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Methodological and Ideological Options

The unequal exchange of Dutch cheese and Kenyan roses: Introducing and testing an LCA-based methodology for estimating ecologically unequal exchange

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ABSTRACT

The theory of ecologically unequal exchange (EUE) posits that international trade is structurally organized in a manner that allows a net transfer of resources from peripheral developing to core industrialized countries. The consequence, it is argued, is under-development in the periphery and augmented productive capacity in the core. EUE thus challenges the neoliberal free-market argument that exchange at market prices is symmetric and fair. An LCA-based methodology for estimating EUE that holds constant the variable market price is introduced and tested on contemporary trade of Dutch cheese and Kenyan coffee and roses. Specifically, the exchange of embodied land, water, energy, global warming potential, and labor is assessed. The results confirm the theory's hypothesis. At a fixed market price, more embodied Kenyan resources are exchanged for less Dutch resources. However, Kenyan roses give different results from coffee. EUE between countries can only be conclusively determined by considering the total biophysical trade balance, but by calculating quantities of embodied resources per unit of exchange value, it is possible to detect unequal exchange even at the level of individual commodities. While integration of biophysical metrics alongside monetary valuation is recommended, ultimately, rethinking the structure, policies and politics of international trade is necessary.

1. Introduction

International trade is structurally organized in such a way that some countries act as natural resource depots and sinks for the waste products of other countries. Materials and energy extracted from peripheral countries predominantly located in the Global South are being used to feed industrial processes and capital accumulation in core Northern countries. The consequence is environmental degradation, poverty, and general underdevelopment in the peripheral countries and improved productive capacity in the developed world (Rice, 2009). This exploitative international division of labor is the essence of the theory of ecologically unequal exchange (EUE). It is concerned with the unequal environmental and human well-being consequences of international trade and the relations of power that generate and maintain such inequality (Hornborg, 2009; Jorgenson et al., 2009). Rather than take present comparative advantages as a given, EUE theory questions the historical power relations that have shaped them and, in so doing, departs from neoclassical economic thought. By considering global terms of trade as favoring core countries to the detriment of the periphery (Jorgenson et al., 2009), the perspective takes a 'zero-sum' view of development (Hornborg, 2011) akin to David Harvey's (2003) 'accumulation by dispossession.'

Rooted in classical trade dependence, unequal exchange, and world-systems traditions (Jorgenson et al., 2009), EUE traces a direct genealogy to Karl Marx's 'metabolic rift' (Hornborg, 2009). The growing asymmetric exchange of nutrients and other material resources between town and countryside in 19th-century Europe amplified by long-distance trade deeply concerned Marx (Foster, 1999). Credited with coining the term unequal exchange, Arghiri Emmanuel (1972), through the labor theory of value, argued that developing countries always exchange a larger amount of their labor for less foreign labor. But it is Raul Prebisch who is credited with founding the theory of unequal exchange (Kohler and Tausch, 2002; Love, 1980). Refuting David Ricardo's theory of comparative advantage, Prebisch observed a hierarchy in the global economic system and deteriorating terms of trade for developing countries which he attributed to low income-elasticity of demand for primary products and asymmetries in the functioning of labor markets (UN., 1963). EUE has also benefited greatly from world-systems analysis (see Frank, 2008; Wallerstein, 1974). World-systems analysis sees an economic and geographical division of the capitalist world-economy into a strong core (metropolis) and weak periphery (satellite) in which surplus value flows from the periphery to the core, a process which limits the periphery's developmental potential. Through his research on the Amazon, Stephen Bunker inserted 'ecology' to earlier labor- and energy-based theories of unequal exchange and, in a sense, assembled the first formulation of a concept of ecologically unequal exchange (Hornborg,

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2009). He argued that (i) differences in the economies of peripheral and core countries create unequal exchange in terms of labor embodied in products *and* the appropriation of energy and matter from the periphery to the core, and (ii) the extraction and export of natural resources affect the subsequent developmental potential of the periphery (Bunker, 1985).

Ecologically unequal exchange rejects neoliberal economics' assumption that market prices are fair or tantamount to reciprocity. Free market transactions are by definition equal and fair since the actors voluntarily exchange currency or goods for what they assess to be of equal value (Clark and Tsai, 2009; Hornborg, 2009). This win–win positive-sum game is a liberal understanding of capitalism encapsulated in David Ricardo's theory of comparative advantage. But the free market functions as an ideology, a myth (Wallerstein, 2004). The equal exchange in monetary terms may very well be consistent with unequal exchange in physical terms. Monetary valuation excludes other possible measures of exchange through which it can be shown that free trade is indeed unequal (Hornborg, 2009). Georgescu-Roegen (1971) illuminated the inverse relationship in which raw materials are of low economic value while manufactures which have dissipated much of their productive potential have a high monetary value. That is why Hornborg (2011; 2009) argues for analytically separating human valuation and physical properties in order to reveal the inequality inherent in capitalist processes. Contrary to comparative advantage claims, free trade does not make all nations equally competitive but rather exposes the weak to the strong who, inevitably, devour the weak (Shaikh, 2007). Such 'free trade' policies are used to open up and integrate peripheral countries into relations of unequal exchange (Bieler and Morton, 2014).

The EUE theory is backed by a growing number of empirical studies using different approaches and methods (see Section 2). Most of these methods and studies take an economy-wide approach that tracks total flows rather than a product-specific perspective. Apart from showing the net flow of biophysical resources, most are also geared towards revealing the environmental or socio-economic impacts of such unequal exchange. What they fail to illustrate is the mechanism(s) through which EUE occurs. Reiterating that the core element of any EUE theory is the exchange of more ecological wealth for less, Foster and Holleman (2014) argue that existing EUE approaches rely on data whose quantitative measures are in monetary prices and which reveal little about the ecological nature of the exchange, i.e. in terms of embodied energy or other resources. As a result, "we learn little or nothing […] about the *processes involved* or the real extent of the unequal exchange" (ibid. pg. 210, emphasis added). This paper introduces a life cycle analysis (LCA)-based methodology for quantifying EUE that simultaneously investigates a key mechanism through which unequal exchange occurs — the free market ideology. The methodology is tested in the contemporary exchange of specific flagship export products from supposedly core (Netherlands) and peripheral (Kenya) countries. The modern nation state remains a crucial instrument by which industrial centers subordinate and attempt to control extractive peripheries, while systematic consideration of specific export commodities has many benefits (cf. Bunker, 1985; Hardt and Negri, 2000). Organizationally, the Introduction discusses the EUE theory, including its critique of free-market trade. Next is a review of some approaches to estimating EUE followed by the Methodology. Finally, the results are presented, discussed, and conclusions drawn.

2. Common Approaches to Estimating Ecologically Unequal Exchange

How societies organize their exchange of material and energy with the natural environment is termed social metabolism (Fischer-Kowalski and Haberl, 1997). Trade is an important socio-metabolic mechanism. While in conventional international monetary trade exports are 'good' and imports 'bad', the reverse is true for trade in physical terms: exports are a loss to the exporting country of the resources embodied in the exports and vice versa. Haberl et al. (2013) distinguish two approaches to analyzing social metabolism. Systemic approaches aims at a comprehensive account of all biophysical flows needed to build up, sustain and operate a defined socioeconomic system. The LCA approach, on the other hand, accounts for resource requirements, wastes and emissions resulting from a single product. As the following review reveals, most methods of quantifying EUE predominantly apply the systemic approach even if some (e.g. footprints and input–output analysis) incorporate elements of LCA.

Material flow analysis (MFA) is one approach to estimating EUE. Based on the mass balance principle from Lavoisier's law of conservation of mass, it accounts for biophysical flows in mass, usually metric tons (Bringezu and Moriguchi, 2002). Physical trade balance (PTB), an MFA-based indicator which measures an economy's physical trade surplus or deficit, can give insight into EUE. Mass is a robust measure in classical physics and PTB gives information on world resource supply and demand, inter-country group resource flows, and resource dependencies (Fischer-Kowalski et al., 2011). Using MFA, Pérez-Rincón (2006) has shown that between 1970 and 2002, 85% of Colombia's export was directed at satisfying the material and energy requirements of Northern countries, in particular the EU and USA. Several other studies (e.g. Behrens et al., 2007; Bruckner et al., 2012; Dittrich and Bringezu, 2010; Schaffartzik et al., 2014) apply MFA to arrive at similar proof of EUE. One drawback of MFA is that weighting of trade does not tell us the ecological impacts of the goods.

Another method, the human appropriation of net primary production (HANPP), estimates the sum of changes in net primary production (NPP) or biomass resulting from land-use change and human harvest from ecosystems, including losses thereof (Haberl, 1997; Haberl et al., 2012). Measured in units of carbon, HANPP is calculated by estimating a country's potential NPP (without human land use) using vegetation models, then calculating the actual NPP (often less than potential NPP), and finally determining the actual part of the NPP utilized by human beings. Embodied HANPP (eHANPP) involves adding the HANPP related to imports and subtracting that related to exports, hence can be used to estimate EUE. Krausmann et al.'s (2013) analysis of HANPP trends shows that Asia, Africa, and Latin America's high HANPP growth rates are due to their importation and consumption by industrialized countries.

Footprints take a consumer responsibility approach to provide a simple but graphic measure of the environmental impact of human activity (Hammond, 2006; Steen-Olsen et al., 2012). The 'footprint family' (Galli et al., 2012) refer to the ecological, carbon and water footprints. The ecological footprint (EF), measured in global hectares (gha), calculates human demand on the biosphere compared to the planet's 'supply' (Wackernagel and Kitzes, 2008). A popularization of Borgstrom's 'ghost acreages', it builds on the concepts of LCA, bio-productivity accounting, and embodied energy analysis (Moran et al., 2009). The water footprint (WF) or 'virtual water' is the total volume of freshwater used to produce a good or consumed by a community (Hoekstra, 2009a; Hoekstra et al., 2009; Mekonnen and Hoekstra, 2011). Expressed in volume per unit of product (m^3/t), the WF is a combination of the blue, green and gray water footprints. The carbon footprint is the total amount of carbon (or CO_2 equivalent) emissions caused by or accumulated over the life of a product or activity, or the sum of a country's emissions related to its consumption, including imports but excluding exports (Galli et al., 2012). It is expressed in kilograms or tons of CO_2 with no conversion to area. Primarily a measure of the appropriation of global sink capacity, the carbon footprint can also gauge EUE. For example, Steinberger et al. (2012) have shown that socio-economic benefits are accruing to carbon-importing rather than carbon-exporting countries. Steen-Olsen et al. (2012) have shown that the EU-27 displaces all the three footprints to the rest of the world through trade.

Input–output (I–O) analysis describes an economic sector's output and its relationship to the corresponding levels of activities in other sectors. Initially applied to economic impact analyses through monetary I–O tables (MIOTs), they have been extended to pollution and other environmental “externalities” (Leontief, 1970; Allan et al., 2007). A physical I–O table (PIOT) comprises the traditional I–O table in physical units and material flows between the environment and economy (Giljum and Hubacek, 2004; Strassert, 2002). Because an I–O approach can track the transformation and impact of goods through an economy, if extended to multiple regions, the spatial distribution and growth or decline over time of output and consumption of goods can be explained (Moran et al., 2009). It is often used in combination with other methods, e.g. Steen-Olsen et al.'s (2012) use of a multiregional input–output (MRIO) model to assess the displacement of carbon, land and water footprints through trade within and without the EU-27.

Energy metrics such as eMergy (energy memory) have also been used to estimate EUE. Alfred Lotka's postulation that ‘natural selection’ favors those populations that convert the greater amount of energy has found support from a trade perspective whereby countries or regions that import more embodied energy than they export have a relative economic advantage (Bunker, 1985; Lonergan, 1988). Rydberg (2011) confirms that developed countries' wealth is largely based on imported eMergy.

Life cycle analysis (LCA) is a technique for systematically assessing the environmental aspects and potential impacts associated with a product by compiling an inventory of relevant inputs and outputs; evaluating the potential environmental impacts associated with those inputs and outputs; and interpreting the results of the inventory and impact phases in relation to the objectives of the study (ISO 14040, 2006). It considers the embodied resources and emissions throughout the entire life cycle of a product, i.e. from ‘cradle-to-grave.’ Going beyond the mass balance principle of MFA, LCA is often used to identify ecological ‘hotspots’, elements with a high contribution to a product's ecological impact (De Haes, 2002; Van Middelaar et al., 2011). By providing a holistic and systematic overview of embodied resources and emissions, it is routinely used to compare the potential environmental impact of two or more products (Thrane and Schmidt, 2007). Economic and social aspects have also been integrated into LCA (cf. Franze and Ciroth, 2011; UNEP, 2009; Weidema, 2006).

Some challenges such as assuming a functional unit for products with many potential uses and the risk of double counting bedevil LCA (cf. Ayres, 2004; Ayres, 1995; Van der Voet et al., 2005). Nevertheless, it remains the tool of choice for many modern sustainable consumption and production policies. It is often combined with other tools for more extensive assessments (cf. Rochat et al., 2013; Schmidt, 2014; Weinzettel and Kovanda, 2009). Van der Voet et al. (2005) combine aspects of MFA (quantitative information) and LCA (environmental impacts) to assess the environmental impacts of the annual throughput of a number of materials for The Netherlands. Haberl et al. (2013) allude to the future possibility of applying LCA to studies in society–nature interactions across space and time. Until now, LCA has not been used to estimate ecologically unequal exchange.

3. Methodology

The proposed methodology has two key parts. First, the embodied resources and impacts per unit of product are determined using LCA. However, what we have not yet brought into the picture are the structural aspects of international trade, so-called ‘market forces’. The second part of the methodology is dedicated to this. By combining the resource embodiment of each product (from step 1) with exchange rates deduced from the world market, the resource intensity per unit of exchange value (e.g. US Dollar) is determined and compared across the products. In this way, we can illuminate the ‘free market’ mechanism through which asymmetric resource flows occurs.

3.1. Embodied Resources per Unit of Product

ISO 14040 (2006) and ISO 14044 (2006) are internationally accepted standards which describe the principles, framework, requirements, and guidelines for life cycle assessment. These have been used to establish embodied resources and emissions per unit of product. The LCA framework is comprised of four iterative phases: goal and scope definition, inventory analysis (LCI), impact assessment (LCIA), and interpretation of results (ISO 14040, 2006). The goal of this study is to quantify the biophysical resource and emission embodiments of the target products with a view to establishing the occurrence of unequal exchange. The scope involves defining the functional unit, system boundary and co-product allocation criteria. A functional unit (FU) is a quantified output of a production system which allows different such systems to be compared (Thrane and Schmidt, 2007). The FUs were defined as follows: 1 kg of long-stemmed, plastic greenhouse-grown, graded and packaged Kenyan rose flowers; 1 kg of milled and packaged green Kenyan coffee beans (not roasted); and 1 kg of Dutch Gouda cheese produced from conventional (not organic) milk. Figs. 1, 2 and 3 show the system boundaries of the processes included in the analysis. Since the focus is on bilateral trade, only domestic resources and related emissions were considered, with imported raw materials treated as if they were locally sourced. While this may distort the results especially for Dutch agricultural products due to their relatively high external inputs (De Boer et al., 2013; Thomassen et al., 2008; Van Bruchem et al., 1999; Vellinga et al., 2011), such a distortion implies that there are in fact less truly Dutch resources embodied in a unit of their cheese. Hence, in the context of the present investigation of EUE, the distortion, though important to keep in mind, does not compromise but rather underscore the integrity of the conclusions. Emissions due to use of imported inputs in the production process (e.g. combustion of imported fossil fuels) were attributed to the final product and country of production. Allocation of inputs to stages with more than one output (co-product allocation) was based on their relative economic value (i.e. economic allocation).

Infrastructure and capital goods such as roads, buildings, and machinery were omitted due to their relatively small impact per functional

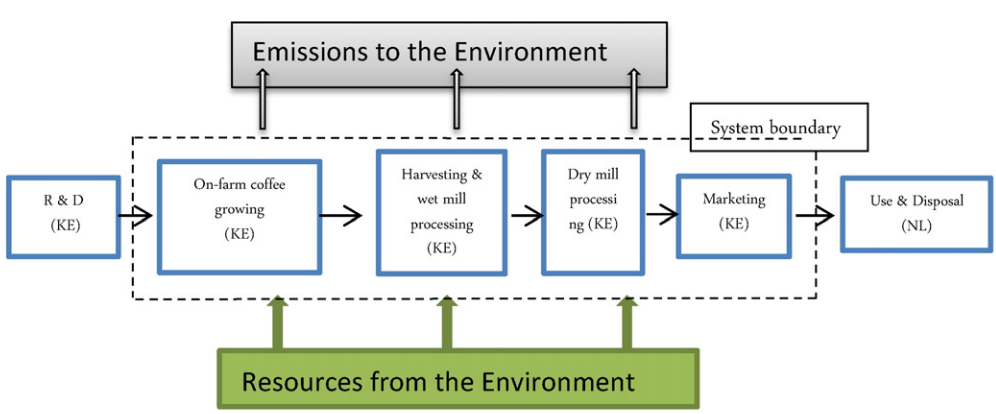

Fig. 1. System boundary for Kenyan coffee.

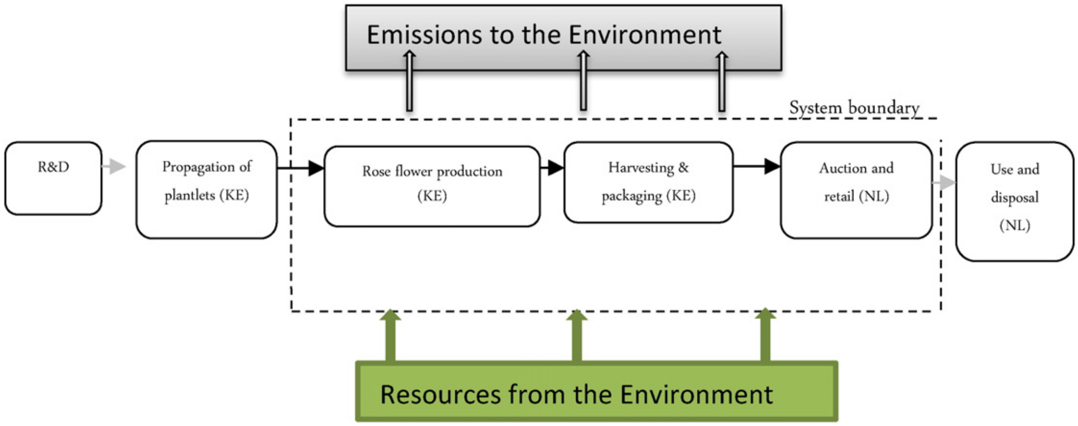

Fig. 2. System boundary for Kenyan roses.

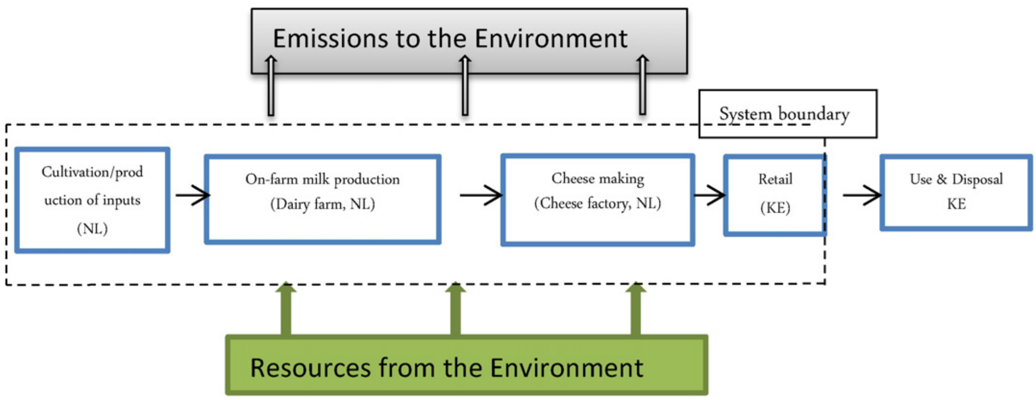

Fig. 3. System boundary for Dutch cheese.

unit, the norm in many LCA studies (cf. Thomassen et al., 2009, 2008; Van Middelaar et al., 2011). While the ISO standards suggest treatment of capital goods as integral parts of a product system, the justification for such omission hinges on the fact that due to their often long lifespans and the many different products and socio-economic activities utilizing the same infrastructure, the resources and emissions embodied in the capital goods attributable to a unit (1 kg) of a particular product is not only difficult to estimate but would, if done, turn out to be negligible. Cumulatively, infrastructure has significant ecological impacts, a point often better captured by the systemic EUE approaches. Processes similar across the products (e.g. inter-continental air freight) were disregarded on the assumption that, assuming similar technology, transporting a unit (1 kg) of coffee or cheese between the two countries should expend or emit roughly similar amount of resources. Land use, water, energy, CO_2 emissions or global warming potential (GWP), and labor were the focal resource and impact categories, i.e. the environmental components and issues of concern.

The inventory phase (LCI) involves collecting and quantifying the inputs and outputs of production processes included in the system boundary and relating the data to the functional unit, i.e. determining resource intensity per functional unit (ISO 14040, 2006; Thrane and Schmidt, 2007). Data on Kenyan roses was collected from Nini Flower farm located in Naivasha between October and December 2012. That of coffee was collected from Mchana estate, a coffee plantation located in Ruiru District, central Kenya between December 2013 and January 2014. Farm records, observation, and direct measurements were relied upon and triangulated with other secondary data sources and literature to verify their accuracy. No LCA database or software was used as none specific to Kenya currently exists. Data on Dutch cheese was sourced from literature. Tables 1, 3 and 5 summarize each product's inventory. The third phase (impact assessment) uses the LCI data to evaluate the significance of the resource requirements and environmental impacts of a production system. The result is total embodied resources and impacts per functional unit (the last row of the

Table 1
Life-cycle inventory table of Kenyan rose flower production.

Process/input	Land use	Energy	GWP	Water	Labor
1. Greenhouse	0.5 ha (1.5×10^{-5} ha/kg)	–	–	–	
2. Rose production:					
–Water consumption	1.267 ha (8.45E-7 ha/kg)	–	–	360 l/kg	
–Synthetic fertilizer	–	–	0.017 kg CO_2eq/kg		
3. Packaging:					
–Cardboard	1.2×10^{-6} ha/kg	9 MJ/kg	–	–	
–Plastics	–	3.32 MJ/kg	0.0776 kg CO_2/kg	–	
4. Transportation	–	2 MJ/kg	0.152 kg CO_2/kg	–	
5. Electricity	–	2.6 MJ/kg	0.19 kg CO_2/kg	–	
TOTAL	1.7045×10^{-5} ha/kg	16.92 MJ/kg	0.4346 kg CO_{2eq}/kg	360 l/kg	0.86 h/kg

Table 2
Trade volumes and embodied resources.

Year	Kenyan rose exports to The Netherlands		Embodied resources				
	Export (Mt)	Inflation adj. sales (US$)	Land use (ha)	Water (l)	Energy (MJ)	GWP (Kg CO_2eq)	Labor (h)
1995	9257.43	19,611,423.24	157.79	3,332,674,800	156,635,715.6	4,023,279.08	7,961,389.8
1996	9834.37	18,486,187.89	167.63	3,540,372,732	166,397,518.4	4,274,016.64	8,457,557.09
1997	11,871.15	23,557,977.48	202.34	4,273,613,370	200,859,828.4	5,159,201.03	10,209,187.5
1998	12,659.90	31,560,545.99	215.79	4,557,564,180	214,205,516.5	5,501,992.76	10,887,514.43
1999	16,017.47	41,749,599.32	273.02	5,766,287,436	271,015,509.5	6,961,190.33	13,775,019.99
2000	18,023.75	39,613,177.08	307.21	6,488,550,432	304,961,870.3	7,833,122.27	15,500,426.03
2001	19,664.44	58,440,251.81	335.18	7,079,198,958	332,722,351	8,546,166.30	16,911,419.73
2003	29,684.57	63,722,172.38	505.97	10,686,443,742	502,262,855.9	12,900,912.36	25,528,726.72
2004	31,407	77,108,800.71	535.33	11,306,521,044	531,406,489.1	13,649,483.46	27,010,022.49
2005	39,684.1	86,607,806.79	676.42	14,286,275,640	671,454,955.1	17,246,709.43	34,128,325.14
2006	41,221.74	94,059,747.61	702.62	14,839,825,104	697,471,779.9	17,914,966.64	35,450,693.3
2007	43,100.06	139,763,305.6	734.64	15,516,022,392	729,253,052.4	18,731,287.03	37,066,053.49
2008	35,182.20	182,338,645	599.68	12,665,592,000	595,282,824	15,290,184	30,256,692
2009	30,588.33	167,193,690	521.38	11,011,798,800	517,554,543.6	13,293,688	26,305,964
2010	32,377.83	164,656,369	551.88	11,656,018,800	547,832,883.6	14,071,405	27,844,934
2011	60,698.21	175,473,795	1034.60	21,851,355,600	1,027,013,713	26,379,442	52,200,461
2012	58,500.01	157,954,455	997.13	21,060,003,600	989,820,169.2	25,424,104	50,310,009

Source: Trade data sourced from COMTRADE (2014) and HCDA (Horticultural Crops Development Authority) (2014). Embodied resources calculated by author.

Table 3
Life-cycle inventory table of Kenyan coffee.

Process/input	Land use	Energy	GWP	Water	Labor
1. Coffee production	908.9 ha (2.23 ha/t)	–	–	23,573 m^3/t	113.774 h/kg
2. Fertilizer application	–	–	0.94 t CO_2eq/t	–	–
3. Fuel consumption	–	31, 435 MJ/t	2.28 t CO_2eq/t	–	–
4. Electricity consumption	–	3440 MJ/t	0.3 t CO_2eq/t	–	–
TOTAL	2.23×10^{-3} ha/kg	34.875 MJ/kg	3.52×10^{-3} t CO_2eq/kg	23.573 m^3/kg	113.774 h/kg

inventory tables). However, the calculation of resource intensity per functional unit is only the first stage in the methodology. The next stage relates these calculated figures to exchange value to determine unequal exchange per dollar.

3.2. Determination of Unequal Exchange

Determination of unequal exchange per dollar helps us investigate the reciprocity claims of free trade and comparative advantage theories from a biophysical perspective. Doing so requires information about the exchange rates obtaining in the world market. The exchange rates were deduced from annual import and export trade statistics retrieved, in both weight and monetary sale values, from the UNCOMTRADE database. The COMTRADE codes of interest were 060,311 (fresh roses), 090,111 (coffee, not roasted, not decaffeinated) and 0406 (cheese and curd). Kenyan rose exports to The Netherlands from 1995 to 2007 were missing from COMTRADE and were instead sourced from Kenya's Horticultural Crops Development Authority (HCDA (Horticultural Crops Development Authority), 2014) by assuming 65% of all Kenyan rose exports go to The Netherlands (cf. Dolan et al., 2003; Kargbo et al., 2010; KFC (Kenya Flower Council), 2014; Rikken, 2011). Based on life cycle assessments of the respective trade goods (from Step 1), how much of a particular resource (e.g. embodied land) was traded on the world market at a fixed exchange value (e.g. US$1) in a given year is determined. Then a comparison (visualized in the form of a graph) is made between how much of each resource embodied in a Kenyan product was exchanging for a similar resource embodied in Dutch cheese at a fixed exchange value (arbitrarily set at US$10,000 in this paper). But first, the monetary prices were adjusted for inflation using the respective countries' consumer price index (CPI). The CPI figures for Kenya and The

Table 4
Trade volumes and embodied resources.

Year	Kenyan coffee export to The Netherlands		Embodied resources				
	Export (kg)	Inflation adj. sales (US$)	Land use (ha)	Water (l)	Energy (MJ)	GWP (kg CO_2eq)	Labor (h)
1995	4,848,414	16,995,446	10,812	1.1429E + 11	1,690,884,38.3	17,066,417.28	551,623,454.4
1996	6,280,511	15,871,298	14,006	1.4805E + 11	219,032,821.1	22,107,398.72	714,558,858.5
1997	2,533,000	6,697,142	5649	5.971E + 10	88,338,375	8,916,160	288,189,542
1998	1,420,250	2,836,781	3167	3.348E + 10	49,531,218.75	4,999,280	161,587,523.5
2000	10,624,371	14,983,643	23,692	2.5045E + 11	370,524,938.6	37,397,785.92	1,208,777,186
2001	6,511,145	7,923,508	14,520	1.5349E + 11	227,076,181.9	22,919,230.4	740,799,011.2
2002	1,298,142	1,558,224	2895	3.0601E + 10	45,272,702.25	4,569,459.84	147,694,807.9
2004	4,137,129	5,063,479	9226	9.7525E + 10	144,282,373.9	14,562,694.08	470,697,714.8
2005	3,933,267	7,079,750	8771	9.2719E + 10	137,172,686.6	13,845,099.84	447,503,519.7
2007	3,286,199	6,214,796	7328	7.7466E + 10	114,606,190.1	11,567,420.48	373,884,005
2008	597,691	1,374,477	1333	1.4089E + 10	20,844,473.63	2,103,872.32	68,001,695.83
2009	615,105	1,198,491	1372	1.45E + 10	21,451,786.88	2,165,169.6	69,982,956.27
2010	443,046	1,062,602	988	1.0444E + 10	15,451,229.25	1,559,521.92	50,407,115.6
2011	697,387	2,503,568	1555	1.644E + 10	24,321,371.63	2,454,802.24	79,344,508.54
2012	1,040,826	2,793,308	2321	2.4535E + 10	36,298,806.75	3,663,707.52	118,418,937.3

Source: Trade data sourced from COMTRADE (2014). Embodied resources calculated by author.

Netherlands were sourced from the Kenya National Bureau of Statistics (KNBS (Kenya National Bureau of Statistics), 2014) and the International Monetary Fund (ECONSTATS, 2013) respectively.

3.3. Case Study Countries and Products

From a world-systems perspective, Kenya is peripheral and The Netherlands a core country. Ranked as a low-income economy by the World Bank, Kenya exports mainly 'low-value' agricultural products such as tea, coffee and horticultural crops to Europe and the US and imports 'high-value' industrial manufactures such as machinery and other capital equipments, fuel and other non-food industrial supplies from the Middle and Far East. Manufactures' contribution to GDP has stagnated at about 10% for decades. Kenya has become a net importer in recent years with deteriorating terms of trade. The Netherlands is Kenya's third largest export market, accounting for between 8 and 9% of all exports, mainly cut-flowers (Bridgat, 2013; KIPPRA, 2013; KoN (Kingdom of Netherlands), 2014; UNStats, Undated). The industrialization and 'core' attributes of The Netherlands was already present as far back as the fifteenth century (Van Bavel and Van Zanden, 2004). It exports about 1.48% worth of its goods to Kenya, mainly chemicals, machinery and dairy products, making Kenya the fifteenth largest export destination for Dutch products (Bridgat, 2013; KoN (Kingdom of Netherlands), 2014).

Coffee is exclusively a tropical and labor-intensive crop grown by less-developed countries but largely consumed in the developed world (Austin, 2012). Cut flowers are an important export-directed world trade commodity, are both capital- and labor-intensive, and have significant environmental and socio-economic impacts (cf. Kargbo et al., 2010). Cheese is a traded product from the dairy industry which embodies significant environmental resources and emissions (cf. Steinfeld et al., 2006). Green coffee beans and fresh cut flowers are primary products while cheese is processed from milk, and thus a manufacture of sorts. In addition to their socio-economic value, these characteristics make them good candidates for estimating EUE. However, any other product can be chosen to test the proposed methodology for assessing the veracity of EUE theory.

World floriculture production was valued at US$40 billion in 2009 (Kargbo et al., 2010). Considered an economic success story, horticulture accounts for about 26.7% value of all Kenyan exports (Leipold and Morgante, 2013; UNStats, Undated). Produced almost exclusively for export, cut flower is the most important sub-sector of the Kenyan horticultural industry, accounting for about 57% of the total horticulture exports (ITC (International Trade Centre), 2004). Over 65% of the flower exports go to The Netherlands (Dolan et al., 2003; Kargbo et al., 2010; KFC (Kenya Flower Council), 2014; Rikken, 2011). The area around Lake Naivasha, an internationally important Ramsar wetland, account for about 95% of all flower production (Becht et al., 2006; Kargbo et al., 2010). Roses (*Rosa* sp.) account for over 50% of all cultivated flowers and 70% of all exports (Kargbo et al., 2010; KFC (Kenya Flower Council), 2014; Mekonnen et al., 2012). Kenya supplied 63% of all EU rose imports in 2006 (Muhammad, 2009). Rose production is both capital and labor intensive, requiring temperatures of between 15 and 28 °C, constant humidity, and a minimum 10 h of daily sunlight (Franze and Ciroth, 2011), conditions achieved in Kenya by growing them in plastic greenhouses (HCDA (Horticultural Crops Development Authority), 2014). Over 90% of Kenya's annual coffee production is exported, contributing about 4% of total export earnings. Largely grown by small-scale farmers, the superior quality but low yielding Arabica coffee (*Coffea arabica*) is the main variety (CRF (Coffee Research Foundation), 2014; ICO (International Coffee Organization), 2014).

The Dutch dairy industry utilizes 44% of the country's land and accounts for about 17% of the value of its food exports (CBS (Netherlands Central Bureau of Statistics), 2012). About 98% of Dutch milk is conventional, i.e. not organic (Thomassen et al., 2008). Over half of all milk supplied to dairy factories is processed into cheese, 75% of which is exported (CBS (Netherlands Central Bureau of Statistics), 2012; CBS (Netherlands Central Bureau of Statistics), 2005; Van Middelaar et al., 2011). Gouda is the dominant cheese (Van Middelaar et al., 2011; Walstra et al., 1999). Dutch agriculture is intensive in capital and external nutrient input (Van Bruchem et al., 1999; Vellinga et al., 2011).

4. Results

4.1. Embodied Resources in Kenyan Rose Flowers

Nini Flower farm's productivity is 65.172 t/ha. This approximates Orr and Chapagain's (2006) reported yield of 66 t/ha for Kenyan roses. About 23 ha are under rose flower cultivation and 1.267 ha is appropriated annually for lake water collection, treatment and disposal. Due to lack of comprehensive water use records, Mekonnen et al.'s (2012) reported water footprint of rose flowers grown around L. Naivasha of 9 l per stem (or 360 l/kg) was used.

Kenya does not produce any artificial fertilizers, hence only nitrous oxide (N_2O) emissions related to synthetic nitrogen fertilizer application (Kramer et al., 1999; Rotz et al., 2010) were considered. The emissions are 0.017 kg CO_2eq/kg of roses.[1] One export box contains about 250 rose stems weighing 6.25 kg, and packaging material made up of 1.91 kg cardboard and 0.25 kg plastic. The cardboard embodies a land use of 1.2×10^{-6} ha/kg[2] and energy of 9 MJ/kg of roses,[3] while the plastic packaging embodies 3.32 MJ/kg[4] and 0.0776 kg CO_2/kg of roses.[5] The annual fuel consumption (452.6 l petrol and 83,829 l diesel) embodies 2 MJ/kg[6] and emits 0.15 kgCO_2/kg of rose.[7] Electricity consumption embodies 2.6 MJ/kg[8] and emits 0.19 kgCO_2/kg.[9] With 538 employees and

[1] Based on Kenya's 2010 CO_2 emissions from synthetic nitrogen fertilizer use of 457 GgCO_2eq (FAOSTAT, 2013) and total fertilizer consumption of 500,000 metric tons (IFDC, 2012) gives an emission rate of 0.9 t CO_2eq/t of fertilizer. The annual Nitrogen (N) fertilizer consumption of 624.61 kg/greenhouse emit 562 kgCO_2eq, translating into 0.017 kg CO_2eq/kg.

[2] 78,000 ha of Kenya's plantations and 10% (100 ha) of farmlands were under wood production in 2000 (Wass, 2000). Kenya produced 135,000 t of packaging paper between 2006 and 2008 (FAO, 2012). Since general industrial roundwood weigh 750 kg/m^3 (FAO, 2012), packaging paper appropriated 180,000 m^3 of the annual roundwood production. Kenya's total wood production in 2010 was 27,646,000 m^3 (FAO, 2012). Assuming acreage (78,100 ha) and wood production (27,646,000 m^3) has remained constant, 135,000 tonnes (or 180,000 m^3) of packaging paper require 508.5 ha to produce. 305.6 kg of packaging paper (to wrap 1 tonne of roses) require 0.0012 ha of land annually to be produced, or 1.2×10^{-6} ha/kg of rose.

[3] Cardboard embody 29.97 MJ/kg (Hammond and Jones, 2008). Since 6.25 kg of flowers require 1.91 kg of cardboard to wrap, 1 kg of flowers will need 0.3 kg of cardboard, or about 9 MJ of energy.

[4] General plastic embody 83 MJ/kg and 1.94 kg CO_2/kg (Hammond and Jones, 2008). The 40 kg of plastics used to wrap 1 t of roses gives an embodied energy of 3320 MJ/t (or 3.32 MJ/kg) of rose flowers.

[5] From d above, emissions from plastics is 77.6 kg CO_2/t (or 0.0776 kg CO_2/kg).

[6] Petrol and diesel have an energy content of 44.3 MJ/kg and 43 MJ/kg respectively (IPCC, 2006). Since 1 kg of petrol is approx. 1.3 l, 452.6 l = 15,546 MJ. On the other hand 1 kg of diesel is approx. equal to 1.2 l, hence 83,829 l = 3,003,873 MJ. The combined total fossil fuel energy use (3,019,419 MJ) and annual rose flower production of the entire farm (1,498,956 kg) gives an energy use rate of 2 MJ/kg.

[7] The CO_2 emission factor of petrol and diesel are 69,300/TJ and 74,100 kg CO_2/TJ respectively (IPCC, 2006). 452.6 l of petrol = 15,546 MJ which emits 1.077 tCO2eq, while 83,829 l of diesel = 3,003,873 MJ which emits 222.587 tCO2eq. The combined emission is 224 tCO_2 per annum, or 0.15 kg CO_2/kg.

[8] Kenya generated 7273 GWhs of electricity less imports in 2010/2011 (GoK, 2012), while its 2010 CO_2 emissions from electricity production was 2.1 million tons (IEA, 2012). 21,551 KWh (annual consumption of a greenhouse) thus emits 6.2 tonnes CO_2, or 0.19 kg CO_2/kg.

[9] Fossil fuels generated 2288 GWhs of electricity out of which 2020 GWhs were from combustion of diesel and 268 GWhs from petrol. Based on electricity generation-related emissions for 2010, this translates to 583,253 tCO_2 and 77,382 tCO_2 emissions linked to diesel and petrol respectively. With CO_2 emission factors of 74,100 kg CO_2/TJ and 69,300 kg CO_2/TJ for diesel and petrol respectively (IPCC, 2006), the CO_2 emissions above come from 7871 TJ of diesel and 1117 TJ of petrol, a total of 8988 TJ. Since 2288 GWhs was produced from 8988 TJ of fossil fuels, it follows that 21,551 kWhs (single greenhouse annual electricity consumption) was generated from 0.085 TJ, which translates to 2.6 MJ/kg of roses.

Stage	Ecological impact		
	GWP (kg CO_2-eq./FU)	Land use (m^2/FU)	Energy use (MJ/FU)
Cultivation of concentrate ingredients	1.03	1.63	15.58
Concentrate production	0.08	0.00	1.04
Other up-stream stages	0.91	1.03	9.68
On-farm milk production	5.50	3.94	5.89
Sum on-farm milk production and up-stream stages	7.5	6.6	32.2
Cheese-making	0.30	0.01	6.01
Storage	0.29	0.01	4.46
Packaging	0.38	0.17	3.38
Retail	0.02	0.00	1.11
Sum stages after farm gate	0.99	0.2	15.0
Total	8.5	6.8	47.2

Fig. 4. LCA of Dutch cheese. Source: Van Middelaar et al. (2011). FU (functional unit) = 1 kg cheese.

Table 5
Summary inventory of Dutch cheese.

Stage/Resource	Land use	Energy	GWP	Water	Labor
Cheese production	6.8×10^{-4} ha/kg	46.09 MJ/kg	8.48 kg CO_2eq/kg	2623 l/kg	0.118 h/kg

considering sickness and absenteeism, annual labor-time is 1,289,790 man-hours or 0.86 h/kg of rose. Tables 1 and 2 shows the LCA inventory and embodied resources in Kenyan roses respectively.

4.2. Embodied Resources in Kenyan Coffee

The case study Mchana coffee estate occupies 906.91 ha while the dry mill stands on 2 ha, a total land use of 908.91 ha. The average annual yield is 407 t of milled green coffee beans, giving a land use rate of 2.23 ha/t. Mekonnen and Hoekstra's (2011) reported Kenyan coffee water footprint of 23,573 m^3/t (green: 22,222, blue: 802, gray: 549) was used. The wet mill utilizes only 0.34% of the water used to grow the coffee plant (Chapagain and Hoekstra, 2007). Fertilizer application emits 0.94 t CO_2eq/t.[10] Annual fuel consumption (diesel: 83,405 l and kerosene: 279,844 l) embodies 12,794,225 MJ of energy or 31,435 MJ/t[11] and emits 926,480 kg CO_2eq or 2276 kg CO_2eq/t.[12] Annual electricity consumption (357,622 kWh) emits 103 t CO_2eq or 0.3 t CO_2eq/t[13] and embodies 1.4 TJ or 3440 MJ/t.[14] The GWP would be lower if CO_2 removals by coffee plants was considered. The 18,552 employees supply 46,305,792 man-hours annually, translating into 113.774 h/kg of green coffee. Tables 3 and 4 shows the LCA inventory and embodied resources in Kenyan coffee respectively.

[10] About 393,758 kg of synthetic fertilizer is applied in the coffee fields annually. Considering Kenya's 2011 emissions from fertilizer application of 487.53 GgCO_2eq (FAOSTAT, 2014) and the country's 2011 fertilizer consumption of 500,000 t (IFDC, 2012), the farm's annual fertilizer consumption emits about 384 t of CO_2eq. This translates to 0.94 t CO_2eq/t.

[11] The energy content of diesel and kerosene is 43 TJ/Gg and 43.8 TJ/Gg respectively (IPCC, 2006). Since 1.2 l of diesel is approx. equal to 1 kg, 83,405 l = 69.5 t, containing 2,988,500 MJ. On the other hand 1 l of kerosene is approx. equal to 0.8 kg, 279,844 l = 223.875 t, containing 9,805,725 MJ. The combined energy use (12,794,225 MJ) and coffee yield (407 t) gives an energy use rate 31,435 MJ/t.

[12] Diesel and kerosene have a CO_2 emission factor of 74,100 and 71,900 kg CO_2eq/TJ respectively (IPCC, 2006). Therefore the above (k) energy contents of diesel (2,988,500 MJ) and kerosene (9,805,725 MJ) emit 221,448 kg CO_2eq and 705,032 kg CO2eq respectively. The combined total is 926,480 kg CO2eq, or 2276 kg CO2eq/t.

[13] Kenya's electricity generation was 7273 GWh less imports in 2010/2011 (GoK, 2012). Its 2010 CO_2 emissions from electricity production were 2.1 million tons (IEA, 2012). Therefore 357,622 kWh emitted 103 t CO_2eq, or 0.3 t CO_2eq/t.

[14] Fossil fuels generated 2288 GWhs of Kenya's electricity in 2010/2011 (GoK, 2012). Out of this, 2020 GWhs were generated by combustion of diesel and 268 GWhs from petrol. Based on the country's electricity generation-related emissions for 2010 (2.1 million tons), this translates to 583,253 tCO_2 and 77,382 tCO_2 respectively. Given the CO_2 emission factors of 74,100 kg CO_2/TJ and 69,300 kg CO_2/TJ for diesel and petrol respectively (IPCC, 2006), the CO_2 emissions come from 7871 TJ of diesel and 1117 TJ of petrol, a total of 8988 TJ. Since 2288 GWhs was produced from 8988 TJ of fossil fuels, it follows that 357,622 kWhs was generated from 1.4 TJ, or 3440 MJ/t of green coffee.

4.3. Embodied Resources in Dutch Cheese

Van Middelaar et al.'s (2011) LCA of Dutch cheese (Fig. 4) was used, minus the retail stage, which was assumed to take place in Kenya. The Dutch cheese study relied on data from Thomassen et al. (2009; 2008), who report purchased concentrate ingredients as originating from within The Netherlands and outside. Generally, a significant part of Dutch livestock feed is imported (cf. De Boer et al., 2013; Van Bruchem et al., 1999). As already indicated under Methodology, the imported ingredients were assumed to be locally sourced, i.e. produced from Dutch domestic resources. Mekonnen and Hoekstra's (2010) reported water footprint for Dutch cheese of 2623 m^3/t (green: 2283, blue: 219, gray: 121) was used. A labor input of 0.118 h/kg of cheese was applied.[15] Tables 5 and 6 show the LCA inventory and embodied resources in Dutch cheese respectively. The first cheese import from The Netherlands to Kenya reported in COMTRADE is in 1995, three years after liberalization of the Kenya dairy industry in 1992 (EPZA (Export Processing Zones Authority), 2005). A sharp rise in imports is seen in 1998 and 2004, and very low figures in 2008 and 2009, giving an overall irregular trend. While this is puzzling, the data for cheese imports from the rest of Europe (EU-27) retrieved from the same COMTRADE database (Table 6) in comparison show a general steady increase over the same period. No explanation for the apparent irregularities could be found, but the data were deemed reliable.

5. Discussion

5.1. Exchange of Kenyan Coffee for Dutch Cheese

More embodied Kenyan resources are consistently exchanged per dollar in the trade of Kenyan coffee for Dutch cheese. This is observed in all the resources considered, namely embodied land, water, energy, and labor. In a hypothesized exchange system in which only these two commodities were under consideration, a net flow of resources to The Netherlands would clearly be realized.

A diagram indicating the quantity of embodied land exchanged per dollar (Fig. 5) shows that Kenya in the trade of coffee for cheese is exchanging more of its embodied land resources for less of Dutch land.

[15] In 2007, the Dutch agricultural sector employed about 165,100 people working full time, with 25% of all the agricultural holdings specialized in dairy farming (Martins, 2008), giving an estimated 41,275 people employed full time. With official working hours of 40 h a week, this translates into 85,852,000 h per year. In the same year (2007), 730,333 t of cheese were produced (CBS, 2014), giving a labor use of 0.118 h/kg cheese.

Table 6
Trade volumes and embodied resources.

Year	Dutch cheese export to Kenya		EU-27 cheese export to Kenya	Embodied resources in Dutch cheese exports to Kenya				
	Export (kg)	Inflation adj. sales (US$)	Export (kg)	Land use (ha)	Water (l)	Energy (MJ)	GWP(kg CO_2eq)	Labor (h)
1995	89	1906	–	0.06052	233,447	4102.01	754.72	10.50
1996	18	1945	–	0.01224	47,214	829.62	152.64	2.12
1997	671	8822	–	0.45628	1,760,033	30,926.39	5690.08	79.18
1998	12,666	65,933	–	8.61288	33,222,918	583,775.94	107,407.68	1494.59
2000	2060	18,450	45,573	1.4008	5,403,380	94,945.4	17,468.8	243.08
2001	1360	11,886	80,264	0.9248	3,567,280	62,682.4	11,532.8	160.48
2002	978	19,321	71,053	0.66504	2,565,294	45,076.02	8293.44	115.40
2004	5253	39,566	65,972	3.57204	13,778,619	242,110.77	44,545.44	619.85
2005	58	1714	50,508	0.03944	152,134	2673.22	491.84	6.84
2007	829	13,688	73,714	0.56372	2,174,467	38,208.61	7029.92	97.82
2008	5	277	98,522	0.0034	13,115	230.45	42.4	0.59
2009	1	99	113,798	0.00068	2623	46.09	8.48	0.12
2010	5856	38,694	113,671	3.98208	15,360,288	269,903.04	49,658.88	691.01
2011	6574	38,067	158,300	4.47032	17,243,602	302,995.66	55,747.52	775.73
2012	3584	22,725	133,965	2.43712	9,400,832	165,186.56	30,392.32	422.91

Source: Trade data sourced from COMTRADE (2014). Embodied resources calculated by author.

The highest inequality of such exchange was in 2002 when US$10,000 was able to buy about 18.58 ha of embodied Kenyan land, while a similar amount of money could only buy 0.34 ha of embodied Dutch land. Virtual water (Fig. 6) follows a similar trend. The exchange of embodied energy per dollar (Fig. 7) also fits the hypothesized ecologically unequal exchange pattern. Through the factor-price equalization theorem, it is claimed that with free trade, the wages and rents earned on capital will progressively equalize across the world (cf. Suranovic, 2010). This is not the case in the exchange of Kenyan coffee and Dutch cheese. There is no discernible convergence in wages since US$10,000 is continuously able to buy more embodied Kenyan labor than Dutch labor (Fig. 8). The generally low wages of coffee workers verifies Emmanuel's (1972) observation that peripheral countries tend to trade many badly paid domestic hours of work for a few hours of well-paid foreign work. Mass is the metric used by MFA. The exchange of mass per dollar yields similar results — more Kenyan mass is exchanged per dollar (Fig. 9).

5.2. Exchange of Kenyan Roses for Dutch Cheese

Analyzing the exchange of Kenyan rose flowers for Dutch cheese presents mixed results. In several instances, the results seem to contradict the EUE hypothesis. The exchange per dollar of embodied land is illustrated in Fig. 10. Here, The Netherlands consistently exchange more of its embodied land resource for less Kenyan land at a fixed market price. In the exchange of virtual water (Fig. 11), no clear pattern of unequal exchange constantly to the detriment of one partner is visible, but Kenya seems to have an advantage, losing out in only five out of the fourteen years under consideration. Energy exchange similarly presents no clear pattern constantly in favor of one trading partner, even

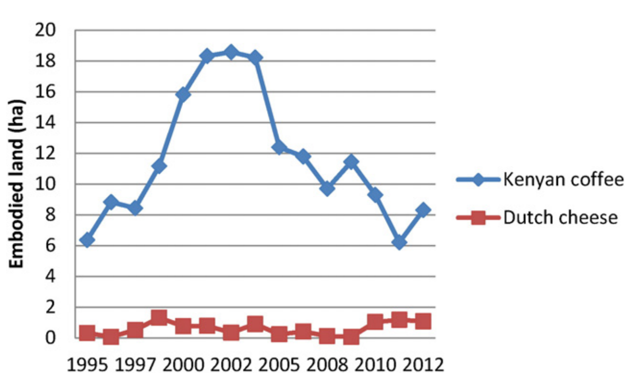

Fig. 5. Exchange of embodied land at fixed (US$10,000) price.

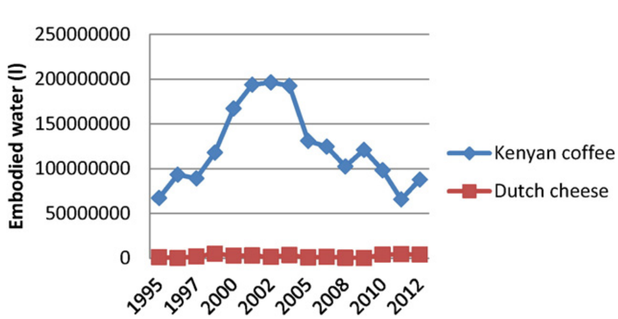

Fig. 6. Exchange of virtual water at fixed (US$10,000) price.

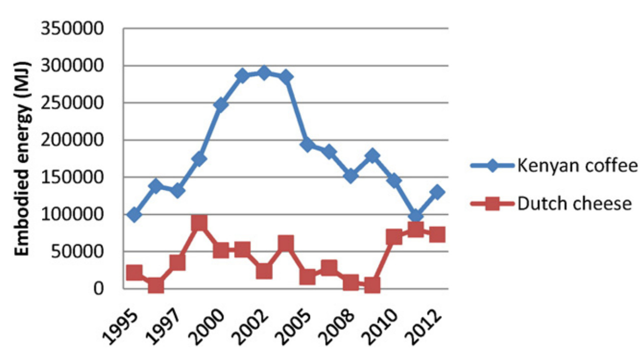

Fig. 7. Exchange of embodied energy at fixed (US$10,000) price.

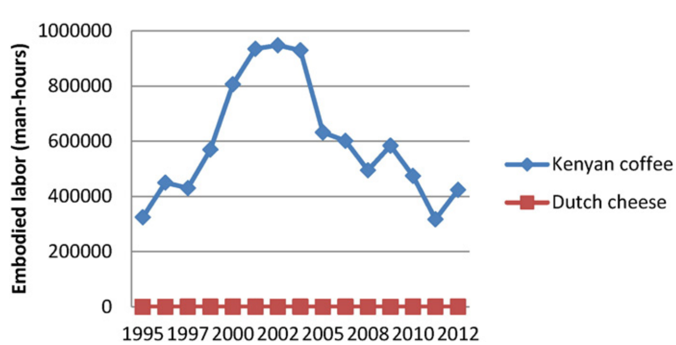

Fig. 8. Exchange of embodied labor at fixed (US$10,000) price.

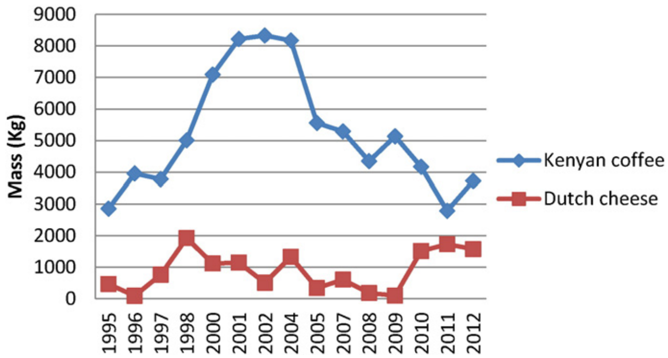

Fig. 9. Exchange of embodied mass at fixed (US$10,000) price.

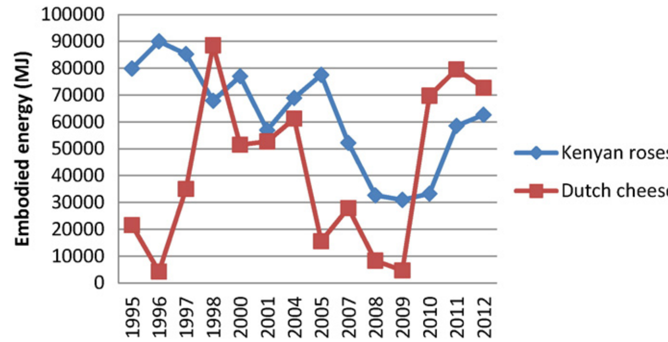

Fig. 12. Exchange of embodied energy at fixed (US$10,000) price.

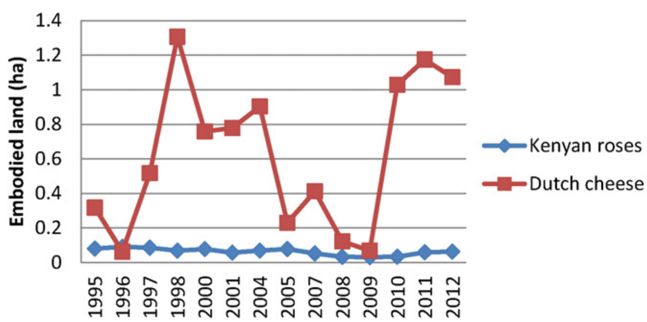

Fig. 10. Exchange of embodied land at fixed (US$10,000) price.

though The Netherlands still has a slight advantage, exchanging less embodied energy per dollar for a combined ten out of the fourteen years considered (Fig. 12).

From a traditional comparative advantage and free market trade perspective, rose flowers would perfectly fit the bill of a product for which Kenya has a 'comparative advantage'. The typical recommendation would thus be for Kenya to continue to invest in and internationally trade in the crop (cf. Hoekstra, 2009b; Mekonnen and Hoekstra, 2011). The export of less water-intensive yet high value roses would thus be a water-saving strategy. Even so, such enthusiasm is tempered by environmental considerations. Cut flower and vegetable farms around Lake Naivasha have been blamed for polluting and reducing the lake's water levels and biodiversity (Becht et al., 2006; Food and Water Watch, 2008; Mekonnen et al., 2012). As Kargbo et al. (2010:7406) puts it, "the tons of flowers flown out of Kenya to Europe go with the lake."

In contrast to the above argument and in line with the EUE theory, we explain the apparently anomalous case of Kenyan rose flowers by its core-like characteristics. Wallerstein (2004) distinguishes core-like and peripheral products based on degree of monopolization, which is directly related to profitability, core-like products being those controlled by quasi-monopolies. Thus, in the exchange process, there is a constant flow of surplus-value from the owners of peripheral products to those of core-like products. Core products are often capital intensive through deployment of technology hence less labor-intense; characterized by a high ratio of capital to market value, spatially aggregated to reduce infrastructure costs and attract a lot of labor which reduces wages, and requires little or no further processing (Bunker, 1985). These conditions, typical of intensive agricultural production in the developed countries, are largely satisfied by Kenyan rose flower production. But technology can serve as a fetish that mystifies relations of unequal exchange (Hornborg, 2011; Hornborg, 2001). Moreover, foreign direct investment (FDI) and international outsourcing of production have been shown to make developing countries more vulnerable to global political–economic conditions and often leads to negative domestic consequences such as environmental pollution and deforestation, suppressed economic development, income inequality, food insecurity, and poor human health (Cavanagh and Hackel, 1983; Jorgenson, 2010). Land tenure regimes in extractive peripheral economies are often under the control and direction of the state (Bunker, 1985). But in the Kenyan flower industry, land and capital is almost exclusively owned by foreign investors and transnational corporations (TNCs) from the developed world (cf. Ngunyi, 2014). These characteristics make Kenyan roses a core product in more respects than not as it is owned and controlled by a quasi-monopoly of capitalists from the developed world who have geographically outsourced its production to Kenya. Apart from the embodied resources, there is nothing Kenyan about Kenyan roses.

Unlike other core products, rose flower production is labor-intensive. Many husbandry activities, harvesting, grading and packaging are difficult to mechanize. This unique characteristic is evident in the exchange of embodied labor (Fig. 13) which, as expected under the EUE theory, shows that at a fixed price, more embodied Kenyan labor is exchanged for less Dutch. Even though the difference seems to have diminished slightly over time, no factor-price equalization is discernible. This is reflective of the huge wage differential between the two countries. Kenyan cut flower workers earn slightly over a dollar a day

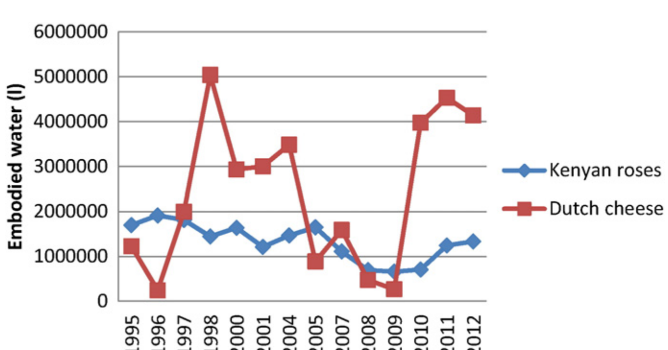

Fig. 11. Exchange of virtual water at fixed (US$10,000) price.

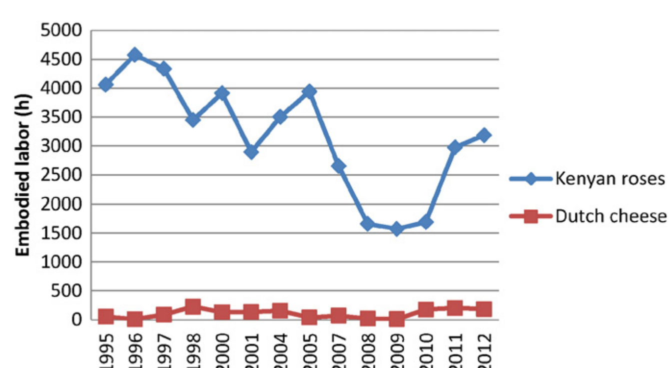

Fig. 13. Exchange of embodied labor at fixed (US$10,000) wage.

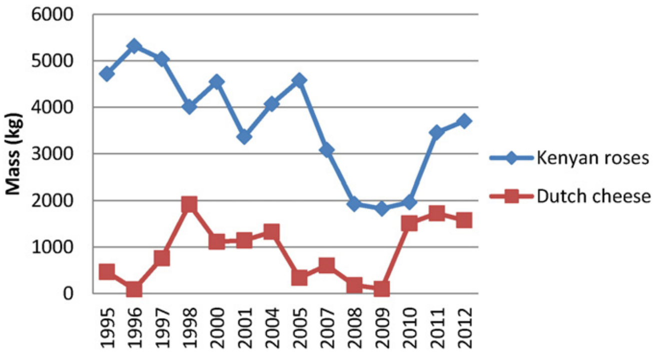

Fig. 14. Exchange of embodied mass at fixed (US$10,000) price.

(Dolan et al., 2003) while the minimum daily wage of Dutch workers is about US$93 (Ministerie van Sociale Zaken en Werkgelegenheid, 2013).

The exchange of mass per dollar also fits the EUE hypothesis (Fig. 14), but in terms of land (Fig. 10), water (Fig. 11), and energy (Fig. 12), The Netherlands seem generally to be losing embodied resources in trading its cheese for Kenyan roses. It seems that the potential for profit inherent in the great wage difference between the two countries has encouraged the establishment of labor-intensive cut flower production in Kenya, even though in terms of embodied resources it appears to contradict the EUE pattern.

5.3. Environmental Load Displacement

The gray water footprints and CO_2 emissions illustrate environmental load displacement, how a country shifts environmental burdens onto another or suffers burdens caused by another (cf. Muradian and O'Connor, 2001), a key characteristic of ecologically unequal exchange. Since they are displaced burdens rather than resources per se, quantifying their exchange per dollar was considered superfluous. However, their different potential impact on the target countries is worth noting. The gray water footprint is the volume of freshwater required to assimilate a load of pollutants based on existing ambient water quality standards (Hoekstra and Mekonnen, 2012). Unlike The Netherlands, Kenya is water scarce (cf. Marshall, 2011). The impact of even equal gray water footprints on the countries' environments and livelihoods can thus be markedly different. Although nations which import embodied CO_2 emissions in energy-intense products do not physically exert their carbon footprint on the providing nation but rather on the global commons (Moran et al., 2009), less developed countries are more vulnerable to climate change (cf. UNFCCC, 2007). Moreover, the offshoring of energy-intensive production stages increase air pollution and can have significant health and environmental consequences in the receiving country.

6. Conclusions

This paper develops and tests an LCA-based methodology for estimating ecologically unequal exchange (EUE) and rejects the ideology of market reciprocity, a key EUE mechanism. In combination with flow data on embodied materials and energy in relation to exchange values, the practicability of the methodology has been demonstrated for trade in specific flagship export commodities exchanged between Kenya and The Netherlands. Although the methodology was applied to specific products, the same approach can be extended to entire economies. This is an area for future research. It should be emphasized here that EUE between two countries or regions can only be conclusively determined if most or all exchanged products are considered in a total physical trade balance (PTB). Such analyses are made easier if comprehensive national product LCA inventories and databases exist. A number of core countries have or are in the process of developing such inventories (cf. Rochat et al., 2013; Thrane and Schmidt, 2007; Van der Voet et al., 2005; Weinzettel and Kovanda, 2009). Not so with many peripheral countries. Such efforts offer a double dividend as they serve regular LCA applications in addition to allowing estimation of EUE.

Ecologically unequal exchange can be demonstrated in several ways, but the clearest illustration is through consideration of the quantity of embodied biophysical resources exchanged per dollar or other unit of exchange value. By holding market price constant, we are able to quantify the asymmetric resource transfers, as well as test a key mechanism through which EUE occurs. This helps empirically lift the veil off the discursive filters and illusions which continue to sustain the free market ideology as fair or tantamount to reciprocity.

Since monetary valuation evidently obscures biophysical unequal exchange, integration of biophysical metrics alongside monetary valuation in international trade is imperative. Revelation of EUE may motivate interested actors and schools of thought to respond differently. One possibility would be the urge to promote certain products in line with the traditional persuasion to pursue comparative advantage, another to try to negotiate 'better' prices in an attempt to 'internalize externalities.' However, such efforts are most likely doomed to fail so long as they do not address the underlying structural and skewed power relations at play. Ultimately, a rethinking of the structure, politics and policies of the international capitalist system of resource exchange is necessary.

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