[9] The largest trade volumes are intraregional (especially NAFTA and the EU). The largest interregional flows are from North America to Latin America, and from North America to Asia-Pacific.

Table 2: Energy Footprint imports (CO_2) between regions

CO2 Imports (Mt CO2), by GDP bracket

By geographic region

Source:

Imports Into:	Africa	Asia-Pacific	Latin America	M. East & C. Asia	North America	Other Europe	Western Europe
Africa	-	63	6	36	16	10	182
Asia-Pacific	80	-	84	423	374	35	209
Latin America	13	2,107	-	25	27,453	9	690
M. East & C. Asia	19	156	15	-	42	82	173
North America	50	663	389	123	-	23	243
Other Europe	8	58	7	80	10	-	319
Western Europe	216	659	92	287	209	463	-
Grand Total	**213**	**3,775**	**817**	**534**	**4,197**	**668**	**6,933**

Table 3: Imports of Ecological Footprint between Regions

Footprint Imports (M ha), by geographic region

Source:

Destination:	Africa	Asia-Pacific	Latin America	North America	Western Europe	M. East & C. Asia	Other Europe
Western Europe	1.5	4.3	0.8	2.3	60.7	7.0	3.9
Other Europe	1.0	0.5	0.1	1.0	20.4	9.3	8.1
North America	2.0	37.6	58.3	57.2	7.3	4.3	0.4
M. East & C. Asia	5.6	3.2	0.2	0.5	7.9	12.0	1.4
Latin America	1.1	8.3	12.8	16.3	14.4	3.9	0.9
Asia-Pacific	3.0	55.2	5.8	22.4	11.5	9.7	1.1
Africa	1.7	1.5	0.1	0.9	11.7	4.8	0.5
Grand Total	**15.9**	**110.6**	**78.0**	**100.5**	**133.9**	**50.9**	**16.2**

Table 4: Comparison of Footprint and monetary imports (grouped by income bracket)

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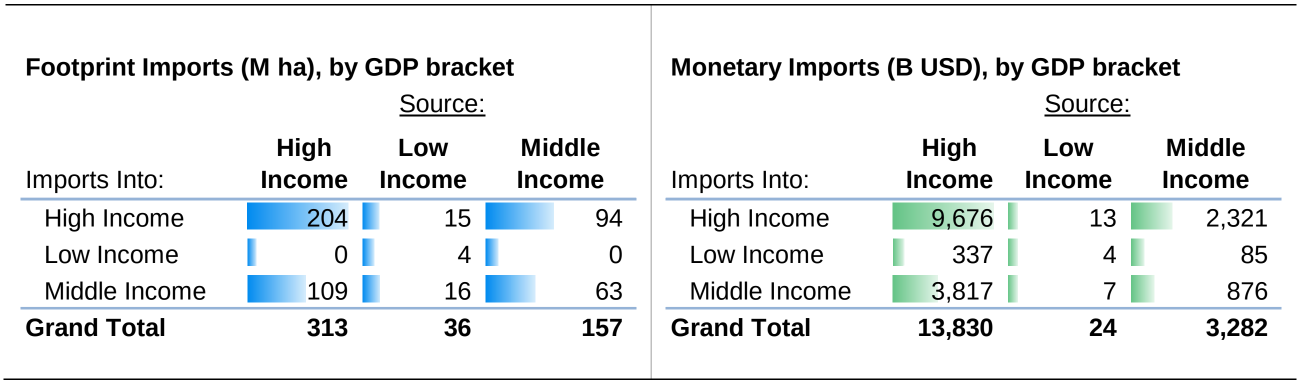
[9] The table reports Import flows. Due to data asymmetry in COMTRADE import flows do not match the inverse export flows perfectly; discrepancies range from 0-30%. This discrepancy is essentially insurmountable given current data quality, and we chose to report import flows rather than export flows or attempt to reconcile the two.



Footprint Imports (M ha), by GDP bracket

Imports Into:	Source: High Income	Source: Low Income	Source: Middle Income
High Income	204	15	94
Low Income	0	4	0
Middle Income	109	16	63
Grand Total	**313**	**36**	**157**

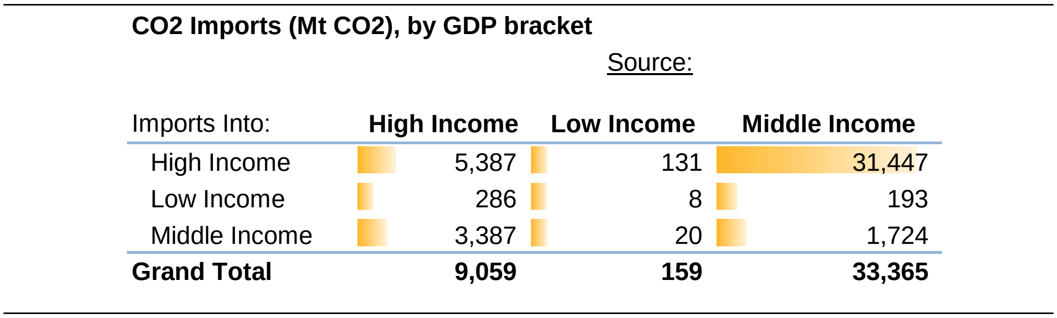
Monetary Imports (B USD), by GDP bracket

Imports Into:	Source: High Income	Source: Low Income	Source: Middle Income
High Income	9,676	13	2,321
Low Income	337	4	85
Middle Income	3,817	7	876
Grand Total	**13,830**	**24**	**3,282**

Table 4 compares the imports in Footprint and monetary terms, grouped by income brackets. There is a noticeable de-linkage between monetary and Footprint flows.

One element of the Footprint is the energy component. This consists of the estimated embodied CO_2 in imported goods. Table 5 summarizes the import of Energy Footprint, by income bracket. A striking finding is that middle income nations export a large energy footprint to high income nations. Comparing this result to that in the monetary flow Table 4 above shows that the exports of middle income countries are much more CO_2-intensive than the flows between other countries. This could be due either to the trade stream being richer in more energy-intensive products or to those exporting countries having more CO_2 intensive energy infrastructure.

Table 5: Energy (CO2) Imports (grouped by income bracket)



CO2 Imports (Mt CO2), by GDP bracket

Imports Into:	Source: High Income	Source: Low Income	Source: Middle Income
High Income	5,387	131	31,447
Low Income	286	8	193
Middle Income	3,387	20	1,724
Grand Total	**9,059**	**159**	**33,365**

The results do not appear to support the widely accepted hypothesis than natural resources flow predominantly from less developed regions to more developed regions. North America and Europe are the source of 46% of Footprint imports. Less developed regions export much less Footprint than do more highly developed regions. Another surprising finding is that Western Europe imports from abroad only 18% as much Footprint as does North America. Further analysis of the results will be presented at the 2007 BRASS Ecological Footprint conference in Cardiff, and in future publications. The primary intention of this paper has been to introduce the PLUM methodology.

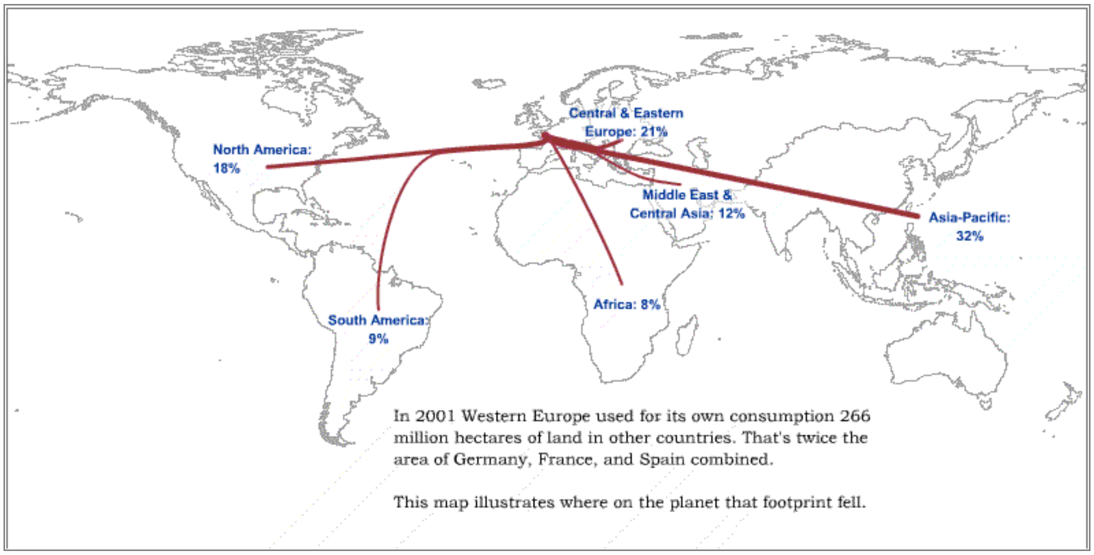
1.9. Data Visualizations

The resulting dataset of international trade flows contains almost 2.5 million trade-partner tuples. Data visualizations can help analyse these voluminous results. Two complementary styles of maps may be used to visualize the international trade in terms of its embodied biocapacity. One style (see Figures 2 and 3) is to use flow arrows (where width denotes magnitude) to show the source of all imports to, or exports from, to the selected country. The second style (see Figures 4 and 5) is a ‘nighttime lights’-type which shows, for a given country, the areas around the world where that country’s Footprint falls. These maps must distinguish between actual land area used within a country’s borders and on the global commons (as in the case of the energy Footprint and deep sea fishing).

1.9.1. Flow Map Visualization

Flow maps effectively depict the movement of objects among geographic locations. Traditionally, cartographers have produced flow maps by hand (*15*, *16*). This results in aesthetically pleasing maps but is a time-consuming process. Recently Phan and colleagues (*17*) have developed a method for automatically producing flow maps. As a result, we are better able to understand the extent and spatial patterns of trade flows among 150 countries.

Figure 1: The analysis can be conducted on the regional level. This example illustrates the regions from which Western Europe imports biocapacity.



In 2001 Western Europe used for its own consumption 266 million hectares of land in other countries. That's twice the area of Germany, France, and Spain combined.

This map illustrates where on the planet that footprint fell.

Figure 2: Aggregated imports of ecological good and services into France from its largest trade partners. Units are global hectares. Unlabeled arrows are to the USA, Morocco, and China.

1.9.2.Spatial Analysis Maps

A second style of map to visualize Ecological Footprint of international trade is mapping the land used by imports for a given country using GIS (Figures 4 and 5). This technique combines national Footprint data with global remote sensing data. While it is impossible to determine the exact location of production of specific imports (e.g. milk producing cattle), the area used for imports can be attributed to a land-use type within each country. Footprints attributed to forest, pasture, and cropland are represented by green, brown, and yellow fill, respectively. Land-use types are determined using the Global Land Cover Classification (*18*). The Ecological Footprint locations are a weighted random distribution within each country-land type according to the 2002 net primary productivity (NPP) estimates from the Moderate Resolution Imaging Spectroradiometer (MODIS).

A large component of many Footprints is the energy Footprint, i.e. the area required to provide and absorb waste from energy production. Presently this Footprint is calculated based on the extent of forest that would be required to sequester the CO2 released in generating that energy. A cloropleth map layer (blue tinted fill) represents energy as calculated as equivalent in land area.

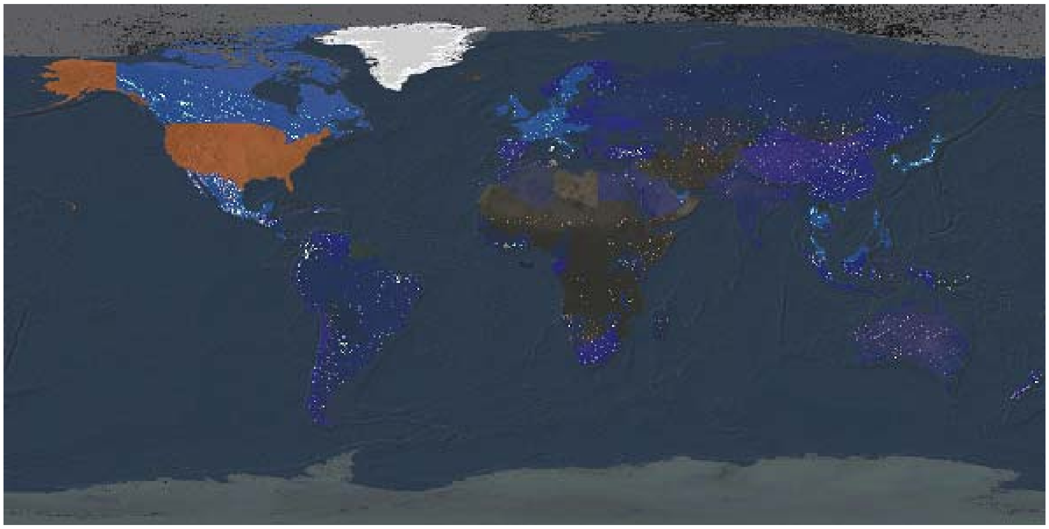


Figure 3: USA's Ecological Footprint around the world. Lit dots represent areas within the countries from which the US imports biological capacity. Blue tinted fills represent imported energy Footprints.

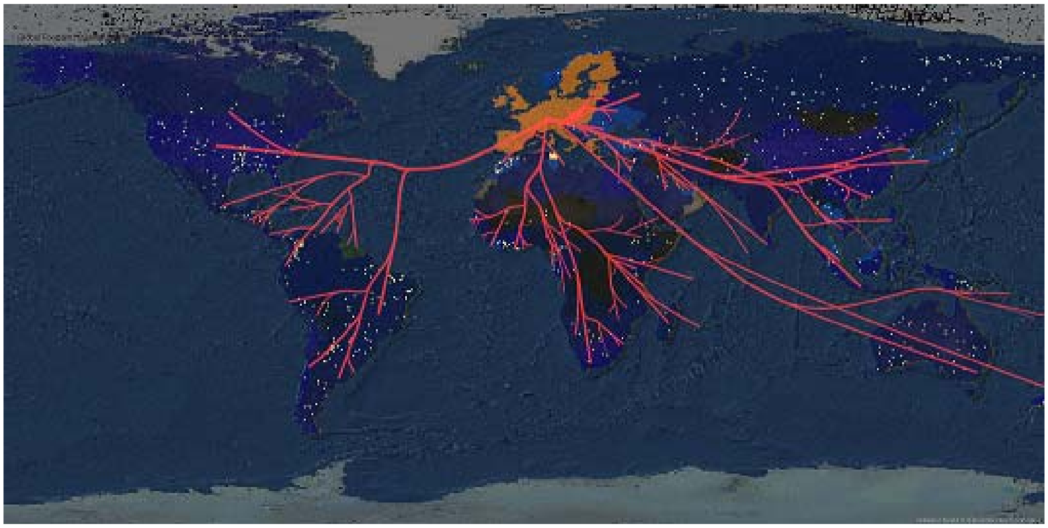


Figure 4: EU's Ecological Footprint around the world, with flow arrows overlaid showing volume and source of imports. Lit pixels represent areas within the countries from which the EU imports biological capacity. Blue tinted fills represent imported energy Footprints. Arrow widths encode magnitude of flows, in hectares.

Conclusion

Developing techniques to analyse trade in non-monetary terms is a foundational project of ecological economics. This paper has described a method in support this goal. We have detailed a procedure to calculate international trade flows in terms of Ecological Footprint. Drawing out meaningful patterns from the resulting vast data set is also a considerable task. We have described two visualization techniques – using flow maps and spatial analysis – which can help countries to understand the extent and patterns of their ecological trade relationships.

Countries' Ecological Footprints fall across the globe. We have implemented a coefficient approach using a PLUM table to quantify the trade of bioproductive land between nations. Knowing the patterns and extent of their ecological trade relationships will help countries understand more clearly their interactions with the biosphere beyond their borders, including revealing ecological burden shifting and negative ecological trade balances.

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