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Article

Historical trends in abiotic and biotic resource flows in the EU (1990 – 2010)

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Abstract: In its Communication "Roadmap to a Resource Efficient Europe" the European Commission defined a vision for EU resource consumption by 2050: the economy will have grown compatibly with resource constraints and planetary boundaries, preserving a high standard of living and lowering the environmental impacts. Such vision entails the sustainable management of natural resources, i.e. raw materials, energy, water, air, land and soil as well as biodiversity and ecosystems. In order to support the scientific discussion on the sustainability of resource use and the evaluation thereof, we have analysed the trends of abiotic and biotic resource consumption within the EU27 over the past 20 years. Beyond traditional mass-based approaches to resource accounting (e.g. Domestic Material Consumption DMC and Domestic Extraction Used, DEU), our assessment is twofold: accounting for the biophysical flows of resources and assessing the impact associated to the flows, , using different life-cycle impact assessment methods (LCIA) for resource depletion and scarcity. The resources considered in the analysis include only those extracted in EU territory, including: raw materials (metals and minerals), energy carriers and biotic resources and the timeframe is 20 years (1990-2010). The final aim is the assessment of the evolution of resource flows in the economy and the related resource depletion due to European production and consumption. Trends of resource production and associated depletion as well as other existing indicators for monitoring resource efficiency are reported and analysed with the aim of: highlighting the occurrence of decoupling over time, both in absolute and relative terms; and giving a comprehensive overview of trends related to different resources, usually handled separately in the existing literature. To complete the sustainability assessment of resource consumption research needs are listed, particularly concerning the need of complementing the study with the analysis of socio-economic drivers underpinning the resource consumption trends.

Keywords: abiotic resources, life cycle impact assessment, resource efficiency, MFA

1. Introduction

Improving the efficiency in resource use is one of the EU targets for the next decade [1-2]. Monitoring the consumption of natural resources used by economies – both domestically extracted and traded - is required in order to achieve this objective and to tailor appropriate policy measures.

In its Communication “Roadmap to a Resource Efficient Europe” the European Commission defined a vision for EU resource consumption by 2050: the economy will have grown compatibly with resource constraints and planetary boundaries, preserving a high standard of living and lowering the environmental impacts. Such vision entails the sustainable management of natural resources, i.e. raw materials, energy, water, air, land and soil as well as biodiversity and ecosystems. In order to support the scientific discussion on the sustainability of resource use and the evaluation thereof, we have analysed the trends of abiotic and biotic resource consumption within the EU27 over the past 20 years. Traditionally, the trends in resource consumption are based on mass-based approaches to resource accounting (e.g. Domestic Material Consumption DMC and Domestic Extraction Used, DEU). Despite the importance of this kind of accounting, the impact associated to resource consumption both on future resource availability and as driver of further environmental pressure is hardly accounted for.

Indeed, at European level, Economy-wide material flow accounts (EW-MFA) are used to measure the physical material needs of the economies and derive resource productivity indicators relating, e.g., Gross Domestic Product (GDP) and Domestic Material Consumption (DMC) [3]. The reasoning behind this approach is that the use of natural resources constitutes a pressure on environment and many environmental impacts are linked to resource use. Therefore the resource consumption is used to track progress towards the dematerialization of the economies and the decoupling between the economic growth and resource use.

To overcome the shortcomings related to the mass-based approaches, life Cycle based indicators [4] have been developed - by the Joint Research Centre of the European Commission - with the aim of providing information on the economies’ resource use, and related environmental impacts caused by both domestic extractions and trade flows. Such indicators combine the Life Cycle approach (and in particular the phase so called “Life Cycle Impact Assessment”) with macroeconomic statistics on EU and member states use of resources. They complement the information provided by MFA-based indicators with an insight on the impact caused by resources extraction, i.e. in terms of depletion potential, along with other impact categories covering environmental issues such as climate change, acidification, ozone depletion and toxicity. In order to serve this purpose, the impact assessment of such has been performed by following the recommendation defined at EU level for the impact assessment methods [5]. Under this framework, the EC-JRC is currently developing an expanded inventory of resources and emissions flows, the so called territorial inventory, which covers all EU27 countries for a 20 years’ time span (1990-2010).

In the present paper, our assessment is twofold: accounting for the biophysical flows of resources and assessing the impact associated to the flows, using different life-cycle impact assessment methods (LCIA) for resource depletion and scarcity. The resources considered in the analysis include only those extracted in EU territory, including: raw materials (metals and minerals), energy carriers, biotic and water resources and the timeframe is 20 years (1990-2010).

2. Methods

The analysis of the trends in extraction of material resources is developed on the basis of the territorial inventory. Such inventory is composed of statistical datasets which have been collected to assess extraction figures for the following resources: raw materials -metals and minerals-, energy carriers, biotic and water resources. The scale of the analysis is the EU27, the timeframe is 20 years (1990-2010). The focus is on the domestic extraction of natural resources and the related impacts in terms of resource depletion, assessed through LCIA methods. Additionally, the results, both in mass terms and in depletion terms, are compared to the EW-MFA statistics so to analyze whether general trends of resource depletion can observed within the timeframe of the analysis, regardless of the methodology adopted. Export and import, while being extremely relevant to understand consumption-related issues, are not included in the analysis.

3. Results and Discussion

The results of the inventory as well as the associated impact depletion are reported below, along with further details in the underlying methodological steps. A comparison of the results to the EW-MFA indicators is provided for each of the resource category. In particular, the resulting figures have been compared to the domestic extraction used (DEU), the domestic material input (DMI) and the domestic material consumption (DMC) figures, as estimated by Eurostat [6]. Such comparison is performed in order to compare the consistency of the estimated resources flows in EU27 as well as the relative share of each resource on the overall figures. The data for DEU and DMI were retrieved from Eurostat [6], and are available only for the period 2000-2013, as aggregate figures by resource category (biomass, metal ores (gross ores), non-metallic minerals, fossil energy materials/carriers).

3.1. Inventory of resources and emissions in EU27

The inventory of resources and emission flows in the EU27 for the period 1990-2010 has been recently developed by the EC-JRC as further development of the LC indicators [4]. The dataset includes natural resources in input to the economy as well as emissions to the environment due to human activities. In particular, it is composed of import, domestic and export estimates which cover the overall EU27 economy. In order to allow for consistency with LCT, the database has been developed following the ILCD requirements [7], particularly for what concerns the formatting (terminology, unit of measurement, etc.).

The inventory covers the following categories of resources extracted within the EU27: metals, minerals, energy carriers, and biotic resources. Water extraction figures, despite being included in the inventory, are not analysed in this work. The dataset is based on available statistics and data-gap filling procedures. In particular, the following statistics have been used: BGS (Bristish Geological Survey), WMD (World Mining Data) and RMG (Intierra Resource Sector Intelligence) for metals, Eurostat – PRODCOM for minerals and energy carriers and FAOstat and Eurostat – MFA and crop productions for biotic resources. Data-gap filling procedures have been applied for estimating missing values through proxies such as sectorial statistics, trends of similar flows or observed historical trends. Because of data availability, this analysis a focuses on domestic resource extraction only (i.e. resources extracted within the EU27 territory), not including import and export figures and implicitly adopting a production-based perspective.

3.2. Measuring resource depletion

The resource depletion due to the extraction of biotic and abiotic resources in EU27, has been assessed through life-cycle impact assessment (LCIA) methods on the basis of the flows reported within the inventory. In particular, following the recommendation in the ILCD Handbook [5] for resource depletion impact assessment, the CML method [8-9] has been used for assessing metals and energy carriers' depletion. Due to the fact that the biotic resources are not taken into account within this methodology, the EPS 2000 endpoint method [10] has been used instead for assessing biotic depletion.

3.3. Abiotic depletion – Energy carriers

The flows of energy carriers are reported in MJ within the inventory as the reference unit of the ILCD flows for those four fossil resources and for uranium are based on the net calorific value[1] expressed in MJ/kg. Oppositely, the statistics which are used within the calculation of MFA indicators are generally expressed as unit of mass, gross ores for what concerns Uranium and Thorium. The statistics from BGS are reported in tons of metal content. Hence, in order to allow for comparability of energy-related figures, statistical data for Uranium were retrieved from BGS (as mass) and then converted into MJ. The conversion has been done by calculating the relative thermic energy equivalent of the energy carriers according to the net calorific values reported in the table below. Such values draw on the ILCD documented mass/energy ratios of these energy resources, as well as from the World Energy Council [11]. Hence, the figures of Uranium equivalent thermic energy in MJ have to be intended as equivalent thermic energy associated with the extracted resource, not as the actual thermic energy produced in EU27 by nuclear facilities. It is important to note that Uranium, beside its relevance also in non-energy applications, has been included among the energy carriers.

The results related to the energy carriers are reported below. As it can be seen from figure 1, the energy carriers domestically extracted in EU27 are sensibly decreasing, at least when expressed in terms of equivalent thermic energy. The sources of uncertainty of such figures are substantially the ones characterizing the Eurostat database, as the dataset is complete for the period 1990-2010 and then no further estimations were needed. The only additional source of uncertainty is represented by the calculation of the thermic energy equivalent for uranium, as mentioned in the method description. The most relevant reduction is the one observed for coal extraction, in particular for hard coal, and crude

[1] For Uranium the usable energy content considering an average light-water reactor (open cycle) was taken and inserted as "Lower calorific value" to ease aggregation of potential primary energy production with fossil fuels

oil. Uranium extraction in the EU27 contributes as well to the overall reduction in energy carriers' extraction. The same trend can be observed by looking at the DEU composition for fossil energy material in tons (figure 2). However, such overall reduction of energy carriers' extraction should be compared to the import and export of each energy carriers to better understand whether the reduction is due to a shift in trade or it reflects a reduction in consumption. By looking at figure 3, it is possible to see how the overall consumption of energy carriers (DMC) has slightly decreased, consistently with the DMI figures.

Table 1. Net calorific value considered for fossil fuels and uranium

Resource	Net calorific value (MJ/kg)	Source
Crude oil	42,3	*ILCD Elementary flow definition*
Hard coal	26,3	*ILCD Elementary flow definition*
Brown coal	11,9	*ILCD Elementary flow definition*
Natural gas	44,1	*ILCD Elementary flow definition*
Uranium *	544284	*World Energy Council 2010*

* 1 ton Uranium was assumed to be equivalent to 13 000 toe (41,87 GJ/toe), considering an average light-water reactor (open cycle). This value was documented as Net calorific value, to support practice, while acknowledging that Uranium has no "Lower calorific value" in *sensu stricto*.

Oppositely, the depletion of energy carriers is dominated by the reduction of uranium extraction from ground. This is due to the fact that its characterisation factor is very high according to the CML method, hence the difference in mass is two order of magnitude higher than fossil fuels which range from 6.75E-09 kg Sb eq./MJ (peat) to 7.79E-09 kg Sb eq./MJ (natural gas, coal, oil).

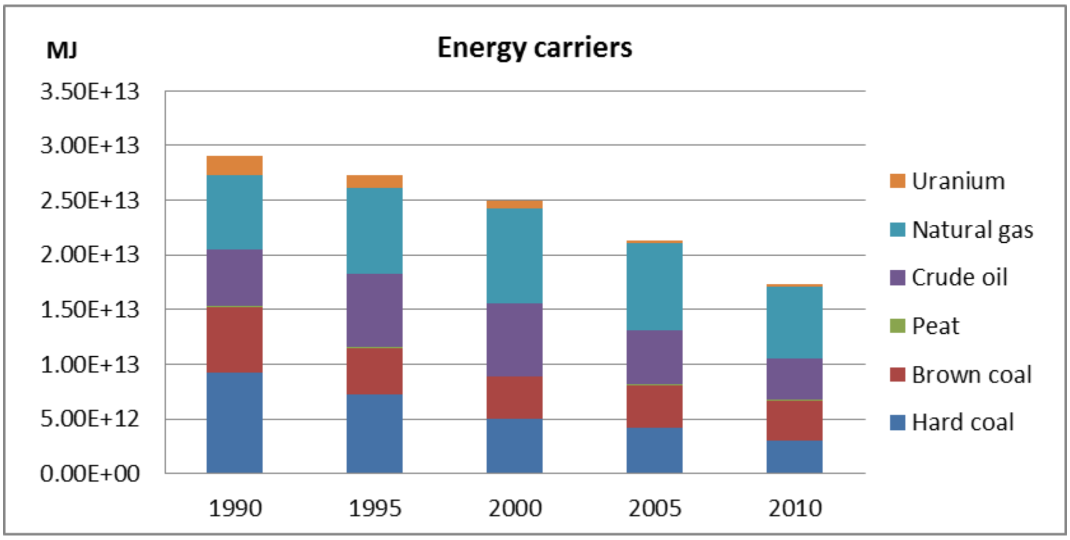

Figure 1. Energy carriers accounts (thermic MJ) as estimated within the inventory

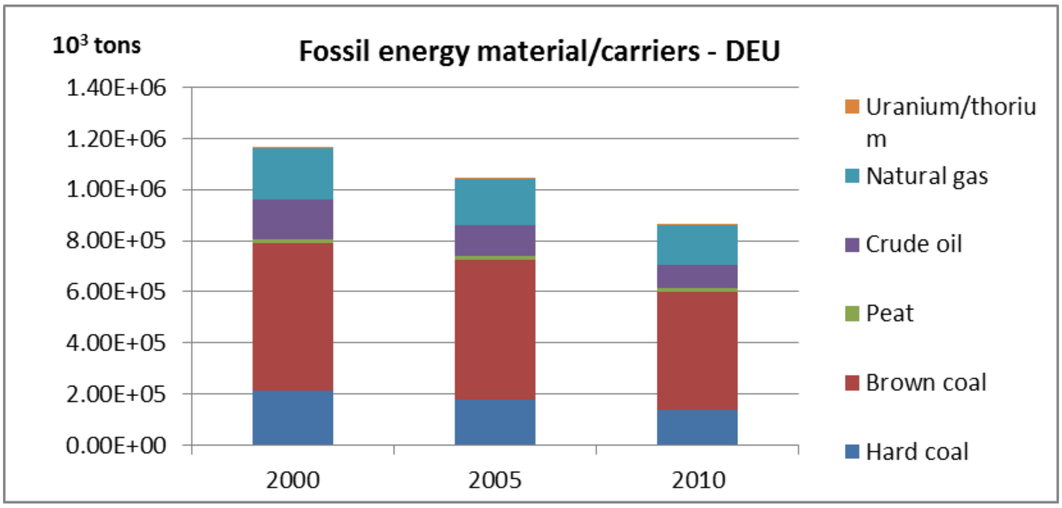

Figure 2. Fossil energy material/carriers – Domestic Extraction Used, retrieved from Eurostat [6]

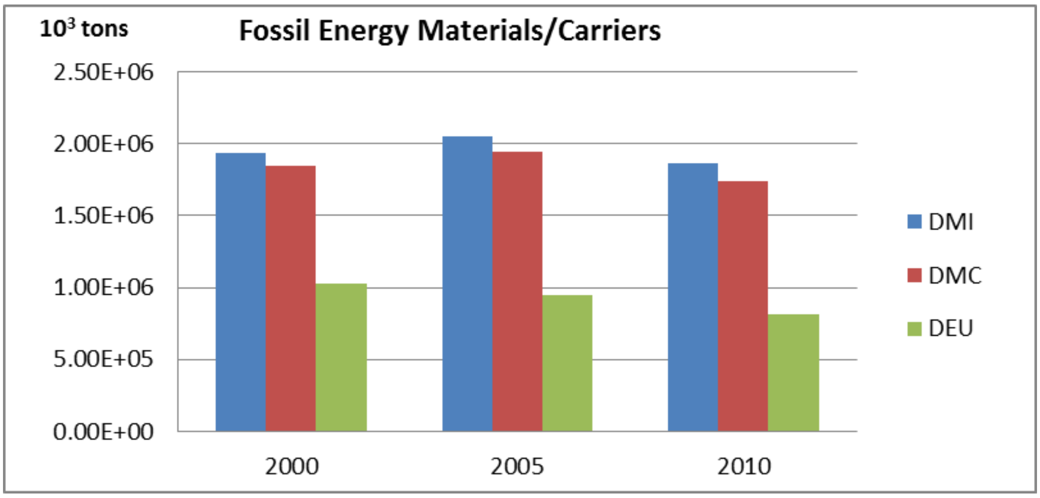

Figure 3. Domestic Material Input, Domestic Material Consumption and Domestic Extraction Used indicators for EU27, retrieved from Eurostat [6]

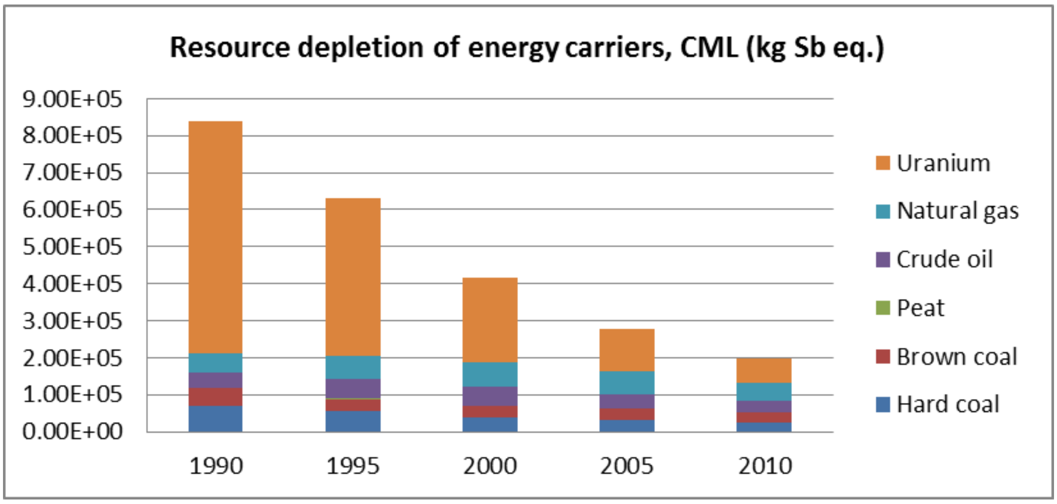

Figure 4. Resource depletion of energy carriers, as estimated according to the CML method

3.4. Abiotic depletion – metals and minerals

Both metals and non-metals extractions are accounted within the inventory. Metal are accounted for both as metal content and gross ores. While the latter is consistent with EW-MFA, the metal content is consistent with the LCIA method used within this paper. Hence, the estimated overall mass of minerals extracted is compared to the DEU and DMI indicators, both for metals and minerals. On the contrary, the metal content figures are used as basis for the calculation of the resource depletion according to CML [8-9]. Statistics on gross ores are incomplete for the period 1990 – 1999 and the estimated figures are not robust; hence the values for these years are not reported in the comparison. Similarly, for what concerns minerals, the data from 1990 to 1994 are not shown as not reliable enough for comparison to DEU. On the contrary, the dataset on metals is sufficiently populated with statistics. Additionally, the ReCiPe [12] and the EPS 2000 methods [10] were applied with the aim of comparing the results of the impact assessment. From the results reported in figure 5, it is possible to note that the extraction of metals (gross ores) is not increasing over the period 2000-2010, only relative changes in composition are observed. The highest share of the total is due to copper, bauxite and iron. On the contrary, the DEU data reported for the same category of resources show a net increase from 2005 to 2010, whereas the consumption had decreased in the same period.

According to the results of the impact assessment reported in figure 6, it is possible to observe that strontium (in red) and silver (in orange) are the main contributors to resource depletion from 2000 to 2010, while the share of arsenic is high in 1990 and 1995 and is negligible in the next timeframe (from 2000 to 2010 due to the drastic reduction in the EU extractions. The relatively high characterization factors (CF) of silver (8.42) and arsenic (2.40) explain this result (CFs for the other metals range between 10^{-1} and 10^{-6}) while in the case of strontium the high impact is partially due to the CF (0.177) and partially to the amount extracted.

Oppositely, by analyzing the results in terms of metal contents, aluminum, bauxite, copper, zinc, chromium and lead show the highest extraction rates, ranging from $2.3 \cdot 10^6$ to $1.8 \cdot 10^5$ tons. As already explained within the methods section, the characterization factors are applied on the metal content of the minerals, therefore it is not possible to directly compare the results with the amount extracted reported in figure 5, as it is accounted in gross ore.

In addition, the results of the application of two endpoint methods are reported below. Being different the assumptions and the perspectives underlying the ReCiPe and the EPS methods (i.e. additional cost and willingness to pay, respectively) the CFs differ substantially, as described by [13] along with the results. Several metals which were absolutely central in the previous analysis are now much less relevant than others. However, according to what stated in recent review [13], there is the need of identifying ah harmonized method for the impact assessment of resource. In fact, the methods for assessing resources depletion are not in agreement in measuring the depletion of metal ores extracted within the EU27. For instance, copper and platinum play a very important role within both the EPS 2000 and ReCiPe methods, on the contrary of CML.

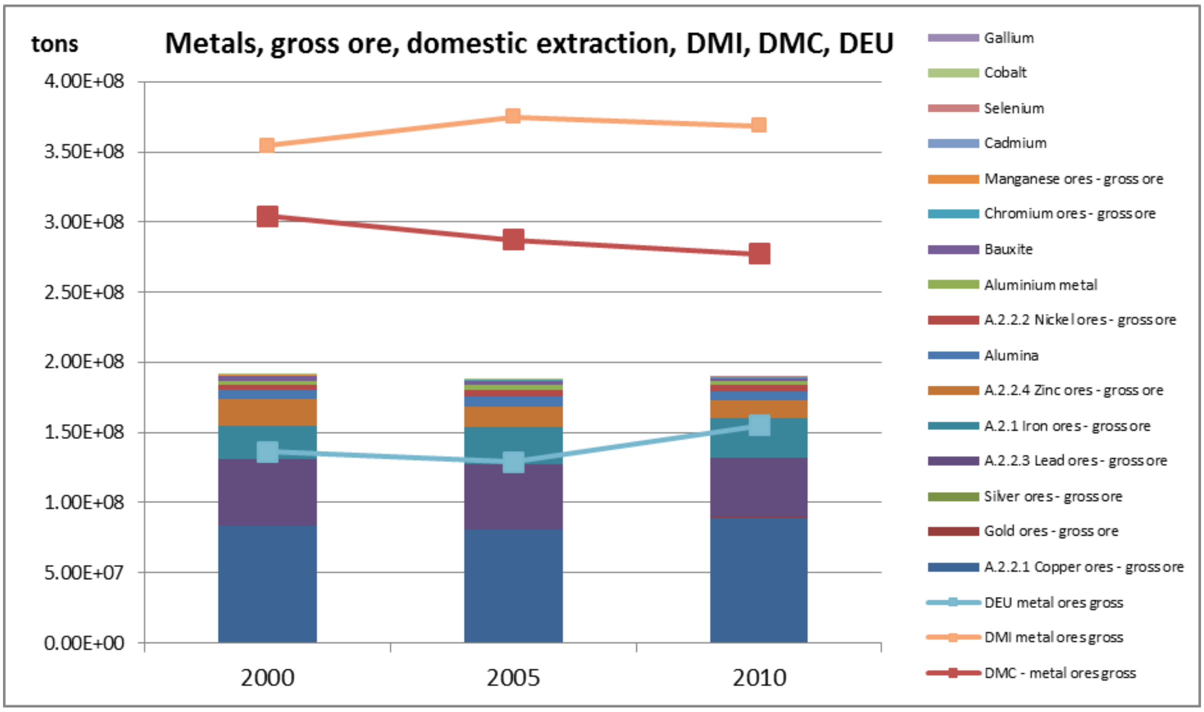

Figure 5. Metal gross ore – domestic extraction and MFA indicators – DMI, DMC, and DEU in EU27

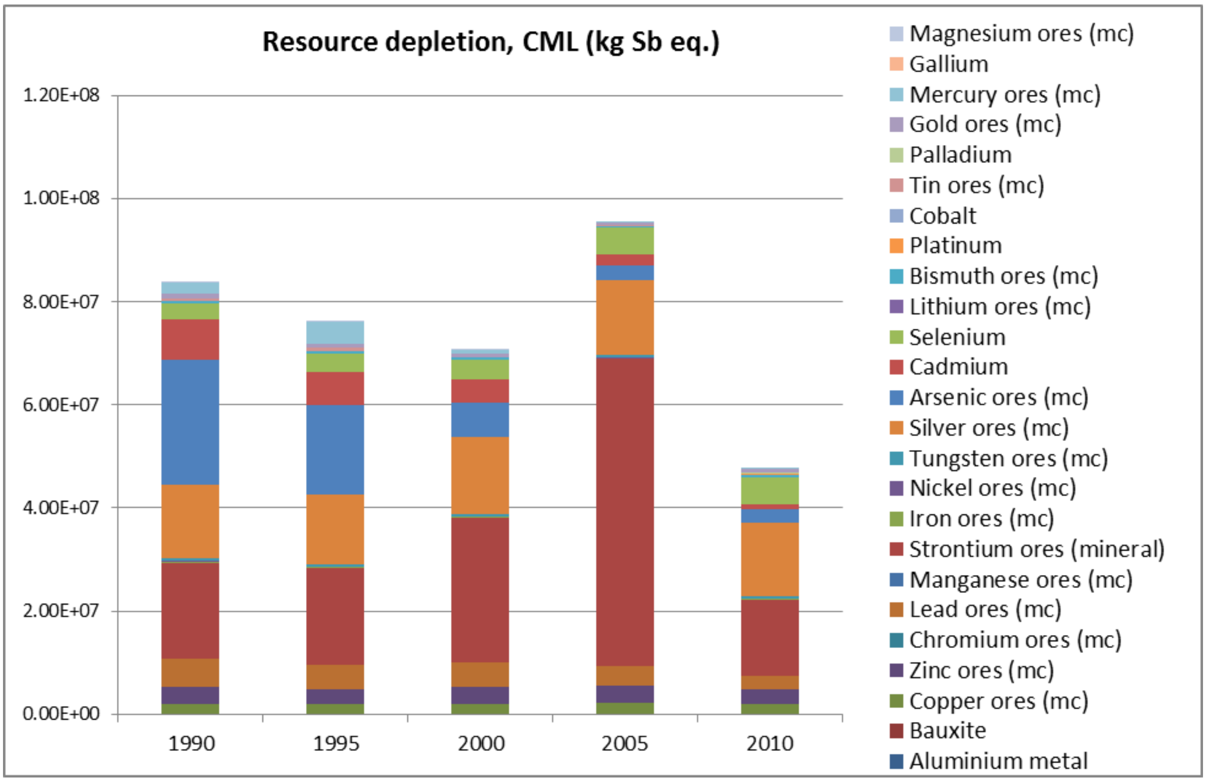

Figure 6. Resource depletion for metals in EU27 expressed as kg of Sb eq.

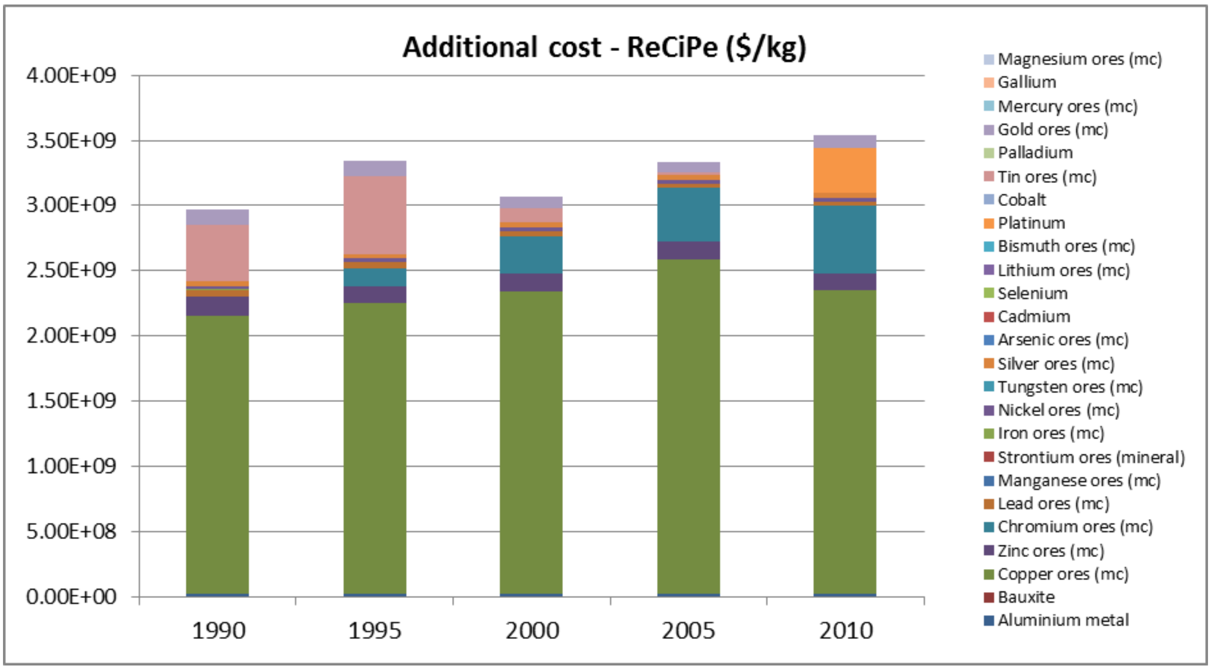

Figure 7. Resource depletion for metals in EU27 expressed as $/kg

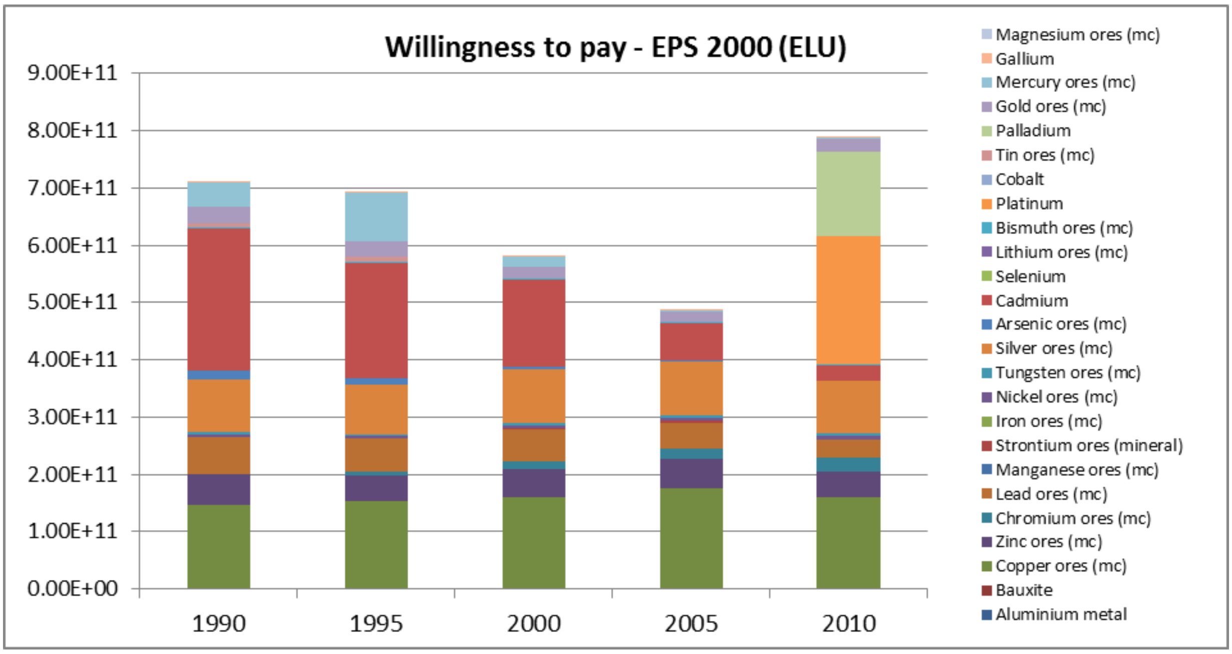

Figure 8. Resource depletion for metals in EU27 expressed as ELU

Non-metallic materials are dominated by weight by clays, salt, gypsum, dolomite and porphyry, which cover approximately 63% of the total volumes in 2010, at EU27 scale. There are no evident overall trends in mineral extraction. Few relevant changes are observed within the time frame, such as the reduction in clay extraction and the increase in porphyry and gypsum. Such trends have to be assessed by means of comparison with the relative import and export figures so to better understand the relative role of domestic extraction over the actual internal consumption. A very relevant inconsistency was found between the estimated material flows in the inventory and the MFA statistics. The figures on DEU for non-metallic minerals are sensibly higher than the ones estimated within the LC indicators. This can be explained with a different accounting system, however better refinements of the analysis are needed in order to identify the main source of discrepancy between the two estimations.

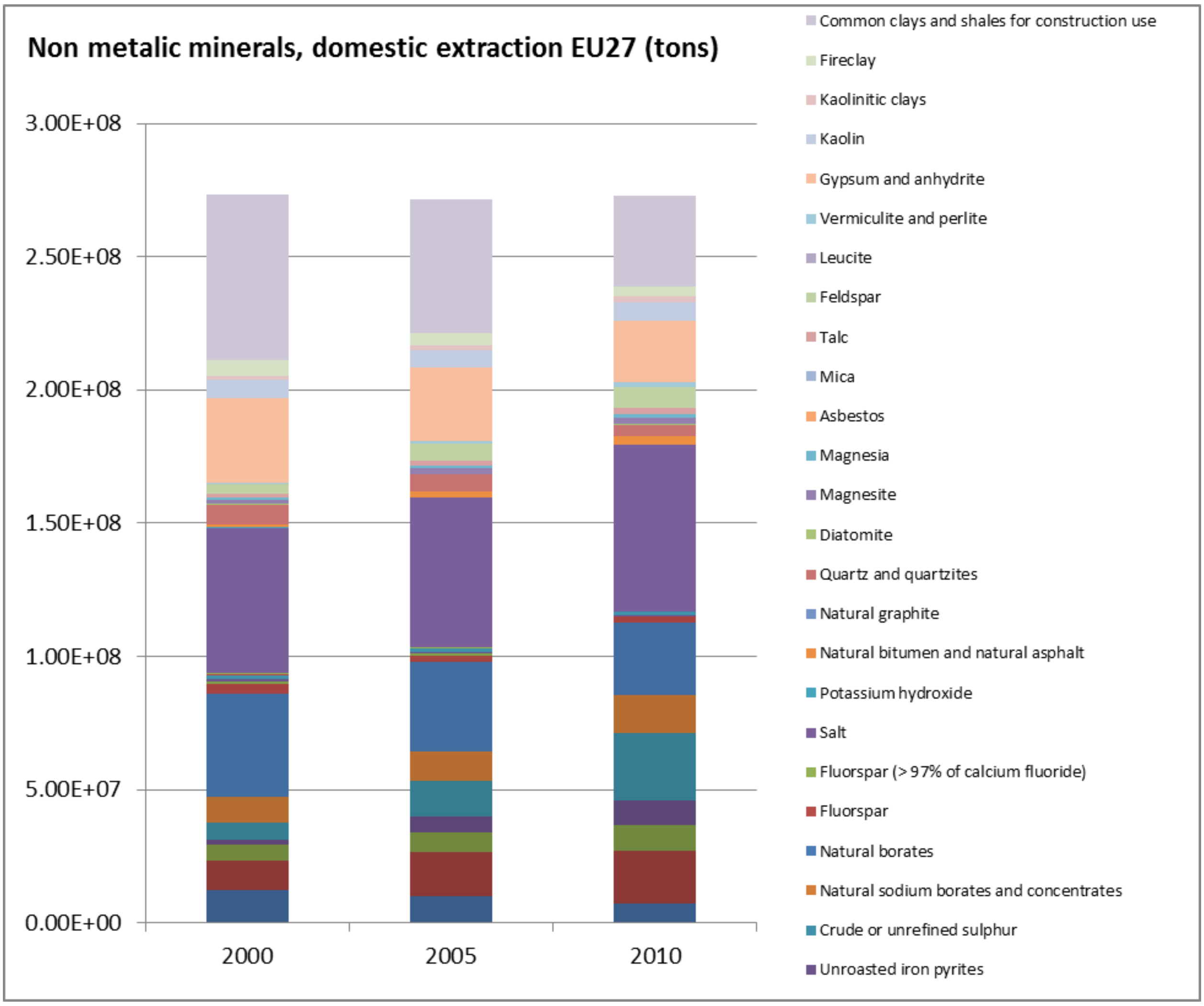

Figure 9. Non–metallic minerals domestic extraction

3.5. Biotic resource depletion

The biotic resources accounted within the inventory are: crops, crops residues, grazed biomass, fodder, wood, fish catches and hunting, and gathering products. Such values were originally found in the FAOstat datasets for crops and in the Eurostat database. The overall values are compared to the DEU and the DMI statistics related to biomass, retrieved from Eurostat EW-MFA [6]. The CML methodology does not cover biotic resources, as many of the LCIA do. Hence, the EPS 2000 method was used for estimating the depletion of biotic resources as it has the highest coverage of biotic resources, including: wood, fish and meat.

The extraction of biotic resources within EU27 does not show a clear trend over the time frame of the analysis. The values estimated for the period 1990-1999 are characterized by high uncertainty and poor robustness as some of the flows have been estimated through gap-filling techniques. In general, for the period 2000-2010 the figures estimated within the inventory are slightly inconsistent with the statistics on MFA calculated by Eurostat (2013) and the difference between the DEU and the inventory ranges from +40% to +60%. The reason of such discrepancy has to be found in the accounting scheme adopted, as well as in the estimations techniques used and in the statistical sources which were retrieved. According to MFA results, the extraction of domestic biotic resources has reduced from 2005 to 2010; the same trend on a different scale is also observed within the inventory results.

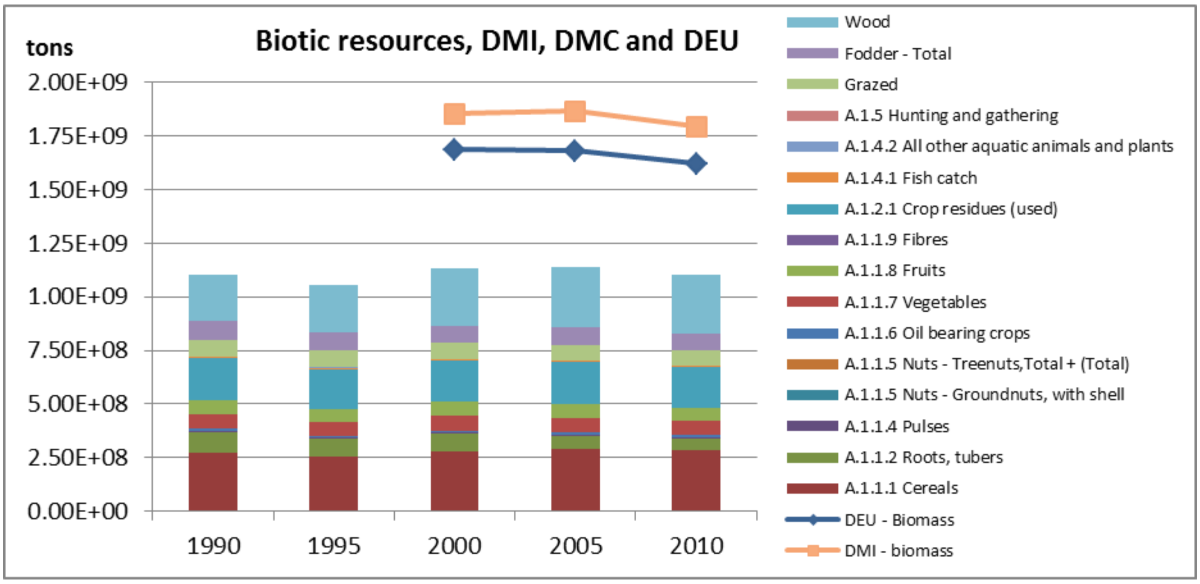

Figure 10. Biotic resources extracted within the EU27, DMI, DMC and DEU indicators

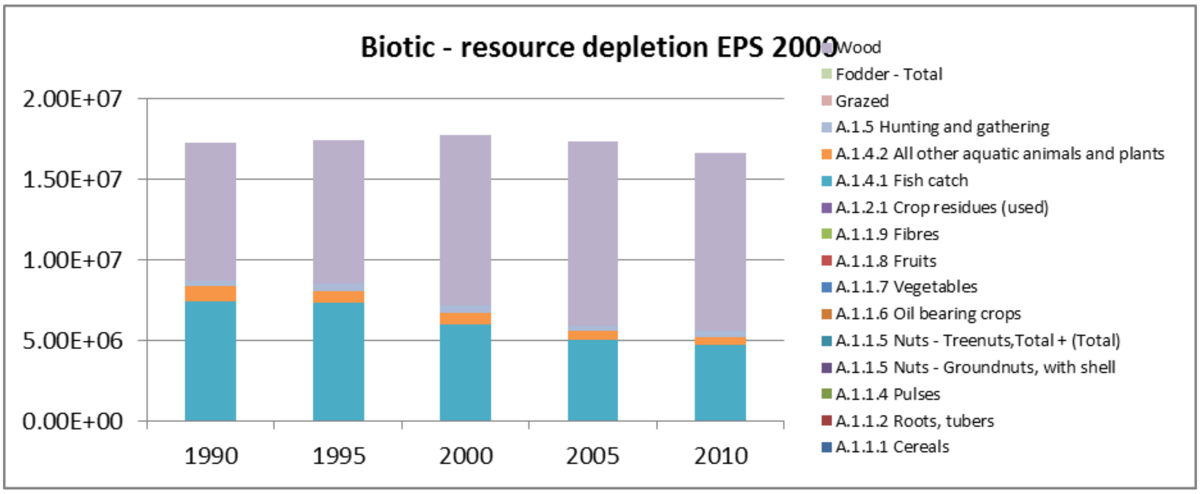

Figure 11. Depletion of biotic resources extracted within the EU27, assessed according to EPS 2000

In figure 11 the depletion associated with the biotic resources extracted within the EU27 is shown. The methodology used for such assessment is the EPS 2000, being one among the few LCIA which cover biotic resources. The methodology only reports CFs for wood, animal and fish resources, hence the results only account for such categories. Wood extraction, along with haunting and gathering drives the biotic resource depletion.

4. Conclusions

In conclusion, it has not been possible to identify an overall trend in biotic and abiotic resource extraction within the EU27. Except for the extraction of energy carriers, which decreases sensibly over time, the other resources do not show evident trends. Relatively small changes in resource extraction are not particularly informative, especially if the change in flows is not related to changes in 'size' of the system under investigation, as suggested by Giampietro et al. [14]. Hence, a further development of this analysis should take into account also variables related to the EU27 economy, such as GDP and relative employment in sectors (e.g. energy, mining and agriculture). Additionally, figures on import/export balance are needed in order to assess whether the observed trends in resource extraction are due to a contraction or upraise of the economy and employment or to a shift in the commercial balance.

Robust estimates are of fundamental relevance for assessing resources depletion and the inventory of resources domestically extracted can serve this purpose. However, it has emerged that the EW-MFA and the figures reported in the inventory are not always consistent. This might be due to the fact that the ILCD nomenclature is not directly comparable to the MFA as different assumptions and boundaries are substantially different and answer different questions. Additionally, accounting principles as well as different statistical sources have led to differences in the overall results. A further refinement of the inventory could lead to better estimates.

Mass-based methods and LCIA methods lead to very different results. Moreover, in the case of metal resources the different LCIA methods have led to contrasting results over the timeframe in terms of resource depletion and common trends among the methods used for assessing resource extraction were not identified. When assessing the impact of resource use the choice of the method is the most important, both when using a material flow-based approach and when using impact assessment models. Within the ILCD framework the CML methodology was selected as recommended midpoint indicator as a result of a meta-analysis. However such method shares some of the drawbacks of the other LCIA method in terms of coverage of biotic flows resources and non-metallic minerals. In general, biotic resources are not well covered by any of the methods considered; this represents a relevant current gap in LCIA.

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Conflict of Interest

The authors declare no conflict of interest.

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