The effect of a consumption-based accounting method in national GHG inventories: a trilateral trade system application

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The allocation of emissions embodied in international trade is crucial to evaluate the real impact that each country has on climate change and its responsibility in greenhouse gas (GHG) emissions. In this paper, we develop a new theoretical framework recently proposed by Caro et al. (2014) that computes the carbon emissions embodied in international trade according to a consumption-based accounting. The method uses the value of the goods traded internationally and the respective carbon intensity as a coefficient of national efficiency. To provide an example of application of the proposed methodology and assess its difference with respect to the current producer-based GHG accounting, we analyze a trilateral trade system composed by three countries (Sweden, Italy, and Poland) with large differences in terms of carbon intensity (low, medium, and high carbon intensity, respectively). From the analysis of the data during the period 2000–2008, it emerges that the proposed consumption-based accounting would imply an increase of Italian and Swedish emission responsibility by 1.4 and 11.8%, respectively, with respect to the conventional GHG accounting, and a decrease of the Polish responsibility by 2.81%. To assess the possible consequences deriving from the application of this new methodology, we also consider the effects of a shift of the Italian imports from Poland to Sweden of Machinery and Transport Equipments, a crucial sector in the trade relations among the three countries, which accounts for about 45% of total exports from Poland and Sweden to Italy. Finally, we discuss some policy implications deriving from the application of the consumption-based accounting, devoting particular attention to the results emerging from its hypothetical adoption in the EU-27. The analysis performed in the paper suggests that the adoption of a consumption-based accounting could be an important tool in the climate change challenge to reduce global emissions.

Keywords: consumer responsibility, consumption-based accounting, carbon intensity, emissions embodied in international trade, GHG emissions

INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) has defined a complete method to standardize the computation of greenhouse gas (GHG) emissions at national level. Currently, the monitoring of GHG emissions within a territorial system (country, region, etc.) uses IPCC guidelines to realize annual inventories assessing the amount of GHG released in the atmosphere (IPCC – Intergovernmental Panel on Climate Change, 2006). IPCC refers to the principle of geographical responsibility to allocate emissions: GHG emissions are in general assigned on the basis of the source localization. However, according to this principle, if a country imported all the goods that it consumes, it would have zero emissions (except those related to burning fossil fuels) (Bastianoni et al., 2004). Consequently, a real problem emerges for the allocation of emissions related to international trade. For instance, as pointed out by Andersen et al. (2010), if a car is produced in Japan and then exported in France, how should emissions be allocated: to Japan as producer

country or France as the consumer country? This crucial choice determines the results of the GHG inventory and the related policy implications.

Several authors proposed alternative approaches to allocate GHG emissions (e.g., Gupta and Bhandari, 1999; Proops et al., 1999; Baer et al., 2000; Ferng, 2003; Rodrigues et al., 2006; Zaks et al., 2009). In particular, some authors have proposed allocation schemes in which carbon emissions are shared between producers and consumers (Shui and Harris, 2006; Lenzen et al., 2007; Andrew and Forgie, 2008; Rodrigues and Domingos, 2008). These studies have highlighted that production-based accounting does not take into account emissions connected with goods produced elsewhere but consumed within national boundaries, so that the full environmental footprint of a country may not be correctly assessed.

Consequently, the scientific community has focused on an alternative consumer perspective that could complement the geographical/producer-based one by including all driving forces

for GHG emissions associated with consumption (Davis et al., 2011). In this regard, the environmentally extended input–output (EEIO) analysis has long been recognized as a useful tool for attributing GHG emissions or resource use to final demand (i.e., total consumptions by households, private and public national bodies, and government) in a consistent accounting framework (Wiedmann, 2009). Consumer-based GHG profiles estimated with EEIO models include, in monetary terms, imports as process vectors responsible for GHG emissions, as well as the indirect emissions in the total supply chain, assigning these to each consumer country as they directly solicit the production of imported goods and services. Recent contributions, either at the level of policy support or basic research, have attempted to overcome these methodological weaknesses and divergences with the development of international data gathering guidelines and IO manuals (e.g., Eurostat, 2011) as well as multi-regional input–output (MRIO) databases (Wiedmann et al., 2011).

By using EEIO and specific MRIO models, several authors provided important results (Li and Hewitt, 2008; Su et al., 2013). Munksgaard and Pedersen (2001) showed that the CO_2 trade balance of Denmark has dramatically changed, turning into a deficit of seven million tonnes from a surplus of 0.5 million tonnes during the period 1989–1994. Consequently, it has become more difficult for Denmark to reach its national CO_2 target as an increasing part of emissions generated on the Danish territory is caused by foreign demand. Peters and Hertwich (2008) determined the CO_2 emissions embodied in international trade among 87 countries for the year 2001. They found that globally there are over 5.3 Gt of CO_2 embodied in trade and that Annex I countries are net importers of CO_2 emissions. Davis and Caldeira (2010) calculated that, in 2004, 23% of global CO_2 emissions (6.2 $GtCO_2$) were traded internationally.

However, in a recent paper, Lenzen et al. (2012) argue that the adoption of EEIO when dealing with GHGs inventory in international agreements has been limited so far by a number of implementation issues: (i) EEIO models are labor-intensive; (ii) EEIO tables do not cover the entire world and are not always available as a long, continuous time series; (iii) currently, EEIO databases only provide results, without accompanying estimates of reliability and uncertainty. As a consequence, Caro et al. (2014) proposed a new emissions allocation method based on a consumer perspective called national carbon intensity (NCI) method. It is less detailed than the MRIO, as it does not use a specific carbon intensity for each sector and does not include indirect emissions; however, it is easy to apply, not labor-intensive to implement, and no further data is needed beyond those already available at the national level. Furthermore, a comparative analysis with MRIO models performed by Caro et al. (2014) showed that the NCI method gives, in general, a realistic picture of the emissions embodied in international trade and consequently of emissions due to consumption. In particular, comparing the results obtained using our method with those of the EEIO, the differences in terms of emission responsibility between the two methods were found to be below 5% for most of the largest import/export countries (Caro et al., 2014).

In this work, we consider the effects of using the NCI method on the allocation of emissions responsibility. For this purpose, different from the previous contribution, we apply the NCI method to a three nation system, showing how the imports from countries with different emission intensity modify results for each nation with respect to the IPCC computation method. The trilateral trade system examined in the paper can provide a minimal model of a worldwide trade among three macro-areas. A further application at the single sector level is then introduced to discuss how a hypothetical change of trade partners induced by the NCI method would affect each country's emission responsibility. The structure of the paper is as follows. Section "Theoretical Framework" presents the NCI method adopted in the paper. Section "A Practical Application" introduces a practical application for three European countries and shows the results that emerge from this trilateral system. Section "Conclusion" discusses the policy implications that derive from the theoretical and practical analysis.

THEORETICAL FRAMEWORK

According to the NCI method (Caro et al., 2014), the responsibility of each country in terms of GHG emissions can be computed by adding to the traditional IPCC scheme (IPCC – Intergovernmental Panel on Climate Change, 2006) – which adopts a purely geographical criterion – the algebraic sum of the emissions embodied in imported goods minus those embodied in exported goods. The emission responsibility of each country can therefore be formally described as follows:

$$R_i = DE_i - g_i \cdot X_i + \sum_{k \neq i} g_k \cdot M_{k,i} \qquad (1)$$

where R_i is the emission responsibility of country i, DE_i represents the Direct Emission generated inside country i, and actually recorded by the IPCC inventory, g_i is the carbon intensity of country i, i.e., the ratio of a country's GHG emissions to its GDP (expressed in tons of CO_2 equivalents, hereafter referred as to CO_2e, divided by the national production level in monetary terms, see, e.g., Zhang, 2011), X_i is the country's exports in monetary terms, $M_{k,i}$ is the country's imports from k countries (rest of the world) in monetary terms and g_k is the carbon intensity of the k countries from which goods are imported.

Therefore R_i is equal to the emissions generated inside the country, minus the total emissions embodied on average in exported goods, plus the sum of all emissions generated outside the country associated to imported goods.

The term $-g_i \cdot X_i + \sum_{k \neq i} g_k M_{k,i}$ represents the amount of emissions (CO_2e) that should algebraically be added to each country's emission balance with respect to the results obtained by using national IPCC inventory. By applying the methodology to a trilateral system in this paper, we calculate emission responsibility (R) for three generic countries (a, b, c) as follows (Eqs 2–4):

$$R_a = \big[DE_a - (g_a \cdot X_{a-b}) - (g_a \cdot X_{a-c}) + (g_c \cdot M_{c-a}) \\ + (g_b \cdot M_{b-a})\big] \qquad (2)$$

$$R_b = \big[DE_b - (g_b \cdot X_{b-a}) - (g_b \cdot X_{b-c}) + (g_c \cdot M_{c-b}) \\ + (g_a \cdot M_{a-b})\big] \qquad (3)$$

$$R_c = \big[DE_c - (g_c \cdot X_{c-a}) - (g_c \cdot X_{c-b}) + (g_b \cdot M_{b-c}) \\ + (g_a \cdot M_{a-c})\big] \qquad (4)$$

where, for example, X_{a-b} indicates the exports from country "a" to country "b," whereas M_{c-a} denotes the country "a" imports from country "c." Notice that it is obviously $X_{a-b} = M_{b-a}$. Also notice that this theoretical framework can be easily generalized to n countries building up a matrix in order to compute the carbon emissions transferred from/to each nation through international trade.

According to Eqs 2–4, the responsibility assignment strongly depends on the carbon intensity factor. This means that importing goods from a country with high carbon intensity indirectly implies an increase of responsibility for the importer nation. If international agreements, policies, and sanction systems were accordingly modified to reflect the consumer responsibility, this would likely induce final consumers to stimulate the production of goods in countries with cleaner technologies and production processes, thus further enhancing the consequences of a shift from the production- to the consumption-based accounting.

In order to assess the possible consequence of the adoption of NCI method, let us assume that country "a" shifts its imports of a given good from country "b" to country "c," and that such a shift is driven exclusively by the difference in the carbon intensity of these two exporter countries. More precisely, country "c" is assumed to have a lower carbon intensity than country "b," so that country "a" is induced to purchase the goods from country "c" in order to reduce its indirect responsibility.

The effect of this change in the trade dynamics on the emission responsibility of country "a" can be described as follows:

$$\Delta R_a = R_a^* - R_a = g_b \cdot \Delta M_{b-a} + g_c \cdot \Delta M_{c-a} \qquad (5)$$

where R_a^* is the responsibility of country "a" modified after the shift in imports from country "b" to country "c" (i.e., the star at the exponent indicates the new value of the variable R_a after such a shift); $\Delta M_{b-a} = M_{b-a}^* - M_{b-a} < 0$ is the reduction in the amount of imports of country "a" from country "b," whereas $\Delta M_{c-a} = M_{c-a}^* - M_{c-a} > 0$ is the correspondent increase in the amount of imports of country "a" from country "c." For the sake of simplicity, in what follows, we will assume that the economic value of the goods previously imported from country "b" is equal to that of the same goods that is now imported from country "c," that is: $\Delta M_{b-a} = \Delta M_{c-a}$.

A PRACTICAL APPLICATION

We illustrate a practical application of our theoretical framework by focusing on three countries: Italy, Poland, and Sweden. The choice of these countries is primarily due to the values of their carbon intensity, in the EU context: Sweden has one of the lowest carbon intensities within the EU, Poland has one of the highest, whereas Italy shows intermediate values between them (Eurostat, 2011). In addition, there are good commercial relations among all the three countries taken into account. We choose a 9-year period of analysis, from 2000 to 2008, just before the beginning of the global financial crisis. Data for import–export are taken from Eurostat (2011) (**Table 1**).

Eurostat provides also data on gross domestic product, GDP (Current prices-million euros), and GHG net emissions, the latter being collected from other institutions. We used these two data

Table 1 | Import–export among Italy, Poland, and Sweden during the period 2000–2008 (Eurostat data "EU-27 trade since 1988 by HS2-HS4"), million of Euro.

	Italy		Poland		Sweden	
	Poland	Sweden	Italy	Sweden	Italy	Poland
2000 export	2089	3566	4405	1568	2230	939
2000 import	4405	2230	2089	939	3566	1568
2001 export	2199	2935	4624	1379	2157	1049
2001 import	4624	2157	2199	1049	2935	1379
2002 export	2395	3021	4888	1383	2310	1326
2002 import	4888	2310	2395	1326	3021	1383
2003 export	2694	3188	5131	1497	2369	1653
2003 import	5131	2369	2694	1653	3188	1497
2004 export	3565	3632	5394	1714	2602	1978
2004 import	5394	2602	3565	1978	3632	1714
2005 export	4160	3531	5376	1884	2955	2100
2005 import	5376	2955	4160	2100	3531	1884
2006 export	5600	3969	6485	2439	3432	2717
2006 import	6485	3432	5600	2717	3969	2439
2007 export	6411	3899	7939	3017	3911	3211
2007 import	7939	3911	6411	3211	3899	3017
2008 export	6708	3884	8932	3142	3916	3742
2008 import	8932	3916	6708	3742	3884	3142

Table 2 | Carbon intensities of Italy, Poland, and Sweden during the period 2000–2008 (ktCO$_2$e/millions of Euro).

	Italy	Poland	Sweden
2000	0.40	2.03	0.10
2001	0.38	1.74	0.12
2002	0.36	1.70	0.11
2003	0.37	1.91	0.11
2004	0.35	1.78	0.12
2005	0.34	1.48	0.11
2006	0.31	1.37	0.10
2007	0.31	1.20	0.09
2008	0.29	0.99	0.09

sets to calculate the values of carbon intensity for each of the three countries for the period 2000–2008 (**Table 2**).

In order to assess the net emissions embodied in Italy–Poland–Sweden trade, we computed the responsibility of CO$_2$e embodied in our trilateral system trade as expressed in the theoretical framework. **Table 3** presents net emissions relative to bilateral commercial relationships[1].

The result is given by the difference between imported CO$_2$e (given by the economic value of imported goods times the carbon intensity of the foreign producer) and exported CO$_2$e (given by the economic value of exported goods time the carbon intensity of the country). When the value is positive, it means that

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[1]The calculations reported in the table are based on the portion of Eqs 2–4 dealing with trade, that is, the last four terms on the right-hand side of these equations.

Table 3 | Net emissions embodied in Italy–Poland–Sweden trade according to NCI method.

	Italy			Poland			Sweden		
	to-from Poland (A) $[-g_i X_{ip} + g_p M_{pi}]$	to-from Sweden (B) $[-g_i X_{is} + g_s M_{si}]$	Carbon transferred (A + B)	to-from Italy (C) $[-g_p X_{pi} + g_i M_{ip}]$	to-from Sweden (D) $[-g_p X_{ps} + g_s M_{sp}]$	Carbon transferred (C + D)	to-from Italy (E) $[-g_s X_{si} + g_i M_{is}]$	to-from Poland (F) $[-g_s X_{sp} + g_p M_{ps}]$	Carbon transferred (E + F)
	Kt CO₂e	Kt CO₂e	Kt CO₂e	Kt CO₂e	Kt CO₂e	Kt CO₂e	Kt CO₂e	Kt CO₂e	Kt CO₂e
2000	8106	−1.183	6922	−8106	−3082	−11188	1183	3082	4265
2001	7232	−844	6388	−7232	−2277	−9509	844	2277	3121
2002	7443	−832	6610	−7443	−2203	−9646	832	2203	3036
2003	8826	−905	7921	−8826	−2678	−11504	905	2678	3583
2004	8368	−972	7396	−8368	−2827	−11196	972	2827	3800
2005	6538	−886	5652	−6538	−2565	−9104	886	2565	3451
2006	7120	−899	6221	−7120	−3064	−10184	899	3064	3964
2007	7545	−848	6697	−7545	−3325	−10870	848	3325	4173
2008	6955	−763	6192	−6955	−2788	−9744	763	2788	3552
Total (2000–2008)	68134	−8.134	60000	−68134	−24810	−92944	8.134	24810	32944
Yearly average	7570	−904	6667	−7570	−2757	−10327	904	2757	3660

In Eqs 2–4 we associate country "a" to Italy (i), country "b" to Poland (p), and country "c" to Sweden (s).

with the proposed NCI method the country imports additional CO_2e emission responsibility from outside its boundaries; when the value is negative, the country transfers a portion of its CO_2e emission responsibility elsewhere.

Our results indicate that, during the period 2000–2008, Italy has been responsible for additional 68134 kt of CO_2e embodied in all the goods imported from Poland, which equals to 7570 kt of CO_2e/year (CO_2e imported from Poland minus that exported to Poland). Conversely, by adopting our method Italy would transfer emission responsibility equal to 8134 kt of CO_2e exporting products to Sweden, corresponding to 904 kt/year, on average. The opposite is true from the point of view of Poland and Sweden, respectively, in their commercial relationship with Italy. Sweden is also responsible for additional 24810 kt of CO_2e, due to its trade with Poland (2757 kt/year of CO_2e). In general, negative figures are the counterpart of positive ones, because additional responsibility for a single country corresponds to a responsibility transfer from its commercial counterpart.

According to the NCI method, the aggregate 2000–2008 emissions trade balance for Italy, given by the algebraic sum of the annual contribution from commercial relationships with the other two countries, results in a net import of 60000 kt of CO_2e; for Sweden it is 32944 kt CO_2e. Consequently, for Poland 92944 kt CO_2e are transferred to the other two countries. These values, that represent the carbon transferred by each nation in this trilateral scheme, should be added (or subtracted) to the results of the IPCC approach, which ascribes the emissions responsibility exclusively to the producer on the basis of where these are generated (geographical principle). In other words, according to Eqs 2–4, for every country, we should correct the results of the official GHG national inventory (Eurostat, 2011), by adding/subtracting the emission responsibility (in CO_2e) due to trade (carbon transfer

in **Table 3**). **Table 4** compares the results obtained from IPCC inventory and NCI method for the three countries. We calculated that, on average, the results from a consumer perspective are higher than those of the IPCC inventory by about 1.4% for Italy (R_a in Eq. 2), and by about 11.88% for Sweden (R_c in Eq. 4); indeed the NCI method would make Polish emissions lower than the national inventory level by about 2.81% (R_b in Eq. 3).

Let us now consider a further application of the NCI method at the level of the single sector. In particular, a change in the import–export of goods in the class of machineries and transport equipment (MTE) among the three countries is hypothesized in order to evaluate the consequences of a possible change in trade partners induced by the adoption of the NCI method. The choice of this crucial sector is primarily due to its relevance in the international trade among the three countries, since it represents 46% of total exports from Poland to Italy and 45% of total exports from Sweden to Italy (Eurostat, 2011)[2]. Let us suppose that Italy shifts its imports of MTE from Poland to Sweden. The hypothetical unilateral decision of Italy to purchase MTE goods from Sweden instead of Poland would bring about a change also in emission responsibility assignment.

In 2008, Italians spent 4349 million Euro to purchase MTE from Poland (Eurostat, 2011). Let us suppose that this amount of money is completely spent to buy the same goods from Sweden. In terms of emission responsibility, Italy would be less charged than before, due to the difference in carbon intensity between Sweden and Poland; no relevant direct consequences would occur

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[2]Products are classified according to the Combined Nomenclature (CN8), e.g. the aggregate MTE.

Table 4 | Comparison between production-based accounting (IPCC inventory) and consumption-based accounting (*NCI method*) and percentage variation between the two approaches.

	Italy			Poland			Sweden		
	IPCC	NCI	Percentage variation (%)	IPCC	NCI	Percentage variation (%)	IPCC	NCI	Percentage variation (%)
	Inventory I.P.C.C DE$_i$	R_i DE$_i$ + column 4		Inventory I.P.C.C. DE$_p$	R_p DE$_p$ + column 7		Inventory I.P.C.C. DE$_s$	R_s DE$_s$ + column 10	
	Kt CO$_2$e	Kt CO$_2$e		Kt CO$_2$e	Kt CO$_2$e		Kt CO$_2$e	Kt CO$_2$e	
2000	472,749	479,671	1.46	376.704	365.516	−2.97	27.925	32.190	15.27
2001	470,567	476,955	1.36	370.057	360.548	−2.57	30.798	33.919	10.13
2002	465,836	472,446	1.42	356.135	346.489	−2.71	29.349	32.385	10.34
2003	489,859	497,780	1.62	366.568	355.064	−3.14	31.148	34.731	11.50
2004	488,628	496,024	1.51	364.232	353.036	−3.07	33.959	37.759	11.19
2005	484,351	490,003	1.17	361.356	352.252	−2.52	31.347	34.798	11.01
2006	466,947	473,168	1.33	372.589	362.405	−2.73	32.294	36.258	12.27
2007	481,259	487,956	1.39	373.735	362.865	−2.91	31.598	35.771	13.21
2008	448,921	455,113	1.38	360.866	351.122	−2.70	29.691	33.243	11.96
Yearly average			1.40			−2.81			11.88

In Eqs 2–4, we associate "R$_a$" to Italy (R$_i$), "R$_b$" to Poland (R$_p$), and "R$_c$" to Sweden (R$_s$).

in emission responsibility for Poland and Sweden as long as they adequate the production level to the new market conditions. In fact, Poland would not produce MTE not requested by Italy any longer so that it would not emit GHGs to produce and export goods, while Sweden would export the additional GHG emissions related to additional goods produced within the country and now requested by Italy. In other words, the net effect of the shift of the Italian imports from Poland to Sweden can be considered equal to zero for the latter two countries[3]. At the same time, from an economic point of view, Poland would not export goods to Italy any longer, while Sweden accounts for a corresponding amount of additional exports.

We can easily compute the variation in the Italian emissions responsibility deriving from this hypothetical shift in its imports of MTE from one country to another.

We know from **Table 4** that in 2008: $R_i = 455,113$ kt CO$_2$e. According to our hypothesis, Italy does not import MTE from Poland any longer, which implies a responsibility subtraction equal to: 4349 mln€ × 0.99 kt CO$_2$e/mln€ = 4305.51 kt CO$_2$e. At the same time, Italy imports MTE from Sweden, with and additional responsibility equal to: 4349 mln€ × 0.09 kt

CO$_2$e/mln€ = 391.41 kt CO$_2$e. The new responsibility assignment for Italy would then be:

$$R_i^* = 455,113 - 4305.51 + 391.41 = 451,198.9 \text{ kt CO}_2\text{e}.$$

In this case, therefore, by shifting its MTE imports from Poland to Sweden, Italy would decrease its emissions responsibility by 3914.1 kt CO$_2$e (= 4305.51 + 391.41), that is 0.86%, with respect to the case of no change in trade partner.

As in Eq. 5, in which both carbon intensity and import differentials are equally important, we obtain a benefit in terms of CO$_2$ emissions whenever the difference in carbon intensity offsets the import differentials in monetary terms. A country, therefore, will have a reduction in its emissions whenever its import differential does not change (as in our example) or it increases less than the relative difference between the carbon intensity of its trading partners.

DISCUSSION

The NCI method (Caro et al., 2014) assigns to each country the import-related emissions and removes the export-related ones. Emissions imputed are calculated as the product of the economic value of traded goods times the carbon intensity of the producer nation. Therefore, on the one hand, an importer nation will be encouraged to find producers with the best environmental performances; on the other hand, exporter nations will be encouraged to reduce their carbon intensity to meet the higher demand for less polluting goods that may derive from the adoption of the NCI method. International trade is characterized not only by the flow of capital and goods, but also by the energy and emissions embodied in goods during their production (Pan et al., 2008). Giving responsibility to consumer countries in international trade

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[3]Different results would emerge as to the Polish and Swedish emissions responsibility, if we assumed that Poland and Sweden reacted to the new market conditions by modifying their stocks. Thus, for instance, Sweden could meet the higher Italian demand of its MTE by reducing its stocks (corresponding to emissions already produced that are now transferred to another country); similarly, Poland could increase its stocks of MTE as a consequence of the lower Italian demand. This would increase the Polish emission responsibility as the emissions embodied in the Polish MTE are no longer transferred elsewhere. In what follows, we will exclude this case for the sake of simplicity and assume that both countries can immediately adequate their production levels to the change in the Italian import flows.

could induce all the subjects involved in commercial dynamics to improve their environmental performances. If one nation were charged for the emissions embodied in goods imported from a higher carbon intensity country, it would be induced to find a more efficient exporter (with lower carbon intensity) in order to reduce its responsibility. At the same time, if a higher carbon intensity country wanted to maintain its commercial relationships with the other countries, it should decrease its carbon intensity. In our example, if Italy were overburdened by the emissions embodied in goods imported from Poland, it would be prompted to find a more efficient exporter in order to decrease its responsibility. At the same time, if Poland wanted to preserve its commercial relationships with Sweden and Italy, it should reduce its carbon intensity.

Assuming a NCI method viewpoint, consumers should take responsibility for choosing the best strategies and policy by showing a preference for producers, who are attentive to GHG reductions. However, as stated by Bastianoni et al. (2004), producers are not motivated to reduce emissions but indirectly. In other words, the effects of adopting a consumer perspective scheme to account for emission responsibility depend on how much consumers influence producer with their choices. To make this measure effective, a combination of environmental consciousness, economic convenience, and appropriate policies should be taken into consideration.
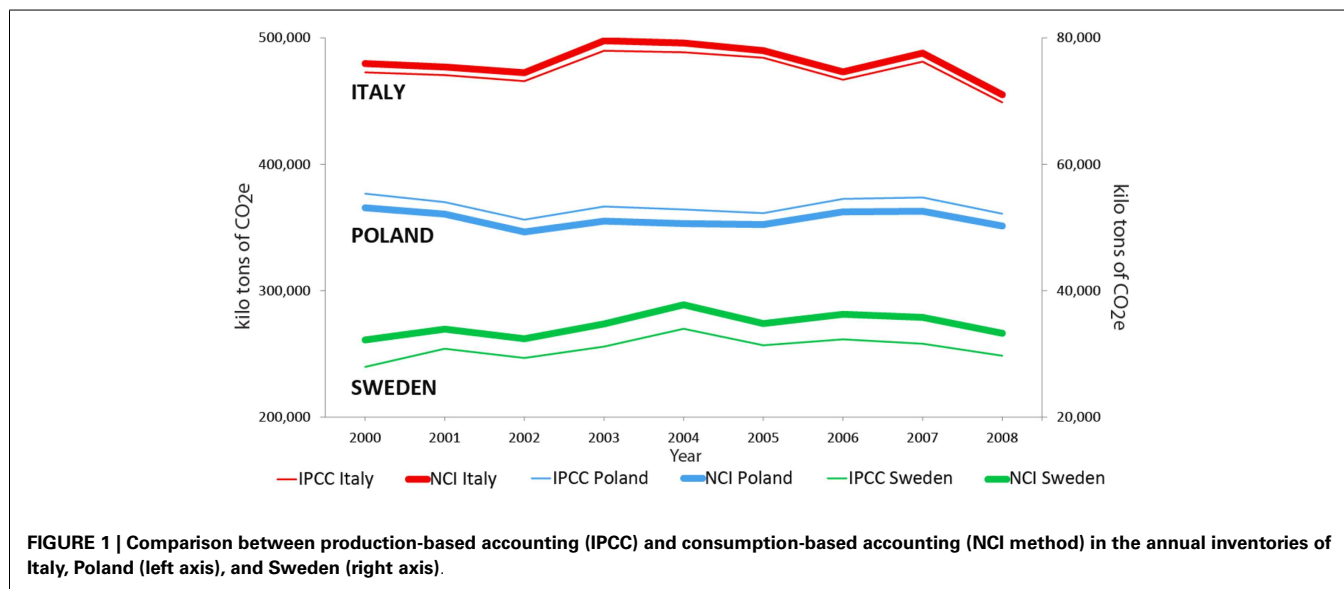
In this practical application (**Figure 1**), the adoption of NCI method would result in lower emission responsibility for the country with highest carbon intensity (Poland), because it exports goods with high carbon content (per Euro), thus transferring emission responsibility elsewhere, and imports goods with low carbon content of which it becomes responsible.

The representation of the country "a" decision to shift from country "b" to country "c" goods contributes to predict the possible consequences of a NCI method in a lapse of time. In our application, the first effect is that Italy would cut its emission responsibility; secondly, Sweden would become a more competitive producer

due to the lower carbon embodied in its goods, and this might result in an increase in GDP, while Poland would have its competitiveness and export capacity (and GDP) reduced. The economic advantage for more efficient countries might more than offset the initial condition of being charged of more emission responsibility than in the case of production-based accounting (**Figure 1**). Finally, Poland would be induced to improve its production processes and efficiency. This new situation may bring about a progressive improvement in production processes aimed at reducing carbon embodied in products and, ultimately, a global reduction of actual CO_2 emissions in the atmosphere.

A further implication can be hypothesized: we can suppose that in order to improve their production efficiency, higher carbon intensity countries could plan to import high technology (in the form of final goods, patents, or simply information) from lower carbon intensity ones. This might result in a "win–win" situation for all countries, as it would satisfy higher carbon intensity country environmental necessities to lower its carbon intensity, while benefiting lower carbon intensity country economies by increasing their exports of technological devices. The higher carbon intensity country imports of clean technologies could also contribute, in the medium run, to restore their market share while stimulating improvements in high technology and emissions reduction in all countries. However, technological expertise and carbon intensity of different countries may not necessarily converge to a common level because more developed economies will always have an incentive to maintain their leadership in industrial efficiency and take economic advantage of this. In general we believe that, in order to solicit adequate incentives and policies for the reduction of climate change in developed and developing countries, the use of a systemic approach to allocate emissions due to international trade in IPCC inventories is crucial.

The advantage of this particular method with respect to the consumer-based accounting characterizing the EEIO analyses is that it is very easy to implement and no further data are needed

FIGURE 1 | Comparison between production-based accounting (IPCC) and consumption-based accounting (NCI method) in the annual inventories of Italy, Poland (left axis), and Sweden (right axis).

than those that are already estimated at the national level. In fact, all we need are the bilateral import/export flows and the carbon intensity of each country, both of which are easily and readily available from many sources. In the case of the EEIO, instead, the quality and quantity of data required are much higher since sectorial information on flows and carbon intensities are needed. The use of indicators (carbon intensity) as tools to evaluate changes in emission responsibility adopted in our approach can be a less detailed but more practical way to obtain adequate advantages and to generate significant policy implications than a consumer perspective obtained through direct and punctual measures (such as the EEIO). It might not be the "ideal" solution, but in our opinion it is more suitable than the present one (IPCC guidelines) to reduce global emissions and it can represent a relevant step toward the consumer perspective (EEIO models), in terms of practical and political feasibility.

CONCLUSION

This paper highlights the problems related to the national GHG inventory approach (IPCC – Intergovernmental Panel on Climate Change, 2006) to estimate emissions embodied in international trade and it applies the NCI method – a theoretical framework recently proposed by Caro et al. (2014) – in order to allocate emission responsibility according to a consumer perspective.

The NCI method adopts a consumer perspective but at the same time it does not replace the current method to estimate national emissions (IPCC), of which it can be considered as a complement. Although the exercise analyzed here is admittedly based on simplistic assumptions, it can provide some interesting insights on the possible implications of adopting a consumption-based accounting that can be easily extended to examine a larger set of countries and different regional aggregation levels. Since the production-based accounting is already calculated for each country that joined the Kyoto Protocol, applying the NCI method is not difficult. In fact, the data that are needed to apply our approach are widely available. The adoption of a consumer perspective would have deep consequences on the global trading system as well as on the international environmental policies aimed at reducing CO_2 emissions. Thus, for instance, it could imply a deep revision of the Emission Trading System proposed by the Kyoto Protocol to cut global carbon emissions. In a consumer perspective, Annex I countries would probably end up with higher emissions responsibility and thus also higher carbon abatement targets with respect to the present production-based accounting. This might lead industrialized countries to increase their demand of tradable permits, with a consequent change in carbon prices and an overall reallocation of tradable permits among participating countries. As shown by the simple theoretical exercise developed here, moreover, the consumer perspective is likely to lead not only to a revision of countries' responsibility with respect to the producer perspective, but also to a consequent change in the trading flows that would further modify the allocation of the emissions responsibility.

In our opinion, the main and ultimate target of the accounting system proposed in this paper should be to generate a trade framework in which countries take binding commitments as a part of a group instead as a individual entities so that the impacts of

trade and global emissions can be acceptably reduced. Although, a deeper analysis of this issue goes beyond the scope of the present paper, this work intends to move a first step in this direction and thus promote future discussion on possible applications and policy implications of the consumption-based accounting.

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