

London Group on Environmental Accounting
XVIII meeting
London, November 2013
MFA/Waste Session

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***On Raw Material Equivalents and their correct use in
Resource Productivity (RP) indicators***

INFORMATION and DISCUSSION PAPER concerning POLICY DEMAND FOR EW-MFA
INDICATORS

Abstract

Estimates of material flows in terms of Raw Material Equivalents (RME) 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 make up the indicators currently in use. In order to derive such estimates, the environmental-economic framework provided by Environmental Accounts is fully exploited. The link between the 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.

This paper illustrates the results of an application on a EW-MFA methodologically very advanced tool, which allows to produce accurate estimates of the material resource use of a country (in our application, Italy's). In these estimates, the material resource use is expressed in RME. We also propose an in-depth analysis of the possible use of these estimates in the derivation of RP indicators suitable for use in a policy setting where indirect flows are not neglected. In such a policy setting, raising RP 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 RP should use figures from the National Accounts and from Satellite Accounts for the Environment in a consistent way.

Introduction¹

In order to evaluate a product's sustainability it is always necessary to consider all the materials used during the whole production process chain and not just at the final product weight. It does not matter that goods are light and will eventually create little waste, if in their entire manufacturing process a lot of residues (emissions, waste, ...) have been produced. We may refer to this as the "life-cycle principle" of dematerialisation. A corollary of this principle is that, since sustainability is basically a global long-run issue, policies, even when implemented at the local level, must contribute to easing the burden on the earth as a whole and in a lasting way. "On the earth as a whole" means that transferring problems from one country to another does not belong to true dematerialisation. Problems are only moved, but not lessened. For example, this happens whenever production delocalisation takes place and goods formerly produced in country A are subsequently produced in country B and then imported into country A anyway. So even if country A has no more waste and emissions directly deriving from that good's production, country B does in its place.

EW-MFA indicators in Raw Material Equivalents

Economy-wide Material Flow Accounts (EW-MFA) provides a whole family of holistic material throughput indicators. Each indicator has its own characteristics and properties, and is therefore suited for representing different concepts. The following components are currently provided in the 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 This paper is based on R. Marra Campanale and A. Femia *Transferring the Burden Abroad: An Environmentally Ineffective Way to Increase Resource Productivity*, [forthcoming](http://www.mdpi.com/journal/resources/special_issues/sustainable-resource-management) (submitted for the Special Issue "How Much Environment Do Humans Need? +20 - Reviewing Progress in Material Intensity Analysis for Transition towards Sustainable Resource Management", online journal "Resources" http://www.mdpi.com/journal/resources/special_issues/sustainable-resource-management)

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 product's 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 indicators in RME

Italian indirect material resource use associated with Imports, Exports and final domestic uses, and then EW-MFA indicators in RME, are calculated on the basis of a model whose ongoing development is promoted by Eurostat². This model consists of a hybrid Input-Output (I-O) application, carried out using conveniently detailed I-O tables of the EU-27, integrated with physical data on metal imports indirect flows. As for the Italian application, Imports in RME are calculated by using the average EU coefficients provided by this 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 other Italian final uses' RME are estimated by a subsequent modelling application based on Italian I-O 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. This approach provides a methodologically advanced and suitable answer to the shortcomings of the Domestic Technology Approach, usually adopted for indirect flows calculations, e.g. in the so-called carbon footprint context.

The RME of domestic final uses, i.e. Raw Material Consumption (RMC), and Exports' RME, refer to 'vertically integrated' activities. The notion of vertical integration was explained by Pasinetti in 1973. It refers, for any given product, to the set of all the activities that are directly and indirectly necessary to obtain the output delivered to final demand. The focus is, for each product delivered to final uses, on the whole production cycle behind it. The vertically integrated activities, from which the individual final products stem, are broad process chains, which includes all the production system. Therefore, although vertically integrated activities take their names from the respective final products, they are very different from the 'standard' activities by the same names. In fact, each of them is an ideal collection of very diverse activities. Each of the vertically integrated activities

² 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, commissioned by Statistical Office of the European Communities – Eurostat; Directorate E – Agriculture and Environmental Statistics; Statistical Cooperation Unit E3: Environment statistics; ifeu - Institut für Energie- und Umweltforschung; Heidelberg, 2012.

resulting from the application of the model is completely autonomous (disjointed) from the rest of the production system, since it encompasses all the phases of the production cycle, starting with the extraction of virgin materials from nature and ending with the final products, through the production of all intermediate inputs, including all ancillary activities connected to commodity transformation and service production. The total raw material equivalents of the vertically integrated products is calculated by cumulating the direct resource requirements of all parts of the economy contributing to the final result. They are not directly observable but result from a hypothetical reattribution to final products of direct resource requirements. In order to calculate final uses' total flows through the environmentally extended Leontief model, it is necessary to know the quantity of materials directly extracted from the domestic or foreign environment. The production costs structure, the knowledge of which is also necessary for the application, is provided by national accounts' monetary Supply and Use Tables system.

According to the notion of vertical integration, capital goods should not be considered final products. As for the capital goods produced in the reference year of the analysis, it should however be kept in mind, when interpreting the results of RME applications like the one illustrated here, that the material flows attributed to Gross Capital Formation represent current environmental costs for the future production of goods or the fruition of services. Correspondingly, the capital goods used during the reference year of the analysis should in principle be quantified (e.g. by taking amortization rates, or better physical wearing indicators) and then "reduced" to their raw material equivalents (possibly by using information on the techniques in use when they were produced). This should be done recursively, since in the past when the capital goods currently used were produced, not only natural resources but also other capital goods were requested in turn. Subsequently, the RMEs of the capital goods currently used, thus calculated, should be allocated to the individual goods and services currently delivered to final consumers and to current gross capital formation, according to the vertically integrated requirements in capital goods of the final demand. All this is – to the best of the author's knowledge – never done in practice, and surely it is not done in RME calculations, including those presented in this paper. But it is clear that the past environmental costs of current production are not represented in any way in RME estimates.

EW-MFA indicators for the Italian economy, expressed in RME, are synthetically shown in Table 1, 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 Leontievan I-O model.

Table 1: 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)	1,437	1,428	1,361	1,280	1,334	1,354	1,403	1,407	1,350	1,172	1,229
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	1,437	1,428	1,361	1,280	1,334	1,354	1,403	1,407	1,350	1,172^(a)	1,229^(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

RP as an indicator for policy-making: current and alternative formulations

Resource Productivity (RP) points to the efficiency with which materials are used in production. This normative concept currently guides some important policy-making processes, especially at the European level 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). 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), 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.

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 2 shows three possible alternative formulations of the RP indicator seen above.

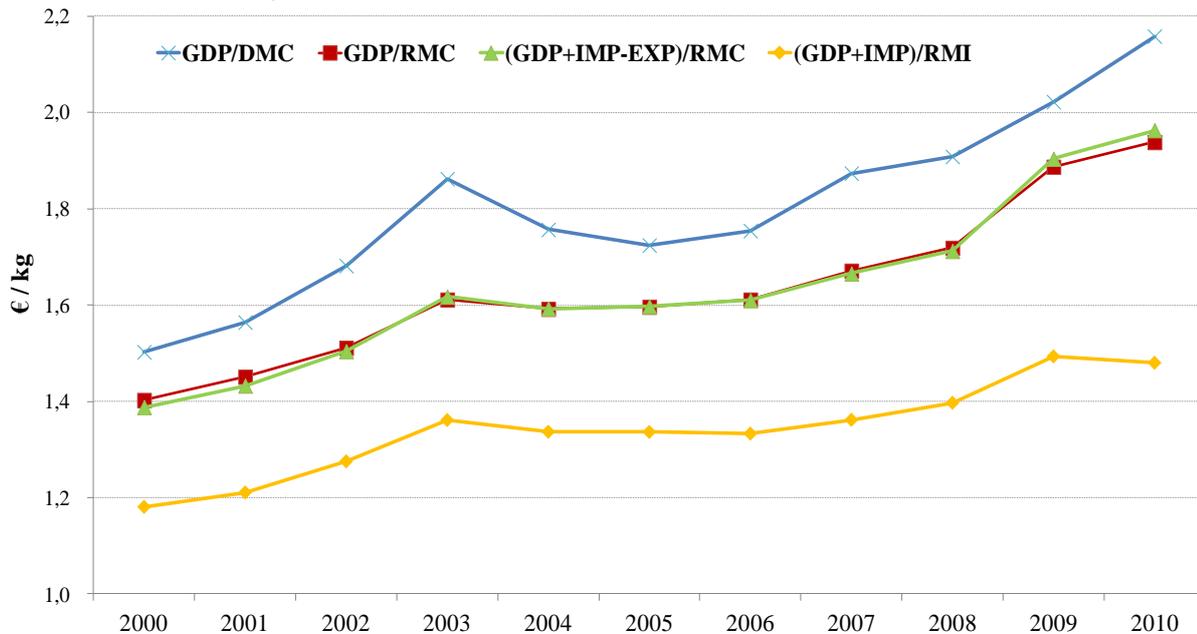
Table 2: Current and alternative indicators for Resource Productivity

	Denominator		
	Domestic Material Consumption (DMC)	Raw Material Input (RMI)	Raw Material Consumption (RMC)
Numerator	Gross Domestic Product (GDP)	Productivity of Raw Material Input: economic resources available for all uses of final domestic production per unit of resource use needed at the global level	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 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
	Total economic resources available for domestic final uses (GDP+IMP-EXP)		

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, 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.

Figure 1 shows the values taken by these indicators over the 2000-2010 period in the Italian case.

Figure 1. Alternative indicators for Italian RP (GDP, Imports and Exports in chain-linked volumes, reference year 2005).



All these four versions have an upward trend. Their levels, however, are quite different. The version with the highest values is GDP/DMC, i.e. the currently used RP indicator. This version gives an optimistic estimate of RP in comparison to the other versions shown in the graph. In the middle range, we find GDP/RMC. It is obvious, in the Italian case, that in any given year GDP/RMC is smaller than GDP/DMC, since the PTB is higher when expressed in RME than when it is expressed in terms of direct flows. If Italy were a net resource exporter, then the picture would be the reverse. The same would happen for all countries with a similar economic structure and natural resources endowment.

The RP indicator having RMC at the denominator and Total economic resources available for domestic final uses (GDP plus the value of Imports minus the value of Exports) at the numerator shows almost the same level and year-on-year changes of GDP/RMC. Using Total economic resources available for domestic final uses for the numerator seems to be a more correct choice than using GDP, since it corresponds to RMC more closely than GDP. As a matter of fact, RMC represents the material inputs necessary to satisfy the domestic final demand. The similar behaviour of (GDP+IMP-EXP)/RMC and GDP/RMC is – at least in the Italian case – no great wonder, as Italy's trade balance is, on average, more or less in equilibrium. However, this might not be the case for other countries, and in other cases interesting differences between the two indicators could emerge.

The picture introduces another variant of the RP indicator. It is a variant that should be taken into serious consideration by policy-makers that are looking for a better economy-wide RP measure than GDP/DMC. This new version comprises, as for the denominator, not only domestic final uses' RME (i.e. RMC) but also Exports in RME. In order to keep the two terms of the RP ratio consistent with each other, the numerator includes the Imports' value, without subtracting the Exports' value from GDP. So, its numerator is GDP plus Imports value rather than GDP alone as in GDP/DMC. Had we not included Imports value, the numerator would be lower and the indicator would be structurally distorted and would systematically underestimate RP and also its possible growth, since the denominator would grow as physical Imports grow, while the numerator would not be affected by Imports value.

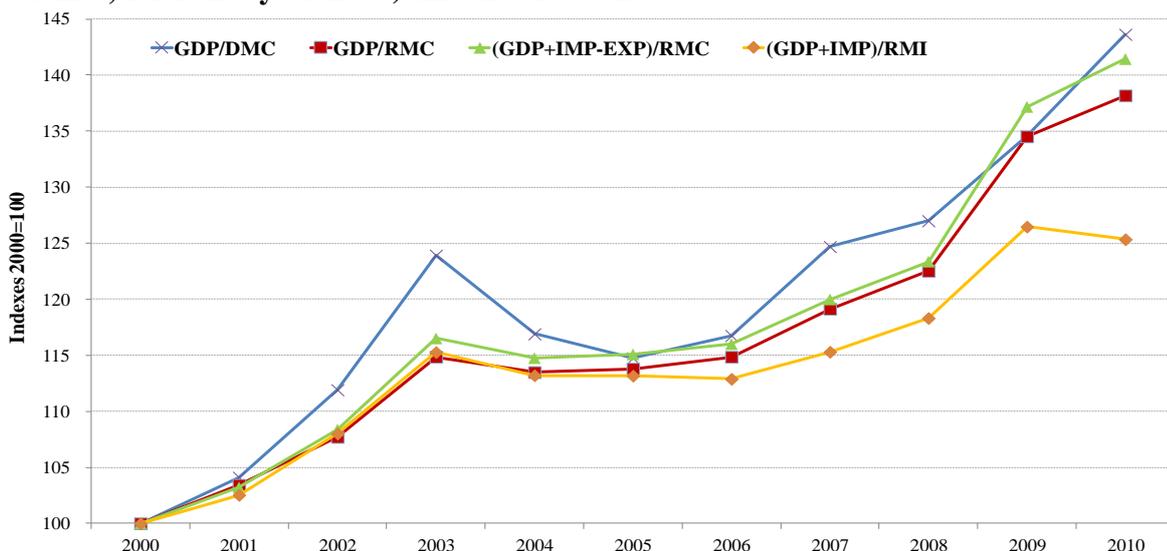
Why should this new version of RP be better than the others?

To begin with, it is worth stressing the following point, which we already hinted at above: 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?

Figure 1 shows that, in the Italian case, RP’s level is quite different depending on the formulation chosen for the RP indicator, while no big difference seem to emerge from this graph with regards to the trend. Indeed, all versions show an upward trend, i.e. a tendency to relative dematerialisation. However, differences in the extent of this tendency emerge from Figure 2, where we show the same information as in Figure 1, but in terms of each indicators’ ratio to its 2000 level.

Figure 2. Alternative indicators for Italian RP (GDP, Imports and Exports in chain-linked volumes, reference year 2005). Indexes 2000=100.



The difference is evident especially between the version of the RP indicator we introduced above - (GDP+IMP)/RMI - and the other three, with the former leading to a much less optimistic evaluation of our economy’s ability to raise RP than the others. Again, GDP/DMC is the one that most emphasises the changes in RP (both upwards and downwards), while GDP/RMC (the pole-position candidate as GDP/DMC substitute), as well as its analogous Domestic final demand/RMC, stay somewhere in the middle. Clearly, including or excluding Exports’ value and their RME makes a big difference. This is due to the fact that in the Italian case the value per RME unit is much lower for Exports than for Domestic final demand. For Domestic final demand, indeed, it is more than

double than for Exports. The 2000-2010 average of the latter is around 0.8 thousand euros per tonne. Moreover, the value per unit RME of Exports is growing only slightly, while it is rising steadily for the Domestic Final Demand, as Figure 2 shows $(GDP+IMP-EXP)/RMC$.

Suggested conclusions, with their rationale

The analysis carried out above highlights some basic problems in the current understanding of the policy use of EW-MFA indicators in the Resource Productivity context.

- There is a need for a clear distinction between meanings and roles of different value-per-material-flow-unit indicators, in relation to different policy targets.
- DMC is a holistic potential pressure indicator. As such:
 - its most appropriate use is not as a resource use measure;
 - it does not suffer from the asymmetry between its components (DE and Imp/Exp);
 - it is *per se* a significant sustainability indicator;
 - it generates, when related to GDP, not so much a Resource Productivity (RP) indicator, as a “potential pressure per GDP” indicator.
- DMC/GDP is a significant efficiency indicator for national economies, relating to sustainability, 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.