GREENHOUSE GAS EMISSIONS, RESOURCE USE AND ENVIRONMENTAL EFFICIENCY OF ECONOMIES FROM A LIFE-CYCLE PERSPECTIVE*

Aldo Femia,
Renato Marra Campanale

This paper illustrates the results of two environmentally extended input-output applications based on environmental-economic accounts concerning the attribution of environmental flows to final demand. First, total (direct and indirect) GHG emissions of the Italian vertically integrated industries from 1995 to 2008 are presented, including emissions avoided thanks to final and intermediate imports. In this case, the classical IO domestic technology assumption is conveniently integrated with supplementary data in consideration of the inexistence or non-representativeness of some primary industries in Italy.

Then, estimates of the Italian material flows in terms of Raw Material Equivalents (RME) for the period 2000-2010 are presented building on the ongoing Eurostat RME project. RME indicators provide a valuable methodological improvement with respect to the current EW-MFA aggregate indicators, as they overcome the asymmetry between the heterogeneous parts by which the indicators currently in use are produced (flows from nature and traded flows).

In order to derive such estimates, the environmental-economic accounting framework is fully exploited: the link between direct and indirect demand for raw materials on the one hand, and the final use of products on the other hand, is established through Leontief's inter-industry interdependence model.

The paper also proposes an in-depth analysis of the possible use of demand-based measures in the derivation of productivity indicators, focussing on resource productivity. In a policy setting where indirect flows are not neglected, raising carbon or resource productivity by transferring abroad of potential environmental burden is recognised as not being environmentally effective, i.e. as not leading to a reduction of pressures on a global scale. Moreover, we argue that the indicators used to measure productivity should use figures from National Accounts and from Environmental Satellite Accounts coherently.

Keywords: environmental accounts, trade and environment, resource productivity, raw material equivalents, vertically integrated products.

JEL: E01, F18, F64, Q56.

Introduction. In order to evaluate a product's sustainability it is always necessary to consider all the environmental pressures (e.g. materials used or air emissions) during the whole production process chain. It does not matter that goods are light and will eventually create little waste, if in their entire manufacturing process a lot of residuals (emissions, waste, etc.) have been produced. We may refer to this as the life-cycle principle of sustainability (or dematerialisation). Considering that sustainability is basically a global long run issue, a corollary of this principle is that policies must contribute to easing the burden on the earth as a whole and in a lasting way. This means that transferring problems from one country to another does not belong to true dematerialisation. For example, this happens whenever delocalisation of production takes place, and goods formerly produced in country A are subsequently produced in country B (possibly to be imported and consumed into country A anyway). So even if country A does not show waste and emissions directly deriving from that good's production anymore, country B does have these waste and emissions.

Perspectives for addressing environmental pressures and policy consequences. Environmental pressures can be analysed following two approaches based on the Supply and Use tables (SUT) and Input-Output (IO) tables. In the responsibility of the producer perspective (direct flows) the pressures are those of the standard industries, i.e. of the industries defined as the sets of all statistical units that carry out the same (main) economic activity. The statistical data on the environmental pressures by industry made available by many National Statistical Offices through the National Accounting Matrix including Environmental Accounts (NAMEA) framework respond to this straightforward approach [1].

On the other hand, according to the responsibility of the final user perspective (total flows) the environmental pressures are referred to the vertically

Femia Aldo (femia@istat.it) - Senior researcher, Istat (Italian National Institute of Statistics), Rome, Italy.

Marra Campanale Renato (renato.marra@isprambiente.it) - Researcher, Ispra (Institute for Environmental Protection and Research), Rome, Italy.

[*] This paper is based on the information and discussion paper «The Italian experience on demand-based indicators» prepared by A. Femia and R. Marra Campanale for the OECD International Expert Workshop on Demand-based measures of material flows and carbon, held in Paris, 2-3 July 2014.

The article is published in author's original version.

integrated industries, i.e. to the sets of all the production activities that are directly and indirectly necessary to obtain the final products [2]. In this case the focus is, for each industry, on the whole production chain of its final products only. This is a broad process involving parts of all the production system. Therefore, although a vertically integrated industry takes the name from its final products, it is in reality something very different from the standard industry with the same name, being the collection of very diverse activities. Each of the vertically integrated activities resulting from the application of the model is completely autonomous (disjoint) from the rest of the production system, since it encompasses all the phases of the production cycle, from the extraction of natural resources to the final products, through the production of all intermediate inputs, including all ancillary activities connected to commodity transformation and service production. Its environmental pressures are calculated by cumulating pressures of all the parts of the standard industries that contribute to the final result, from the extraction of the necessary natural resources up to the delivery of the final product. Indeed, data responding to the total flows approach may only be a mathematical artefact, i.e. they are not observable data but the result of a calculation based on the NAMEA-like description of the direct pressures, which is therefore a prerequisite for the calculation of the total flows through the environmentally extended Leontievian model, along with the description of the inter-industry structure provided by the SUT and IO tables.

In the responsibility of the final user perspective the total environmental pressures stemming from national production are merely reclassified according to their final purposes, the total amount remaining the same at the domestic economy-wide level. However, the total flows approach allows to go beyond the domestic boundaries, since it is possible and straightforward to extend the application of its logic to the production of traded products, in order to focus on all the environmental pressures caused by final purchases, including the pressures directly stemming in foreign production systems. In this case the vertically integrated industries comprise the pressures embodied in the imported products or avoided thanks to them.

The choice between the two perspectives mainly depends on the driving force - production or final use - one wishes to take as explicit target for policy and on the scope of the environmental objective. Under the direct flows approach the environmental efficiency of the individual (standard) industries is at centre of attention and the target is the contribution at the local level given to the environmental pressures analysed. On the contrary, under the total flows approach, the question is how the level and composition of the final uses should change in order to achieve a given change in the environmental pressures at the global level.

Total greenhouse gas emissions embodied in Italian industries' final products and in imports (1995-2008). Total greenhouse gas (GHG) emissions associated with Italian economic activities including those avoided thanks to international trade are calculated by means of an environmentally extended IO model. The model analyses direct and indirect emissions necessary for producing the final products of the Italian industries (including those activated by final demand through imported intermediate inputs) as well as the products imported for final uses [3].

The Italian IO tables are *ad hoc* integrated in order to overcome the domestic technology assumption. Indeed, the information on some industries (extraction of coal, oil and natural gas, non-energy minerals) provided by the Italian IO tables is not representative, as these industries are almost not present in Italy. For this purpose, the information on their cost structure is provided by inserting three virtual industries to the domestic and import matrices, drawing from other European countries' Eurostat datasets and representing the missing parts of these industries.

In order to identify representative and unrepresentative industries, an analysis of the imported products has been undertaken for the period 1995-2008 from the Italian Supply and Use tables. There are several products - used both as intermediate consumption for further production and as final uses - with a large share of imports from abroad. Within final imports, only five typologies of products directly used by final users draw our attention as for their volumes: «Tobacco products»; «Office machinery and computers»; «Radio, television and communication equipment and apparatus»; «Medical, precision and optical instruments; watches and clocks»; «Motor vehicles, trailers and semi-trailers». As these products only integrate Italian production, Italian industries that produce them are deemed representative of those production processes. In particular, the structure of production and the emission intensities of those industries are representative for those imported products.

As regards intermediate imports, coal, crude petroleum, natural gas and metal ores are the most important products both for their share in total intermediate products and for the lack of an equivalent or representative domestic production. Actually there are other imported products with a relevant share, but they do not meet the second criterion: they are produced in Italy, thus they can be treated according to the domestic technology assumption.

As regards activities that are not well represented in the Italian IO tables, the model is integrated by using data on the structure of intermediate inputs and on emission intensities of the same activities in Norway («Extraction of crude petroleum and natural gas»; «Mining of metal ores») and Germany («Mining of coal»), which have been selected on the basis of the relevance of the imports from these countries and of data availability.

Building on the very meaning of an IO model, the three NACE associated with coal, oil, natural gas and metal ores are split into a domestic and an import activity - thus adding three rows and columns to our IO global model - in order to show more clearly environmental responsibilities. The domestic rows and columns reflect the information comprised in the domestic IO table (Italian domestic intermediate and final demand matrix), as well as the environmental data refer to the Italian production in those industries. As regards the import activities, rows show how the intermediate and final use of the imports of the three industries are distributed among the other activities (Italian import intermediate matrix); columns show the inputs that the three sectors need for their production process, their outputs and the air emissions they produce. In this way the total input coefficients in these three couples of industries reflect both the domestic and the foreign technology.

* * *

Domestic emissions (${}_d\mathbf{E}$) may be written as: total emissions that would have occurred if all production steps had been carried out domestically (**E**) minus emission avoided thanks to (intermediate and final) imports (${}_m\mathbf{E}$)[1]:

$$ {}_d\mathbf{E} = \mathbf{E} - {}_m\mathbf{E}\,. \quad (1)$$

In the following formulae we use: **r** for the vector of GHG emission intensities of output by industry; ${}_d\mathbf{A}$ for the matrix of domestic production direct coefficients; ${}_m\mathbf{A}$ for the matrix of intermediate import direct coefficients; $\mathbf{A}={}_d\mathbf{A}+{}_m\mathbf{A}$ for the direct coefficient matrix of total intermediate inputs; ${}_d\mathbf{Y}$ for the matrix of final uses of domestic products by delivering industry and by category of final demand; ${}_m\mathbf{Y}$ the matrix final uses of imported products by delivering industry and by category of final demand; $\mathbf{Y}={}_d\mathbf{Y}+{}_m\mathbf{Y}$ the matrix of total final uses by delivering industry and by category of final demand.

The global-oriented IO model which calculates the total emissions activated world-wide by the final demand for Italian and imported products is:

$$\mathbf{E} = \langle \mathbf{r}\,(\mathbf{I} - \mathbf{A})^{-1} \rangle\, \mathbf{Y}\,. \quad (2)$$

The actual emissions of the Italian production system, seen from the perspective of activation by final demand for domestically produced goods and services, are reallocated to the vertically integrated industries according to the domestic flows of intermediate inputs:

$$ {}_d\mathbf{E} = \langle \mathbf{r}\,(\mathbf{I} - {}_d\mathbf{A})^{-1} \rangle\, {}_d\mathbf{Y}\,. \quad (3)$$

The emissions avoided thanks to final imports are calculated as:

$$ {}_m\mathbf{E}_y = \langle \mathbf{r}\,(\mathbf{I} - \mathbf{A})^{-1} \rangle\, {}_m\mathbf{Y}\,. \quad (4)$$

The emissions activated by final demand through intermediate imports are calculated as a residual:

$$ \begin{aligned} {}_m\mathbf{E}_x &= \mathbf{E} - {}_d\mathbf{E} - {}_m\mathbf{E}_y \\ &= \langle \mathbf{r}\,[(\mathbf{I} - \mathbf{A})^{-1} - (\mathbf{I} - {}_d\mathbf{A})^{-1}] \rangle\, {}_d\mathbf{Y}. \end{aligned} \quad (5)$$

Results for GHG emissions of the Italian economic activities (1995-2008), based on elaborations on matrices at current prices, are presented in Table 1. Various indicators have been calculated, reflecting different meanings of the Italian economy.

Italian indicators in Raw Material Equivalents. Economy-wide Material Flow Accounts (EW-MFA) provides a whole family of holistic material throughput indicators [4]. Each indicator has its own characteristics and properties, and is therefore suited for representing different concepts. The following components are currently provided in the European Union (EU):

- domestic extraction used (DEU);
- imports (IMP) and exports (EXP) in their simple weight.

The material resources associated to imported and exported products are therefore explicitly excluded.

[1] Matrices are indicated by bold capital letters; vectors by bold lower case letters; scalars by italicized lower case letters. Vectors are rows by definition, so that column vectors are obtained by transposition, indicated by a prime. A diagonal matrix with the elements of any vector on its main diagonal and all other entries equal to zero is denoted by angle brackets < >.

Table 1

Italian GHG emissions ascribable to final demand, 1995-2008
(million tonnes)

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Actual emissions of Italian production (a)	**440.5**	**429.3**	**434.1**	**438.8**	**439.9**	**451.0**	**452.1**	**451.3**	**461.7**	**466.7**	**465.8**	**459.8**	**456.5**	**441.4**
Emissions ascribable to final imports and activated through intermediate imports (m)	***183.1***	***161.0***	***173.4***	***176.0***	***173.7***	***201.6***	***205.1***	***197.1***	***199.8***	***212.3***	***217.6***	***233.2***	***242.0***	***229.3***
of which Emissions ascribable to final demand for imported products (m^f)	38.3	34.6	38.4	40.9	42.6	49.6	47.9	47.6	49.0	52.4	52.5	54.8	56.0	50.4
Emissions activated through intermediate imports (m^i-m-m^f)	144.7	126.4	135.0	135.1	131.1	152.0	157.2	149.6	150.7	159.9	165.1	178.4	186.1	178.8
Total emissions ascribable to all final uses (b=a+m)	***623.5***	***590.3***	***607.5***	***614.7***	***613.6***	***652.6***	***657.1***	***648.5***	***661.5***	***679.0***	***683.4***	***693.0***	***698.5***	***670.7***
of which Total emissions ascribable to Exports (x)	173.9	162.0	169.6	166.7	160.5	187.1	189.1	177.0	177.8	192.0	199.4	211.0	219.5	210.7
GHG footprint of domestic final uses	449.7	428.2	438.0	448.0	453.1	465.5	468.0	471.4	483.6	487.0	484.0	482.0	479.0	459.9
of which Total emissions ascribable to Final consumption expenditure	*351.2*	*338.8*	*345.2*	*353.9*	*356.9*	*361.0*	*365.6*	*365.6*	*378.9*	*376.7*	*378.1*	*369.0*	*364.0*	*354.0*
Total emissions ascribable to Gross capital formation	*98.4*	*89.4*	*92.7*	*94.1*	*96.2*	*104.5*	*102.4*	*105.8*	*104.8*	*110.2*	*105.9*	*113.0*	*115.1*	*106.0*
Emissions ascribable to the final demand for Italian products (c=a+m^i)	585.2	555.6	569.1	573.8	571.0	603.0	609.3	600.9	612.4	626.6	630.9	638.2	642.5	620.2
Balance of emissions embodied in trade (x-m)	-9.2	1.0	-3.8	-9.2	-13.2	-14.5	-15.9	-20.1	-21.9	-20.3	-18.2	-22.1	-22.6	-18.5

In order to derive more comprehensive material use measures, overcoming the environmental burden transferring issue, it is necessary to introduce into the picture the raw materials extracted abroad in order to satisfy the demand for imported products. Indicators in Raw Material Equivalents (RME) express Imports and Exports in terms of the virgin materials that it is necessary to extract from the natural environment in order to produce the traded goods and services. Such indicators do not suffer from the consequent methodological inconsistency. A products' RME indicates the raw materials needed throughout that product's entire production chain. The materials required are included in the RME irrespective of whether they were extracted from the domestic environment or from the rest of the world environment. Also, it does not matter where the materials used to realise an imported product reach their final state: whether they become waste or emissions abroad or are incorporated into the product, they belong to the product and follow it as it passes from one economy to another. This approach allows focussing on a much more complete subset of the potential environmental pressures associated to a country's final purchases, by including waste and emission flows generated abroad from used extraction, to the extent that they are functional to national Final consumption expenditure, Gross capital formation and Exports.

* * *

Italian indirect material resource use associated with Imports, Exports and final domestic uses as well as EW-MFA indicators in RME, are calculated on the basis of a model whose ongoing development is promoted by Eurostat [5].

Eurostat's application has at its core an expanded hybrid IO model, carried out using conveniently detailed IO tables of the EU-27, integrated with physical data. As a matter of fact two main issues were identified as being crucial: i) the lack of detail provided by the standard monetary IO tables of the size 60x60 and ii) the domestic technology assumption for imported products.

The expansion of the standard IO tables is needed as most of the product groups comprise too different products and are not worthy of tracking the flows of raw materials through the economy. Then a specific disaggregation of the standard monetary IO table to the level of 166 products groups was carried out. This disaggregation especially refers to branches of extraction of raw materials (agriculture, and mining and quarrying), to branches of primary processing of raw materials (food industry, basic metal production, production of secondary energy carriers) and to some manufacturing branches (metal and chemical industries).

Monetary use structures were replaced by physical use structures in different units for selected product groups. As a matter of fact monetary use structures are less suitable for tracking the flows of products than physical structures as far as raw products and some primary processed raw products are concerned: agricultural crops, forestry and fishery products, fossil energy carriers, metal ores, non-metallic minerals and materials which are clearly dominated by one raw material category.

This product groups are affected by price differentiation and structural effects. As for the first issue, a physical use structure is required since different prices are paid for the same product, i.e. energy carriers. Structural effects appear where product groups comprise materials affected by different uses, i.e. «Other mining and quarrying products». As a general rule, it has to be assessed case by case whether physical or monetary use structures are suitable. When this is the case, physical use structures should take advantage of all the relevant information available, leaving the monetary relationship as the last option.

The Eurostat hybrid IO model combines IO and Life Cycle Assessment (LCA) approaches. It extends the IO approach for those products which are produced domestically with a LCA external module for those products where no - or negligible - domestic production is given. Raw materials embodied in selected imported products (energy carriers, metal ores and basic metals, up to 60 products) were estimated by an external approach. Imported LCA products are treated as being produced by domestic economy: cumulated material requirements embodied in these products are incorporated into the matrix of domestic extraction and specific changes are carried out in the IO tables (rows and columns are added for LCA products, imports of LCA products are set to zero). In this way, in estimating the RME for export products, the import of products used to produce export products is taken into account.

Eurostat provides EU RME import and export coefficients for the period 2000-2010 in a two-dimensional matrix per material categories based on the EW-MFA Questionnaire on the most detailed level (52 materials) and per 166 product groups. Therefore the methodology that Eurostat applies not only improves the EW-MFA indicator of domestic material consumption from DMC to RMC, but also establishes an ecological and economic connection. As a matter of fact RMC originates from an environmental-economic framework as it is linked to the underlying driving forces behind the Leontief's model and to the environmental impacts thanks to the detail by material.

* * *

In the Italian application, Imports in RME are calculated by using the average EU coefficients provided by the model, using the import or export coefficients from the Eurostat model according to the affinity between the Italian and the EU trade patterns. Italian imports are split into their intra-EU and extra-EU components, and EU level import coefficients are applied in the RME estimation for the Italian extra-EU trade, while EU level export coefficients are applied in the RME estimation for the Italian intra-EU trade.

Exports and domestic final uses in RME are estimated by a subsequent modelling application based on Italian IO tables (59x59 product groups), made hybrid on the basis of Eurostat's methodology which has been conveniently integrated by using additional data such as physical energy accounts and Material Flow Accounts. The physical inputs to the economy are domestic extraction used and imports in RME. Then the standard Leontief calculation is integrated by replacing monetary use structures of the following product groups by physical structures due to the heterogeneity of highly aggregated product groups:

- *CPA 14 «Other mining and quarrying products»*[2]: this product group comprises both low (sand and stone) and high (industrial minerals) priced materials used in domestic production and exported respectively. Structural effects arise since the composition within this group varies widely by users and the IO model would apply the average monetary use structure for the CPA 14, which entails overestimation of exports in RME. The physical use structure (in tonnes) of «Other mining and quarrying products» builds on the domestic extraction, imports and exports of material flows of «Non-metallic minerals» of the Italian EW-MFA accounts. Domestic extraction minus exports of non-metallic minerals follows the IO monetary domestic relationships; imports of non-metallic minerals follow the IO monetary import relationships;
- *CPA 02 «Products of forestry, logging and related services»*: the physical use structure (in tonnes) of «Products of forestry, logging and related services» derives from the domestic extraction, imports and exports of material flows of «Wood and wood products» of the Italian EW-MFA accounts. Domestic extraction minus exports of «Wood and wood products» follows the IO monetary domestic relationships; imports of «Wood and wood products» follow the IO monetary import relationships;
- *CPA 05 «Fish and other fishing products; services incidental to fishing*»: the physical use structure (in tonnes) of «Fish and other fishing products; services incidental to fishing» derives from the domestic extraction, imports and exports of material flows of «Wild fish catch, aquatic plants/animals» of the Italian EW-MFA accounts. Domestic extraction minus exports of «Wild fish catch, aquatic plants/animals» follows the IO monetary domestic relationships; imports of «Wild fish catch, aquatic plants/animals» follow the IO monetary import relationships;
- *CPA 10 «Coal and lignite*; peat»: for establishing the physical use structure (in tonnes of oil equivalent) of «Coal and lignite; peat» information is derived from Istat's Energy Use Tables, which provide energy uses of production activities (by industry) and households, and from the Italian National Energy Balances. The latter source is used to input-output, imports and exports of coal, lignite and peat;
- *CPA 11 «Crude petroleum and natural gas; services incidental to oil and gas extraction excluding surveying*»: the physical use structure (in tonnes of oil equivalent) of «Crude petroleum and natural gas; services incidental to oil and gas extraction excluding surveying» derives from Istat's Energy Use Tables (energy uses of crude oil and natural gas by industry and energy uses of households), and from the Italian National Energy Balances (output, imports and exports of crude oil and natural gas);
- *CPA 23 «Coke, refined petroleum products and nuclear fuels*»: the following energy products are comprised in the physical use structure which replaces the monetary use structure of CPA 23: coke, coke oven gas, blast furnace gas, non-energy coal products, gas work gas, LPG, refinery gas, naphtha, motor gasoline, jet fuel, diesel oil, fuel oil, petroleum coke, other non-energy oil products. The physical

[2] CPA 14 comprises: stone, sand and clay, chemical and fertilizer minerals, salt, other mining and quarrying products n.e.c. (bitumen and asphalt, natural; asphaltites and asphaltic rock; precious and semi-precious stones; pumice stone; emery; natural abrasives; other minerals nec).

use structure (in tonnes of oil equivalent) of «Coke, refined petroleum products and nuclear fuels» derives from Istat's Energy Use Tables (energy uses by industry and energy uses of households of the above-mentioned energy products), and from the Italian National Energy Balances (output, imports and exports of crude oil and natural gas);

• *CPA 40 «Electrical energy, gas, steam and hot water»*: the physical use structure (in tonnes of oil equivalent) of «Electrical energy, gas, steam and hot water» derives from Istat's Energy Use Tables (energy uses of electricity by industry and energy uses of households), and from Terna - the company that manages energy transmission in Italy - (output, imports and exports of electricity).

EW-MFA indicators for the Italian economy, expressed in RME, are synthetically shown in Table 2, next to the corresponding «traditional» indicators (including direct flows only). These indicators describe the material flows associated to different monetary aggregates.

The indicators are presented within a consistent and systematic origin-purpose framework, which allows for consideration of the relationships between different indicators. We can see in this table's top and bottom halves, respectively:

- materials used to satisfy Italy's final demand, by extraction, origin and kind of resources (the materials supply side). Imports in RME as reported here are, for each year, the synthesis of a table stemming from the application of the Eurostat coefficients. The latter table, not shown here, includes the requirement of each of 52 materials by 166 distinct product groups (goods and services);

- the same materials, re-attributed to their final use purpose (the materials «demand» side). Final uses are classified here only by final demand category (Final consumption expenditure, Gross capital formation and Exports) and not by product group. But the model results' dataset comprises, for each year, 59 product groups, and for each of these, 52 different materials. Moreover, for each material of each product group, the data are further split by origin of the virgin material (domestic or foreign). This side of the account stems from the reallocation of the materials in the supply side to final demand by category and of product, i.e. from the application of the Italian hybrid Leontievian IO model.

A focus on Resource Productivity. Resource Productivity (RP) points to the efficiency with which materials are used in production. This normatively relevant concept currently guides some important policy-making processes, especially at the European level [6, 7, 8] and in Japan where it is used in the Resource Conservation Policy. The RP concept may be made operational in a number of ways. It is defined within the EU Sustainable Development Strategy as the ratio between Gross Domestic Product (GDP) and Domestic Material Consumption (DMC) [9]. This ratio and its changes through time are meant to provide a clear indication of economic growth's decoupling from material resource use.

However the RP indicator adopted by the EU lacks a great deal in life-cycle perspective: it does not present the complete picture as this measure does not account for the raw materials used to produce traded products. This makes it a doubtful measure for a country's overall material resource needs.

Indeed, the material resources included in a country's DMC correspond neither to those required for generating that country's GDP, nor to those physically embodied in the products whose value is measured by that GDP. This is the case for whichever relevant National Accounting monetary aggregate one may want to take into account: total end uses (consumption plus investments plus Exports), domestic end uses (consumption plus investments), end uses of domestic production (the part of total end uses coming from domestic production) or domestic end uses of domestic production.

Another way to describe this shortcoming is to say that DMC is not neutral to the localisation of activities but - due to its components' inherent asymmetry - it is distorted by the environmental pressure transfer issue described above. The upstream indirect material flows of traded products, also referred to as the «ecological rucksack», are not included in the picture. As a consequence DMC falls when - *ceteris paribus* - a country's activity mix changes in favour of activities at the production chain's end. It is no wonder, therefore, that resource-poor countries, some of which are big importers not only of raw materials but also of intermediate and final products, tend to rank high in RP. Symmetrically, the use of DMC for RP's calculation disadvantages resource-rich countries in which the initial and most waste- and pollution-intensive transformation phases take place.

All this should by no means lead us to refrain from using DMC, but only from using it uncritically and to be aware of its limitations as a resource use indicator. DMC has, on the contrary, an important meaning which should be acknowledged, and to which reference should always be made when using it.

Table 2

Domestic and global resource use associated with Italian production and consumption, by materials origin and type, and by materials use purpose (final demand). Italy, 2000-2010

(million tonnes)

Aggregates	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Materials' origin and type											
Domestic natural environment (Direct Used Extraction)	**699.5**	**682.8**	**615.7**	**528.4**	**577.7**	**606.4**	**598.8**	**573.6**	**560.3**	**510.3**	**463.4**
Biomass	138.2	131.5	134.3	116.3	138.4	140.2	126.3	122.4	124.2	117.2	115.2
Metal ores	0.4	0.2	0.3	0.2	0.0	0.0	0.0	-	0.7	0.3	0.7
Non-metallic minerals	543.8	536.0	465.2	396.4	423.0	449.9	458.1	437.5	422.7	381.2	334.6
Fossil energy resources	17.1	15.1	15.9	15.5	16.4	16.3	14.4	13.7	12.7	11.6	12.8
Foreign natural environment (Imports in RME)	**737.5**	**745.0**	**745.3**	**751.6**	**756.1**	**747.1**	**804.0**	**833.3**	**789.5**	**661.4**	**765.3**
Biomass	117.8	109.8	112.6	108.4	108.7	103.8	106.6	113.1	107.8	110.7	119.5
Metal ores	201.9	208.9	209.0	210.2	217.0	213.5	249.9	251.7	242.5	173.2	223.3
Non-metallic minerals	93.3	100.4	100.7	101.7	96.9	96.7	106.0	117.5	104.9	86.7	105.0
Fossil energy resources	324.5	325.9	322.9	331.3	333.5	333.2	341.4	351.0	334.4	290.9	317.6
Total Input in RME (RMI)	**1437**	**1428**	**1361**	**1280**	**1334**	**1354**	**1403**	**1407**	**1350**	**1172**	**1229**
of which direct flows (**DMI**)	1033.9	1018.3	955.4	877.6	943.8	973.4	980.1	957.3	929.4	822.6	808.2
of which actually embodied in **Imports (direct Imports)**	334.4	335.4	339.7	349.2	366.0	366.9	381.4	383.7	369.1	312.4	344.8
Materials' use purpose (final demand)											
Raw Material Consumption (RMC)	**975.1**	**960.3**	**926.3**	**868.3**	**894.0**	**899.8**	**911.1**	**893.2**	**858.5**	**738.9**[(a)]	**731.8**[(a)]
Final consumption expenditure	604.5	605.1	586.1	560.4	569.4	575.1	563.3	552.6	543.7		
households	*547.7*	*543.4*	*526.0*	*502.3*	*510.6*	*514.4*	*503.8*	*493.7*	*484.0*		
government and non-profit organizations serving households	*56.8*	*61.7*	*60.1*	*58.2*	*58.8*	*60.8*	*59.5*	*58.9*	*59.8*		
Gross capital formation	370.6	355.3	340.3	307.8	324.6	324.7	347.8	340.6	314.7		
Exports in RME	**461.9**	**467.2**	**434.4**	**411.5**	**439.7**	**453.7**	**491.4**	**513.5**	**491.4**	**432.8**[(a)]	**496.9**[(a)]
RMC + EXP_{RME} = RMI	**1437**	**1428**	**1361**	**1280**	**1334**	**1354**	**1403**	**1407**	**1350**	**1172**[(a)]	**1229**[(a)]
of which direct flows (**DMC**)	910.2	890.6	832.3	751.3	810.1	833.0	836.7	796.7	773.2	689.5	657.2
of which actually embodied in **Exports (direct Exports)**	123.7	127.7	123.1	126.3	133.6	140.4	143.4	160.6	156.3	133.1	151.0
Other indicators:											
Physical trade balance	210.7	207.8	216.6	222.9	232.4	226.5	237.9	223.1	212.9	179.3	193.8
Physical trade balance in RME	275.6	277.8	310.9	340.1	316.4	293.4	312.6	319.8	298.2	228.6[(a)]	268.4[(a)]

(a) Estimates based on aggregate data.

First, let us draw a distinction between the environmental pressures that the human system exerts at the material input side - i.e. those immediately due to resources extraction - on the one hand, and those it exerts at the material output side - i.e. those immediately connected to the form taken by the materials at the end of the annual production and consumption cycles - on the other hand.

If we look at the materials' economic cycle from the latter perspective, we see that DMC is equal to the sum of net addition to stocks, emissions and wastes, products' dissipative uses and dissipative losses. In other words, DMC comprises all the used materials that contribute to a country's environmental pressures on the material output side, regardless of whether the materials were extracted domestically or imported. It is important not to be misled, with regards to DMC's meaning, by the way it is calculated. This quantity's real meaning, in fact, is connected to the output side even if it is calculated as a sum of inputs. This connection of the two sides is granted by the law of matter conservation. For these reasons, DMC would be more correctly interpreted as a holistic potential pressures indicator than as a resource use indicator, even though the latter interpretation currently prevails. Using the GDP/DMC ratio in a sustainability monitoring context is not at all wrong in itself, but it is not appropriate to call it an RP indicator. Rather it should be called something along the lines of «productivity of potential pollution».

Table 3 shows three possible alternative formulations of the RP indicator seen above (the table referred to the indicators for Carbon Productivity is provided in the Annex. *Mutatis mutandis*, the above RP rationale still holds true for Carbon Productivity).

They all express an average «value per unit material flow», but interpret the RP concept in different ways. The table shows the possible combinations of numerator and denominator that we deem most relevant, i.e. the one currently used by the EU (GDP/DMC), its version using RMEs with regards to the material flows, and two other ones who have the characteristic that the numerator and the denominator are formally coherent with each other. By «formally coherent» we mean that for each value component of the numerator (GDP, IMP, EXP), a corresponding physical flow in RME is represented (with the same sign) in the denominator (DE, Imports in RME, Exports in RME). The latter ratios express a relationship between the two ends of the production chains: the natural resources extracted from the environment and used, at one end; the net value of production emerging from the production chain, i.e. the value of the products delivered to final demand,

Table 3

Current and alternative indicators for Resource Productivity

		Denominator		
		Domestic Material Consumption (DMC)	Raw Material Input (RMI)	Raw Material Consumption (RMC)
Numerator	Gross Domestic Product (GDP)	**Productivity of potential pollution**: GDP per unit of potential pressures on the economy's output side from the direct (domestic) material consumption		**Productivity of Raw Material Consumption, as would result by a simple substitution of DMC with RMC in the GDP/DMC formula (no consistency between numerator and denominator)**: GDP per unit of the used resources that are needed at the global level for the production of the goods and services delivered to domestic final uses (Final consumption + Gross capital formation)
	Total economic resources available for final uses (GDP+IMP)		**Productivity of Raw Material Input**: economic resources available for all uses of final domestic production per unit of resource use needed at the global level	
	Total economic resources available for domestic final uses (GDP+IMP-EXP)			**Productivity of Raw Material Consumption (with consistent numerator and denominator)**: Total economic resources available for domestic final uses per unit of the resources needed at the global level for their production

at the other end (the reader should keep in mind that GDP + Imports = Final Consumption +Gross Capital Formation + Exports). The very reasoning by vertically integrated sectors that leads to RME figures for Imports and Exports makes this coherence something more than just a matter of form, as it guarantees that there is a clear functional relationship between the two ends.

Once RME indicators are considered for inclusion in the policy-making toolbox, the issue cannot be reduced to simply substituting DMC in its current use by its RME version (i.e. RMC). When going from the current «direct material-flow» type of indicators to RME indicators, a change of meaning of the indicators must be explicitly acknowledged and dealt with.

It should be noted instead that, in the current debate, the fact that RMC overcomes DMC components' asymmetry seems to be automatically considered sufficient to substitute DMC, wherever it appears, with RMC. However, it is not at all granted that RMC should replace DMC in all its uses. The point is that, while DMC has its own meaning as a holistic potential (domestic) pressure indicator, RME indicators are comprehensive resource use indicators for entire national economies. The latter comprise sectors and activities which produce for domestic demand as well as sectors producing for foreign demand. There is no self-evident reason why the exporting part of the economy should be excluded, when it comes to measuring the economy's Resource requirements and Productivity. Exports value is indeed included in GDP. Why should Exports RME be excluded from RP's denominator, then?

Conclusions. The analysis carried out above highlights some issues in the current understanding of the policy use of EW-MFA indicators in the RP context. As a matter of fact a clear distinction between meanings and roles of different value-per-material-flow-unit indicators, in relation to different policy targets is needed.

DMC is a holistic potential pressure indicator. As such, its most appropriate use is not as a resource use measure and it does not suffer from the asymmetry between its components (DE and Imp/Exp). It is *per se* a significant sustainability indicator as it addresses, when related to GDP, the «potential pressure per GDP», rather than a RP indicator. Moreover, DMC/GDP is a significant efficiency indicator for national economies, as it expresses the productivity of potential pressures.

A value-per-material-flow-unit indicator, genuinely expressing *Resource* Productivity is better expressed in terms of value per RME unit and is better referred to the value of the final results of the production chains, rather than to GDP, since value generation chains are intrinsically global and the resource needs of the value added generated in a given country cannot be disentangled from the resource needs of the value added generated in other countries (double counting will always be unavoidable: each of the subsequent works carried out on the same material adds value at all steps). On the contrary, the «final user perspective» is correctly applied to the products delivered to final uses, the resource requirements of which can thus be singled out by kind of use (and also by kind of product).

DMC's formal analogue in RME terms, i.e. RMC, is not automatically DMC's best substitute for RP calculation, since RMC excludes a substantial part of a nation's material resource requirements, namely those of its exporting activities.

Interesting candidates as RP indicators are:

• Final Domestic Uses/RMC (i.e. Consumption plus Gross Capital Formation per unit of its own RME), whose numerator deviates from GDP only by the commercial balance;

• Total Final Uses/RMI (i.e. Consumption plus Gross Capital Formation plus exports per unit of its own RME), which reflects also the RP of the exporting part of the economy.

References

1. **Tudini A., Vetrella G.** NAMEA: from pioneer work to regulation and beyond // Hybrid economic-environmental accounts. Ed. by Costantini V., Mazzanti M., Montini A. - Routledge London, UK, 2011. P. 9-20.

2. **Pasinetti L.** The notion of vertical integration in economic analysis // Metroeconomica, XXV. - 1973. P. 1-29.

3. Eurostat. Manual for Air Emissions Accounts. - European Communities. Luxembourg, 2009.

4. Economy-wide material flow accounts and derived indicators. A methodological guide. Eurostat. - European Communities. Luxembourg, 2001.

5. **Schoer K., Giegrich J., Kovanda J., Lauwigi C., Liebich A., Buyny S., Matthias J.** Conversion of European product flows into Raw Material Equivalents. Final report of the project: Assistance in the development and maintenance of Raw Material Equivalents conversion factors and calculation of RMC time series. - ifeu (Institut f?r Energie - und Umweltforschung). - Heidelberg. - 2012.

6. A resource-efficient Europe - Flagship initiative under the Europe 2020 Strategy. European Commission. - Brussels. - 26.01.2011 - COM(2011) 21.

7. Roadmap to a Resource Efficient Europe. European Commission. - Brussels. - 20.09.2011 - COM(2011) 571 final.

8. Decision 1386/2013/EU of the European Parliament and of the Council of 20 November 2013 on a General Union

Environment Action Programme to 2020. Living well, within the limits of our planet. Official Journal of the European Union. - 28.12.2013 - L354/171.

9. Sustainable development in the European Union. 2013 monitoring report of the EU sustainable development strategy. Eurostat. - Luxembourg, European Union. 2013.

Annex

Table A

Indicators for Carbon Productivity

		Denominator		
		Direct emissions	Global emissions	Footprint
Numerator	Gross Domestic Product (GDP)	**Production-based Productivity:** GDP per unit of emission on the economy's output side		
	Total economic resources available for final uses (GDP+IMP)		**Demand-based Productivity:** economic resources available for all uses of final domestic production per unit of emission needed at the global level	
	Total economic resources available for domestic final uses (GDP+IMP-EXP)			**Footprint Productivity**: total economic resources available for domestic final uses per unit of emission needed at the global level for their production

ВЫБРОСЫ ПАРНИКОВЫХ ГАЗОВ, РЕСУРСОПОЛЬЗОВАНИЕ И ЭКОЛОГИЧЕСКАЯ ЭФФЕКТИВНОСТЬ ЭКОНОМИКИ С ТОЧКИ ЗРЕНИЯ ЖИЗНЕННОГО ЦИКЛА

Альдо Фемиа

Аффилиация: Национальный институт статистики (Рим, Италия). E-mail: femia@istat.it.

Ренато Марра Кампанале

Аффилиация: Институт охраны и исследования окружающей среды (Рим, Италия). E-mail: renato.marra@isprambiente.it.

В статье представлены результаты расчетов двух вариантов применения модели «затраты-выпуск», учитывающей экологическую составляющую и основанной на эколого-экономических счетах, отражающих включение экологических потоков в конечный спрос. Во-первых, представлен общий объем выбросов (как прямых, так и непрямых) парниковых газов вертикально интегрированных промышленных отраслей Италии за период с 1995 по 2008 г., включая и те выбросы, которые не были произведены по причине импорта продуктов конечного и промежуточного использования. В этом случае классическая модель "затраты-выпуск", предполагающая учет отечественной технологии, хорошо интегрирована с дополнительными данными, учитывающими фактически не существующие или не представленные в Италии отрасли промышленности.

Кроме того, даны оценки материальных потоков в Италии, а именно сырьевых эквивалентов, за период с 2000 по 2010 г., построенные в рамках реализации текущего проекта Евростата. Использование показателей сырьевых эквивалентов оказывает положительное влияние на методологию расчета агрегированных показателей текущих счетов потоков материалов в масштабах экономики (СПМ-МЭ), так как благодаря им преодолевается асимметрия между разнородными частями, на основе которых в настоящее время строятся эти агрегированные показатели (природные источники и потоки торгуемых товаров). Для получения такого рода оценок необходимо в полной мере использовать систему эколого-экономических счетов: связь между прямым и косвенным спросом на сырье, с одной стороны, и конечным использованием товаров - с другой, устанавливается через модель межотраслевого баланса Леонтьева.

В статье также предложен углубленный анализ возможности использования измерений на основе спроса для построения показателей продуктивности, в частности показателей ресурсной продуктивности.

Делается вывод о том, что политика, в которой учитываются непрямые потоки, а углеродная или ресурсная продуктивность повышается путем перемещения за границу потенциальной экологической нагрузки, является экологически неэффективной, так как не приводит к снижению воздействия на окружающую среду в глобальном масштабе.

Авторы также утверждают, что для показателей, применяемых для измерения продуктивности, следует использовать согласованные данные из национальных счетов и сателлитных экологических счетов.

Ключевые слова: экологические счета, торговля и окружающая среда, ресурсная продуктивность, сырьевые эквиваленты, вертикально интегрированные продукты.

JEL: E01, F18, F64, Q56.