Ecologic Briefs

Integrating Resource Efficiency, Greening of Industrial Production and Green Industries –

Scoping of and recommendations for effective indicators

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Foreword by Dr. Heinz Leuenberger (UNIDO)

Sustainable industrial development relies to a large part on resource-efficient modes of production. This reality is increasingly finding acceptance amongst a multitude of global actors and is reflected in the evolving legislation, corporate management approaches, reporting tools, guidelines and standards which deal with sustainability. Additionally, a proliferation of renewable, low-carbon and energy-efficient technologies, as well as sustainability reporting mechanisms has proven that businesses are ever more aware of the need to adjust their production modes in order to succeed. Despite this, few attempts were made to gauge the applicability of existing indicators to sustainable industries.

The ability to refer to useful resource efficiency indicators and to undertake the resulting benchmarking serves to open the conversation amongst policy-makers, industry practitioners and knowledge institutions. However, the need for the various stakeholders to speak a "common language" becomes particularly evident in situations where development objectives are diverse.

A case in point is UNIDO's own Green Industry Platform, where businesses, governments, international and civil society organizations have convened to carry out concrete, workable solutions with measurable impacts. This study will help guide the work of multi-stakeholder initiatives such as the Green Industry Platform, and bring clarity to the coming debate on applicable resource efficiency indicators.

It is evident that globally, enterprises are shifting perspective and are embracing the business case for green industry. Useful resource indicators for sustainable industries will eventually come to underpin the global re-adjustment on the part of governments and enterprises to introduce and strengthen sustainable and resource-efficient modes of production. This process cannot be completed, or even continued, without the use of indicators to measure progress towards this goal.

Heinz Leuenberger
Director
Environmental Management Branch
UNIDO

Foreword by R. Andreas Kraemer (Ecologic Institute)

There is no future for human civilization as we know it and aspire to unless an equitable and sustainable global society can be formed. Such a society, to be sustainable, would respect cultural diversity and allow 9 billion or more humans to meet their needs and wants, but within planetary boundaries and in harmony with the natural environment, keeping global balances in long-term equilibrium. It would also avoid, reduce, or least manage conflicts peacefully.

This imperative applies to the use of energy just as much as to the use of practically all other resources, whether mineral, fossil or living, biological, or even just the air we breathe or the water we use to grow crops, prepare our foods or wash away our wastes. Many processes and production and consumption patterns will need to change from current practices on the way towards a sustainable industrial society. This will require invention and innovation just as much as good business management and policy-making.

Like the first, incomplete maps pioneers draw of land that is only half explored, this short blue brief marks some possible points of orientation and suggest a metric for measuring distances and progress in the evolution of a Green Industry. The focus is on resource efficiency indicators, including energy resources, and how they might be used in measuring progress towards sustainable industries.

As a contribution to the Green Industry Platform of the United Nations Industrial Development Organization (UNIDO), this report by Ecologic Institute shows how some gaps may be closed concerning indicators for measuring progress in the greening of industries and further progress industries that may be considered "green" already, and especially improvements in the efficient use of resources in industrial production.

This blue brief and the project behind it could not answer all question or fill all the gaps. It does, however, clarify many concepts and issues, documents what is possible today and where more work is needed. Furthermore, it sketches the work that needs to be done next, so that we may have a better understanding of where we are on the right track and moving fast enough towards an equitable and sustainable industrial society.

R. Andreas Kraemer
Director & CEO
Ecologic Institute

Executive Summary

Increasing resource efficiency is an important and necessary step towards sustainable development, aiming to facilitate the improvement of socio-economic well-being while reducing resource use and its associated environmental impacts. In this context, industrial development and resource use efficiency play key roles in helping to achieve two Millennium Development Goals:

- MDG 1: Eradicate extreme poverty and hunger
- MDG 2: Ensure environmental sustainability

Industrial development must, therefore, pursue sustainable growth by "greening" existing industries and fostering new "green" industries.

Achieving this requires two things: first, a formal definition of what constitutes "green" in the context of sustainable development and the MDGs and, second, the use of appropriate indicators to effectively measure and monitor progress towards these goals. Both aspects remain woefully locked in debate and are characterized by a variety of conflicting perspectives. Definitions of "green industry," for example, range from business activities, such as garden landscaping and planting trees, to the so-called first wave of green industries, such as the environmental remediation and pollution abatement businesses and their products, to the current technology and innovation-driven focus on renewable energy and resource use in the production, manufacturing and service sectors.[1] In addition to and as a consequence of the unclear meaning of the term, hundreds of indicators exist for measuring the "greenness" and sustainability of industrial development. Their utility and integration in a harmonized framework remain largely unaddressed to date.

Such a harmonized framework would be useful for policy makers who have to identify and balance the trade-offs between different dimensions of sustainability, such as social, economic, and environmental objectives and, therefore, need a robust understanding of the right indicators and their correct interpretation.

Hence, the review of such a large set of potential metrics without a clear concept of what they should measure requires at a minimum an organizing framework for selecting, characterizing, and assessing indicators. For the purpose of this study, Life Cycle Analysis (LCA) was chosen as the organising framework because, inter alia, LCA is able to measure the environmental impact of product(s), service(s), and industry; it is flexible and adaptable to specific impact areas and/or steps in the life cycle chain; and it can be used to set and monitor the progress of useful policy or management targets and benchmarks.

The study summarises scientific findings concerning a diversity of indicators and assesses their potential applicability to measuring the sustainability of industries and sustainable industrial development in general through a two-step process.

First, a list of 32 indicators is selected based on a set of criteria, e.g., including LCA compatibility, coverage of sustainability impacts, and policy relevance. From these, the ten most promising indicators where then identified considering methodological soundness and potential to become mainstream industry metrics for evaluating resource use efficiency. Based on an expert ranking, these top ten indicators are:

1. Environmentally weighed material consumption (EMC)*
2. Energy intensity by sector*
3. Production-based CO_2 productivity
4. Water consumption by sector*
5. Sustainable Process Index (SPI)

[1] Battelle Technology Partnership Practice and Council for Community and Economic Research (2010). Emerging Green Industries in Arizona: Definitions, Industry Base, and Opportunity Areas. Prepared in November 2010 for the Office of Employment and Population Statistics, Arizona Department of Administration.

6. Water abstraction rates and water stress
7. Corporations' turnover, value added and exports of the environmental goods and services sector
8. Resource Productivity
9. Total Material Consumption (TMC)*
10. Ecological Footprint (EF)

* proposed for use in tandem in a "basket of indicators".

In a second step, these ten indicators were further analysed regarding the availability and quality of the data needed to calculate them.

The findings that emerged not only helped to clarify the concept of "green industry" from an LCA perspective, but also help practitioners find suitable indicators for their specific objectives and more broadly inform the ongoing debate on the "green economy". The most useful indicators were found to be those that address the environmental impacts not only by quantity of resources used (e.g. EMC) but also by their actual impacts as well as those indicators that include indirect upstream resource flows linked to imports and exports (e.g. resource productivity, if measured including Total Material Consumption). Combining these types of indicators then permits measuring the goal of "double decoupling", which means the progress of industries and industrial development towards decoupling economic growth from resource use (resource decoupling) and from associated environmental impacts (impact decoupling).

Overall, the study concludes that:

- LCA is a useful theoretical and practical framework for selecting and evaluating the indicators and its growing application in studies and industry promises to further this effort.
- Of all selected indicators, none was perfect or outperformed the others on all assessment criteria. Therefore, considering several indicators that complement each other and provide a more complete assessment of the sustainability of an industry or product group is suggested. This approach also balances existing methodological challenges and increases explanatory power.
- The data needed to calculate the selected indicators vary widely in their amount, accuracy, level of resolution and transferability. In addition, the most informative indicators tend to require more information than the more high-level (aggregated) indicators.
- The social aspects of moving toward a resource efficient or sustainable industry have so far received little attention and should be considered in ongoing research.

Introduction

Increasing resource efficiency is one of the core themes of sustainable development because it helps improving socio-economic well-being while reducing resource use and its associated environmental impacts. It is seen as an essential component of sustainable resource management and of achieving absolute decoupling[2] of economic growth from the pollution and degradation of nature. This, in turn, is considered one main avenue for helping to improve the standard of living for millions of people while respecting planetary boundaries.[3]

Sustainable resource management is one of the main objectives of the Agenda 21 adopted at the United Nations Conference on Environment and Development in Rio de Janeiro in 1992. Twenty years later, however, the Agenda's focus on sustainable resource management appears limited mainly to the consumption side of resource use and much less to the contributions of industry through production and manufacturing.[4] Although the Plan of Implementation of the World Summit on Sustainable Development in Johannesburg in 2002 puts greater emphasis on industries by calling for changing unsustainable patterns of consumption *and* production,[5] the political debate in recent years seems to have shifted away from industries and industrial development yet again. This is evident in the discussions about supplementing and integrating the poverty-focused United Nations Millennium Development Goals (MDGs) with Sustainable Development Goals (SDGs) and corresponding initiatives by the governments of Colombia[6] and Guatemala.[7] Both initiatives appear to lack specific targets for industries and industrial development.

Achieving both the MDGs and the SDGs requires incorporating industrial development. Development economics has provided ample empirical and theoretical evidence that industrial development or the transition to higher value production chains plays a key role in alleviating poverty, e.g. through raising incomes, building a skilled and educated workforce, and promoting empowerment of women.[8] But it is similarly clear that, in a world of seven billion, these benefits can only be reaped sustainably when absolute decoupling has been achieved.[9]

The recent economic and financial crises offer both a challenge and an opportunity to embark on a concerted effort to green industry and create entirely new value chains around technology-driven, environmentally friendly production and consumption.[10] [11] Accordingly, in the Rio +20 summit that took place in June 2012, the Secretary-General's Report on Objectives and Themes of the United Nations Conference[12] placed the “green economy” firmly within the dual context of sustainable development and poverty eradication and identified it as a key objective and main theme of the summit.

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[2] One typically distinguishes between resource decoupling and impact decoupling as well as between relative decoupling (where resource use and/or impacts grow at a slower rate than economic growth), and absolute decoupling (where resource use and/or impacts stagnate or decrease). See UNEP 2011. Decoupling natural resource use and environmental impacts from economic growth, A Report of the Working Group on Decoupling to the International Resource Panel. Fischer-Kowalski, M., Swilling, M., von Weizsäcker, E.U., Ren, Y., Moriguchi, Y., Crane, W., Krausmann, F., Eisenmenger, N., Giljum, S., Hennicke, P., Romero Lankao, P., Siriban Manalang, A.

[3] Rockström, J. et al. 2009. A safe operating space for humanity. Nature 461: 472 - 475.

[4] See section II Constervation and management of resources for development, http://www.un.org/esa/dsd/agenda21/res_agenda21_00.shtml.

[5] See section III, Changing unsustainable patterns of consumption and production, http://www.un.org/esa/sustdev/documents/WSSD_POI_PD/English/WSSD_PlanImpl.pdf.

[6] See the proposal by the Governments of Colombia and Guatemala; RIO + 20: Sustainable Development Goals (SDGs), http://www.uncsd2012.org/rio20/content/documents/colombiasdgs.pdf.

[7] UNIDO 2011. Green Industry: A key pillar of a Green Economy. Policy Brief for the Ministerial Meeting on Energy and Green Industry, Vienna, 21 and 22 July 2011. See http://www.unido.org/fileadmin/user_media/Services/Energy_and_Climate_Change/Renewable_Energy/VEF_2011/Green%20industry%20policy%20brief_Final.pdf.

[8] Meier GM, JE Stiglitz (2001). Frontiers of Development Economics: The Future in Perspective. World Bank: New YorkISBN 0 19 521592 3, 575 pp.

[9] UNEP 2011. Towards a Green Economy. Pathways to Sustainable Development and Poverty Eradication. A Synthesis for Policy Makers, www.unep.org/greeneconomy.

[10] UNIDO 2010. A Greener Footprint for Industry. Opportunities and challenges of sustainable industrial development. http://www.unep.or.jp/ietc/spc/news-nov09/UNIDO_GreenIndustryConceptEbook.pdf.

[11] Eurostat 2009. The environmental goods and services sector. Methodologies and Working Papers. European Communities, Luxembourg and OECD 1999. The Environmental Goods & Services Industry. Manual for Data Collection and Analysis, Paris.

[12] UNDESA 2011. Objective and themes of the United Nations Conference on Sustainable Development. Report of the Secretary-General. See http://www.uncsd2012.org/rio20/content/documents/N1070657.pdf

Indicators will without doubt play an integral role in monitoring and benchmarking the environmental, social, and economic dimensions of a resource-efficient and green industrial production. A broad variety of well-developed resource use indicators already exist both at the product and country level and can be used to measure the degree of "decoupling" of resource use and economic growth and the associated environmental benefits.[13] To a lesser extent, indicators for resource efficiency have also been discussed.[14] However, current developments at the European level (e.g., the Roadmap to a Resource Efficient Europe[15]) call for more work to be done on identifying and developing appropriate indicators.[16]

This policy brief reviews the state of play with respect to available resource use indicators for industry. It uses a wide variety of data sources and builds on key European policies and analytical work by, inter alia, BIOIS, IFF, and VITO.[17] It highlights where gaps in data and knowledge exist and offers an outlook on likely developments in the near future at the European level. It is meant to be a useful guide and background document for actors working on initiatives or programs aimed at addressing resource use, generally within the context of sustainable development as well as for specific industrial sectors or product groups, and those who are working on and preparing draft agreements for the Rio+20 Summit.

This policy brief is structured as follows:

- the methodological approach taken to identify and review suitable indicators from the large number of existing metrics in the sustainability, environmental, and macroeconomic as well as microeconomic performance assessment fields
- the results of indicator selection and evaluation
- the resulting conclusions

The brief concludes with selected references and links to further information on this subject.

[13] Giljum, S. et al. 2011. A comprehensive set of resource use indicators from the micro to the macro level. Resources, Conservation and Recycling 55 (3): 300 – 308; JRC and IES 2010. Monitoring progress in Sustainable Consumption and Production in the EU. Decoupling indicators; van der Voet, E. et al. 2005. Policy review on decoupling: development of indicators to assess decoupling of economic development and environmental pressure in the EU-25 and AC-3 countries. Brussels: EU Commission, DG ENV.

[14] UNESCAP 2009. Eco-efficiency Indicators: Measuring Resource-use Efficiency and the Impact of Economic Activities on the Environment. See http://www.unescap.org/esd/environment/publications/EEI/ESCAP_EEI%20Publication%202561.pdf

[15] European Commission 2011. Roadmap to a Resource Efficient Europe. COM(2011) 571 final.

[16] Therefore, the afore mentioned European policies call for the development of indicators to measure progress towards resource efficiency – here, an EU FP7 call for tender has been issued in 2011.

[17] BIOIS, IFF and VITO 2011. Analysis of the key contributions to resource efficiency. Final Report, March 2011. Available at http://ec.europa.eu/environment/natres/pdf/Resource_Efficiency_Final.pdf.

Methodology

The approach taken in this study shares many elements with the design process of indicator sets as it is known in sustainability research.[18] The main steps of indicator set development are

(i) clear specification and delineation of the purpose of the indicators,
(ii) selection of an organizing framework for the indicators,
(iii) merging of literature review, expert knowledge, and, if needed, new design methods to identify the best suited indicators,
(iv) testing or review of the resulting entire set for completeness, accuracy, practicability and other criteria relevant for the purpose of the exercise and
(v) potential revisions based on the results of step (iv).

Our approach differs from indicator set development in that it is a review study not requiring the actual implementation of the indicators and therefore steps (iv) and (v) are unnecessary. As a review study, the focus is also on drawing actionable conclusions regarding the state of play with respect to the availability of indicators for industrial resource efficiency and green industrial production rather than on conducting novel indicator design work. The critical methodological element is therefore embedded in steps (ii)-(iii) while not neglecting step (i).

A well-designed methodology will ensure a smooth progression through these steps and facilitates not only the structuring of the analysis but also supports the specification of evaluation criteria for judging the suitability and utility of different approaches, their strengths and shortcomings, as well as potential areas of further development. This section explains and summarizes the approach taken.

Selection of an organizing Framework for measuring Resource Flows and their Environmental Impacts

The framework of this analysis needed to be capable of capturing different types and amounts of natural resources used in industrial production processes and their environmental impacts. With this information in hand, it is possible to calculate and analyse various resource use intensity and impact indicators, which in turn provide feedback on the efficiency of production processes and signal opportunities for improvements and action to mitigate further environmental degradation. Ideally, the organizing framework is also capable of gathering this information for the entire production chain beginning with the extraction or harvesting of the resource to its final disposal. After reviewing several potential frameworks (more information can be found in the detailed report at http://ecologic.eu/4758), we selected Life Cycle Assessment (LCA), which is specifically designed to gather, organize and analyze information regarding the flow of natural resources through the economy, their use in products and services, as well as the types, amounts and sinks of by-products.

LCA, also known under the terms Life Cycle Analysis, Eco-balance, and cradle-to-grave or cradle-to-cradle analysis, is a suite of methods designed to assess the environmental impacts resulting from a product's entire lifetime (or specified portion thereof).[19] This includes the impacts originating from the sources of the raw materials (e.g., mining, catching, harvesting), material processing (e.g., refining, separation, smelting), the manufacturing process (e.g., assembly, welding), distribution (e.g., transportation and storage), use, and finally either disposal or recycling and reuse.

LCA generally consists of four distinct but interdependent phases (shown in Figure 1).

1. Goal and Scope Definition

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[18] Miller C. (2007). Creating Indicators for Sustainable Development: A Social Approach. Institute for International Sustainable Development (IISD), September 2007.
Pinter L, Hardi P, Bartelmus P (2005). Indicators of Sustainable Development: Proposals for a Way Forward. Discussion Paper prepared for UN DSD UNDSD/EGM/ISD/2005/CRP.2.
[19] Hendrickson, C. T., Lave, L. B., and Matthews, H. S. (2005). Environmental Life Cycle Assessment of Goods and Services: An Input–Output Approach, Resources for the Future Press.

2. Inventory Preparation and Analysis
3. Impact Assessment
4. Interpretation of the Results

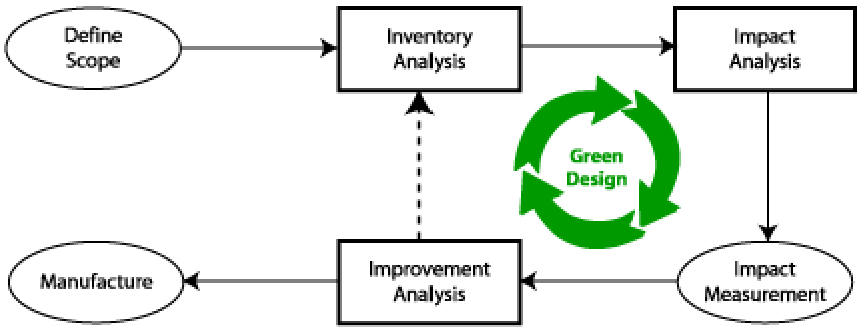

Figure 1: LCA phases (Source: Graedel and Alleby, 1995[20])

LCA is an important tool for product management because it expands the narrow focus of a product's impacts resulting from its use (e.g., CO_2 emissions of operating an airplane) to the full set of emissions, pollution, resource use, and waste generated to make, use, and dispose of the product.[21] However, the information needed to conduct LCAs is substantial and includes inventories of the stocks and flows of relevant energy and materials as well as pollutants, toxics, and other substances released at each step of the LCA chain, and then their potential impacts with respect to environmental characteristics such as air and water quality, climate, habitat, biodiversity, etc. must be evaluated.

LCA can be conducted at the product level as well as for specific product groups or industrial sectors, albeit at a certain loss of detail and accuracy. It is a flexible tool that can be adapted to a broad range of user needs.

Indicator Selection

In order to identify indicators that are promising for this study, existing resource indicators will be measured against a set of criteria. This set builds upon criteria developed in prior research projects[22] as well as upon the existing EEA framework[23] and an evaluation framework known as the RACER framework.[24] Accordingly, criteria with relevance for the selection of resource indicators to be analyzed include:

[20] Graedel TE, Allenby BR (1995). Industrial Ecology. AT&T: New Jersey.ISBN-10: 0131252380
[21] ibid.
[22] Giljum, S. et al. 2011. A comprehensive set of resource use indicators from the micro to the macro level. Resources, Conservation and Recycling 55 (3): 300 – 308; Grünig, M. et al. 2011. Plakative und schnelle Umweltinformation mittels hochaggregierter Kenngrößen zur nachhaltigen Entwicklung. UFOPLAN 3710 12 160. German Federal Environment Agency, Dessau.
[23] http://projects.cba.muni.cz/indikatory/documents/metodiky/metodika_EEA.pdf (accessed 26 11 2011)
[24] The RACER methodology was recommended by the European Commission in its publication "Impact assessment guidelines." SEC2005 (791), available at http://www.mfcr.cz/cps/rde/xbcr/mfcr/SEC_2005_791_Impact_ Assessment_Guidelin es 2006update.pdf. RACER is a generic evaluation framework applied to assess the value of scientific tools for use in policy making. RACER embraces the five criteria Relevant, Accepted, Credible, Easy to interpret, and Robust.

Table 1: List of criteria relevant for selecting resource indicators

Criterion	Question to be answered by the criterion
LCA compatibility	Is the indicator able to measure different life cycle stages? What aspects of the LCA chain does the indicator measure?
Coverage of industries and industrial development	Is the indicator product-specific, or can it capture the performance of specific industries sectors and industrial development?
Sustainability impacts coverage	Is the indicator able to measure environmental, economic, or social impacts?
Required data efforts	How much data is required to establish the indicator? How much effort is needed to collect, prepare, and use the data?
Data availability	Is the data required for the indicator readily available? At which level (global, country, etc.) and at which time intervals (routinely, as necessary, etc.) is it collected?
Consistency	Does the indicator actually measure what it is intended to measure?
Avoiding double-counting	Does the indicator preclude double-counting of resource use?
Compatibility	Is the indicator derivable from existing measurement frameworks such as System of Environmental-Economic Accounts (SEEA), the Dutch National Accounting Matrix including Environmental Accounts (NAMEA), or national LCA databases?
Uncertainties and data imputation	How are uncertainties about data reflected in the indicator and how are missing data imputed? What errors of interpretation can be caused by the imputation method? Is the indicator robust against manipulation?
Scientifically verified	Is the methodology for the indicator backed by scientific research and debate? Is it well-documented?
Understanding and Acceptance	Is the information directionally safe? Is comprehension of the indicator intuitive? Is the indicator accepted and used by different experts and non-experts?
Policy relevance	Does the indicator address and support policy priority issues by measuring progress towards political targets or thresholds? Does the indicator measure aspects which can be influenced by policy makers? Does it provide disaggregated information allowing analysis of causal effects? Is it available to policy makers in short time frames?
Communication	Can the indicator be visually illustrated?

It is noted that data availability was also considered in the study as a separate element because the purpose of the study was to review the current availability of resource efficiency and green industry indicators coupled with their potential development in the future. Data availability was therefore given special consideration. A simple, three-level scoring mechanism was applied that qualitatively assessed for each indicator and criterion to what extent the indicator matched the criterion: fully matched (☺), partially matched (😐), or not matched (☹). Available expertise and the salient literature were used to make these judgments. Each indicator's final score was then simply the sum of the criteria scores. An evaluation factsheet was developed and completed for each reviewed indicator. Appendix I shows the template that was completed to evaluate each indicator.

Before filling out the templates it was necessary to determine the pool of candidate indicators. We focused on existing indicators measuring resource use, environmental impacts and progress achieved in green industries. The following list originates from previous project experiences at Ecologic Institute[25] and an additional literature search on the Internet through Google scholar (http://scholar.google.com) using as key words, in combination, the terms *indicator, resource, efficiency, industry, sustainability*. An article was considered promising based on its link to the study's objectives, the title, and the summary or abstract. We also checked the references cited in each article to identify additional relevant material. At the same time, the project's timeframe and resource allocation demanded that we keep the preliminary set of indicators reasonably small and restrict the final list of indicators that undergo a detailed analysis to the ten most promising.

Altogether, 33 indicators were reviewed and assessed in order to identify the 10 most promising ones. The top ten list and a summary of their evaluations can be found in section 3. Since not all criteria listed in table 1 above are equally relevant in the context of this study's objectives, the top ten ranking was guided by the following five equally weighted core selection criteria:

1. LCA compatibility,
2. Coverage of industries and industrial development,
3. Sustainability impacts coverage,
4. Required data efforts, and
5. Policy relevance.

The ten top-ranked indicators were then further analyzed regarding data availability. Data availability is often used as an elimination criterion in the search for indicators to monitor or evaluate a specific issue for use in the decision-making process. If the timeframe and implementation plan allow the inclusion of indicators with de facto insufficient data availability, e.g. due to the indicator's relative novelty or the high cost associated with data collection, then indicators with limited data availability can still be considered. For the purpose of this study, it was important not to exclude a priori indicators with limited data availability that otherwise have sufficient merit to be used for measuring resource efficiency and sustainable industrial processes. Therefore, data availability was only examined after the selection of the 10 most promising indicators using the following aspects:

Table 2: Data availability of the indicators reviewed

Indicator:	Evaluation: ☺ / 😐 / ☹*
Data requirements:	
Relevant databases:	
Data availability: *Data sets available:* *Level of data:* *Time period:*	

* ☺ good data availability 😐 medium data availability ☹ weak data availability

The following section summarizes the results for the ten indicators along the core selection criteria and data availability, with the full assessment available in the project's final report.

[25] The following projects may serve as examples: Environmental Pressure index (http://ecologic.eu/4202), Potential of the Ecological Footprint for monitoring environmental impact from natural resource use (http://ecologic.eu/2367), Indicator-based environmental reporting (http://ecologic.eu/3862), Establishing thresholds for environmental sustainability and a related set of indicators (http://ecologic.eu/3604), Integrating Mainstream Economic Indicators with Sustainable Development Objectives (IN-STREAM) (http://ecologic.eu/2510).

Results

This section summarizes the strengths and weaknesses of the selected indicators in relation to the five core selection criteria and data availability. Suggestions are derived to further distinguish the indicators from those that are presently the best available, most effective indicators for tracking industrial resource efficiency and environmental impacts.

The discussion is organized by indicator and addresses further methodological and data-specific issues. It also gauges the current and likely future acceptance of the indicator within political circles and decision-making processes as well as the ease with which the indicator's concept and findings can be interpreted and explained to different audiences.

Table 3 summarizes the results of the evaluation for the top ten indicators reviewed. For brevity, the full list of the 33 indicators reviewed and the complete set of evaluation factsheets are not included in this brief but can be found in the full report available from our website at http://ecologic.eu/4758.

Table 3: The ten top-ranked indicators according to core criteria and data availability

Indicator	LCA compatibility	Coverage of industries and industrial development	Sustainability impacts coverage	Policy Relevance	Required data efforts	Ranking	Data availability
Environmentally weighted material consumption	☺	☺	☺	☺	😐	**1**	😐
Energy intensity by sector	😐	☺	☺	☺	☺	**2**	☺
Production based CO_2 productivity	😐	☺	☺	☺	☺	**3**	☺
Water consumption by sector	☺	☺	☹	☺	😐	**4**	😐
Sustainable Process Index	☺	☺	😐	☺	☹	**5**	😐
Water abstraction rates and water stress	☹	😐	☺	☺	☺	**6**	😐
Corporations' turnover, value added and exports of the environmental goods and services sector	☹	☺	☺	☺	😐	**7**	😐
Resource Productivity	😐	☺	☹	☺	😐	**8**	☺
Total Material Consumption	😐	☺	😐	☺	☹	**9**	😐
Ecological Footprint	☹	☺	😐	😐	☺	**10**	☺

Environmentally weighted material consumption (EMC)

The EMC combines data from economy-wide material flow accounts (such as Domestic Material Consumption DMC) with data from LCA by multiplying the mass of 32 selected base materials with the LCA impact coefficients.[26] The shares of each country are normalized against the global impact of each equally weighted impact category.

According to our analysis, the EMC indicator fully matches the first four criteria listed but has some shortcomings in regards to required *data efforts* and *data availability*.

[26] http://scp.eionet.europa.eu/themes/resource_use

The EMC indicator is fully *LCA compatible* because it is based on the accounting principles of Material Flow Analysis (MFA), with an additional step of associating impact factors to different material types and quantities. The indicator is calculated by obtaining a score on the LCA impact categories, such as global warming, acidification or human toxicity,[27] for each material examined.

The indicator is based on DMC and can therefore be applied to assess the sustainability of industries and industrial development. Furthermore, DMC covers the three main categories fossil fuels, minerals and biomass, so that EMC can capture specific industries or sectors within these categories.

A further advantage of the EMC is the inclusion of imported materials and foreign impacts,[28] thus giving a more accurate picture of total environmental impacts and decoupling than an indicator placed solely within domestic boundaries. This makes the EMC indicator uniquely suited to determine material-, industry-, and even country-level environmental impacts resulting from resource use in economic production and waste treatment. Despite some relevant shortcomings of the EMC – e.g. not establishing a link to products as underlying drivers behind the impacts and only covering the use phase via consumption/incineration of fossil fuels[29] – EMC is considered an important advancement, in particular in comparison to DMC, and fully matches the *sustainability impacts coverage* criterion.

In addition, EMC is possibly the most *policy relevant* highly aggregate composite indicator for assessing the combined environmental impact of industry. EMC is able to measure the environmental impacts of material use from cradle to grave. Thus, EMC is of high value to indicate the progress towards decoupling of economic growth from natural resource use and associated environmental impacts. Decoupling is an increasingly import policy issue, from international to the national level, inter alia a core issue of the Agenda 21 and the Roadmap to a Resource Efficient Europe.

However, the EMC is not yet widely adopted and its database is incomplete. Developed in 2005 and based on data for the EU25 for 1990-2000 and for three EU Candidate Countries for 1992-2000, more recent data and studies on the EMC are scarce. A recent study[30] about the possibility of calculating the EMC indicator directly using EU statistics found that "… in principle, suitable databases are available. … However the gaps in these databases are presently so large that no meaningful result can be obtained."[31] Therefore, both *required data efforts* and *data availability* are only partially matched.

Based on the overall assessment, we ranked the EMC highest in our list of potential indicators for gauging resource efficiency and 'greenness' of industries, in particular within the context of decoupling economic growth and development from resource use.

Energy Intensity by Sector

No natural resource is as critical as energy in economic activity. Most energy is still sourced from fossil fuels with well-known effects on climate and the environment. Thus, not only transitioning from fossil fuels to renewable ones but also reducing the energy required for a given unit of economic output is beneficial from a number of perspectives.

[27] Van der Voet, E, van Oers,L., Moll, S., Schütz, H., Bringezu, S., de Bruyn, S., Sevenster, M., Warringa, G. (2005): Policy Review on Decoupling: Development of indicators to assess decoupling of economic development and environmental pressure in the EU-25 and AC-3 countries. CML report 166, Leiden: Institute of environmental sciences (CML), Leiden: Leiden University, Department Industrial Ecology, 2005 available at http://www.leidenuniv.nl/cml/ssp/projects/ dematerialisation/policy_review_on_decoupling.pdf.

[28] http://www.leidenuniv.nl/cml/ssp/publications/eurostat_indicators_final_report_version_141009.pdf.

[29] JRC and IES 2010. Decoupling indicators, Basket-of-products indicators, Waste management indicators – Framework, methodology, data basis and updating procedures. Draft for public consultation, available at http://lct.jrc.ec.europa.eu/pdf-directory/Indicators-framework-for-public-consultation-16082010.pdf.

[30] Van der Voet, E., L. van Oers, S. de Bruyn, F. de Jong and A. Tukker (2009) Environmental Impact of the use of Natural Resources and Products. CML report 184. Department Industrial Ecology. 186p.

[31] http://www.leidenuniv.nl/cml/ssp/publications/eurostat_indicators_final_report_version_141009.pdf page 15.

As an indicator, energy intensity by sector can measure progress toward relative decoupling — when the level of resource use or environmental impact grows at a slower rate than economic output — of energy consumption from economic growth within key sectors. High levels of energy intensity indicate a high cost of converting energy to economic output while low values reflect a low cost of energy conversion to economic value.

According to our analysis, the Energy intensity by sector indicator fully matches *data availability* and all criteria apart from *LCA compatibility*, which it matches only partially.

The Energy intensity by sector indicator can be developed to be product-specific or sector-specific. Sector-specific energy intensity was used by the OECD (2011). As a result, the indicator is useful for measuring the greening of industries, products and industrial development processes.

Though this indicator does not directly measure environmental and social impacts, it does provide a direct measure of economic impacts. There are obvious economic benefits to using less energy to derive a unit of revenue, which encourages economic growth and can in turn have positive second order effects on society. Improving energy intensity can enhance environmental performance in a number of ways, including lowering GHG and other emissions. However, in order to fully understand and quantify the environmental benefits, this indicator must be used in conjunction with a measure of the energy mix (i.e., the share of renewable energy versus fossil resources, etc.). Nonetheless, this is a valid indicator to measure resource efficiency. Therefore, *sustainability impacts coverage* is considered fully matched.

Energy is the vital input to all of human activity and the primary anthropogenic driver of climate change. Therefore, reducing energy consumption and switching to renewable, climate neutral energy sources are two key *policy relevant* components for greening industry. Energy intensity of the economy is a key indicator for measuring the Lisbon Process and its successor Europe 2020. Other relevant agreements and initiatives include the Kyoto protocol (Article 2); the Barcelona European Council (2002); and the Brussels European Council (2003).[32]

Calculating the energy intensity by sector indicator requires data on energy consumption by sector, revenue by sector, total energy supply/consumption (gross inland energy consumption or TPES) and GDP. These data are readily available and publicly accessible via a number of sources, and energy intensity is already published in a variety of national, regional, and global indicator sets such as OECD indicators for monitoring "green growth," the UN Sustainable Development Indicators, and Eurostat's indicators monitoring sustainable development in the European Union. Therefore, both the *required data efforts* and *data availability* criteria are fully matched.

However, the indicator – as used in current sustainability indicator sets – does not incorporate life cycle stages. This would require significant additional effort from the perspective of data collection, preparation and use. Therefore *LCA compatibility*, is only partially fulfilled.

Based on the overall assessment, we ranked the Energy intensity by sector indicator second highest, in particular within the context of energy as the vital input to all human activity and reducing energy consumption and switching to renewable, climate neutral energy sources being key components for greening industry. Since it is not fully LCA compatible, this indicator is considered of lower applicability to sustainable industries than the EMC.

Production-based CO_2 Productivity

Production-based CO_2 productivity, i.e., GDP generated per unit of energy-use related CO_2 emitted, is an important indicator for measuring the environmental performance of production processes for climate protection purposes. It helps to measure decoupling of economic growth from carbon inputs required for growth.

[32] Eurostat 2010

According to our analysis, the Production-based CO_2 productivity indicator fully matches *data availability* and all criteria apart from *LCA compatibility*, which it only matches partially.

This indicator can measure industry's performance over time in reducing emissions emitted from energy use in industrial production processes. Therefore, it can *cover industries and industrial development*.

Furthermore, the indicator can measure the environmental impact of energy-related CO_2 emissions. However, the indicator does not directly measure the impact of CO_2 emissions on the economy, but it does provide information on the extent to which economic growth and CO_2 emissions are interlinked. The indicator does not directly measure social impacts. Though a more complete environmental impact assessment is obtained, when this indicator is used in combination with indicators on energy intensity and additional climate change-relevant greenhouse gases; it is nonetheless suitable for capturing the climate impacts of CO_2 emissions associated with energy use. Therefore, this indicator matches the *sustainability impacts coverage* criterion.

Since the indicator can be used to measure progress on decoupling CO_2 emissions from GDP growth and measures progress towards national or international commitments to reduce GHG emissions, it is highly *policy relevant*.

To calculate this indicator, data on GHG emissions at the national level and by sector, energy use, and GDP growth are needed. This requires only a small effort, because Parties to the UNFCCC agreements have to annually report harmonized data on CO_2 emissions (and five other greenhouse gases) to the UNFCCC secretariat. Thus, comprehensive greenhouse gas inventories, starting in the 1990s, exist for many countries, and both the *required data efforts* and *data availability* criteria are fully matched.

However, the indicator only incorporates production processes and cannot capture the demand and consumption side effects. Therefore, not all life cycle stages relevant to CO_2 emissions are covered and this indicator is only partially *LCA compatible*.

Based on the overall assessment, we ranked the Production-based CO_2 productivity indicator third, in particular within the context of energy use and associated climate impacts. Since this indicator requires combination with other indicators to enable a more complete environmental impact assessment and because LCA compatibility is only partially given, this indicator is considered of lower applicability to sustainable industries than the first two indicators.

Water Consumption by Sector

Water consumption by sector is defined as the annual water consumption for domestic use, industrial use, agricultural use and other sectors expressed in cubic meters per year or as a percentage of total water consumption. These indicators can be used for water resources management by identifying crucial sectors of consumption in which specific future plans have to be developed. Usually, the heaviest water uses are domestic, industrial, and agriculture in ascending order. Water consumption in the agricultural sector is a crucial factor to assess the vulnerability to desertification of areas already facing water scarcity problems.

According to our analysis, this indicator fully matches *LCA compatibility*, *coverage of industries and industrial development* and *policy relevance*. In contrast, as displayed in table 3, *sustainability impacts coverage* is not matched, and *required data efforts* and *data availability* are partially matched.

LCA for products, services and sectors can measure the consumption of water at various steps in the extraction-production-disposal chain. Therefore, this indicator is *LCA compatible*.

In addition, the indicator is able to measure the performance of specific industry sectors in terms of water consumption, so that *industries and industrial development are covered*.

Freshwater is a critical resource for life and our economic system and is becoming increasingly scarce in many parts of the world. Increasing industrial water efficiency is an important contributor to managing this resource within its replenishment rates. The indicator thus helps highlighting the importance of a sector in the total demand for water and it is also useful to show which sectors are consuming the most water, especially in water scarce areas where plans need to be developed to improve access to water. This in turn provides an indication of the sector's—and the economy's— vulnerability to decreasing water supplies. Therefore, it is *policy relevant* and a useful tool for policy makers to evaluate productivity and behavior in water consumption by key sectors over time and to set the price structure of water.

However, the indicator does not measure impacts, but only pressures (water abstraction). As the indicator does not match abstraction with availability, there is no indication as to water scarcity at all. More information would be necessary in order to evaluate whether the water consumption measured is sustainable and whether it fosters sustainable development. Water consumption must be assessed in conjunction with water availability, especially the fraction of water than can be used for economic purposes without depleting resources or harming the environment. In addition, water consumption may also lead to water pollution, which in turn can have adverse environmental and public health effects. The indicator should be complemented by indicators measuring the amount of water available for use and water quality. Therefore, *sustainability impacts* are not covered.

To calculate this indicator, data on water withdrawal by major sector (agriculture, industry and domestic), as well as total water withdrawal are needed. Countries with environmental accounts usually have the information required and not much effort is needed to calculate the indicator. However, this also depends on the willingness of the different sectors to monitor and provide data on their water use. Low willingness among many industries to do so is often reported. As a result, *required data efforts* and *data availability* are partially matched.

Based on the relevance of freshwater for human life and economies, we ranked the Water consumption by sector indicator fourth. Despite the insufficient ability to cover sustainability impacts, this indicator is considered helpful in terms of gauging the quantity of water used by industries and therefore contributes to measuring sustainable industries.

Sustainable Process Index (SPI)

The Sustainable Process Index (SPI) is based on the assumption that a sustainable economy is completely comprised of "solar exergy" – that is, all natural and anthropogenic activities compete for surface area to utilize the limited supply of solar energy that they need to sustain themselves. The SPI therefore calculates which surface area, a limited resource, is needed for the conversion of energy into products and services. Accordingly, the foundation of the SPI is surface area: the more area needed to convert a process into a service, the more it "costs" in terms of sustainability. More specifically, the SPI measures the fraction of the area per inhabitant related to the delivery of a certain product or service unit. In this sense, it is a type of "ecological footprint" indicator.

According to our analysis, this indicator fully matches *LCA compatibility*, *coverage of industries and industrial development* and *policy relevance*. In contrast, *sustainability impacts coverage* is not matched. *Required data efforts* and *data availability* are partially matched.

SPI is used to measure the environmental impacts within LCA, therefore it is *compatible with LCA*. It is similar to the Ecological Footprint in its use of area as the metric to calculate resource use in, but the SPI is better suited to cover life cycle stages because it looks at processes and not end-user consumption.

The SPI can be used at different levels: process, product, and even at the regional level. It can also compare widely different technologies. The indicator captures different sectors' performance in terms of the land used in a process and makes different technologies comparable. It can provide a basis for different industries to seek more sustainable methods, which would be measured by a reduction in land used in a process compared to current use. Therefore, *industries and industrial development are covered.*

In addition, the SPI is *policy relevant*. It allows for valuations at different levels (of processes, products, and regions) to be comparable, because it calculates the total area needed for raw materials, energy, process installation, staff and product dissipation. This may help policy makers evaluate changes in consumption patterns, organization or technology use and base future plans on the information. To some extent, policy makers can influence adoption of more efficient technologies or steer consumption patterns towards those that have a lower footprint in terms of land use because each process and product can be converted into land area.

However, the indicator measures environmental and economic impacts of processes only in terms of land use – it does not provide an estimate of the environmental impacts of resource use. The social impacts of said land use are not self-evident and more information would be required to draw conclusions. Hence, *sustainability impacts* are only partially covered.

Furthermore, calculating the SPI is very complex and requires data on renewable raw material area, non-renewable raw material area, the price of the raw material, the price of one kilowatt-hour (kWh) of energy, the area needed to provide the installation for a process, the number of workers per year in a factory allocated to an area (the more staff a process requires the bigger the pressure on the environment), and the area allocated to dissipation. Therefore, the SPI is used more among universities and research institutions and hardly within businesses or industry. In addition, data availability is a problem, as the database is not updated regularly and the last update was done in 2006. The data are compiled from various sources, such as Eurostat data (for 2002), EC-DG VI (for 1997), "Life Cycle Inventories of Energy Systems" BEW (for 1996), Graz University of Technology. *Required data efforts* and *data availability* are serious shortcomings.

Based on its LCA compatibility, its applicability to industries and industrial development and its policy relevance, the SPI is a relevant indicator. However, due to its lacking ability to measure environmental impacts beyond land use impacts and due to the great data efforts require for calculating the SPI, we ranked it only fifth.

Water Abstraction Rates and Water Stress

Water abstraction rates and water stress reflect the intensity of freshwater resources use. Water abstraction rates are expressed as gross abstractions per capita, as a percentage of total available renewable freshwater resources (including inflows from neighboring countries) and as a percentage of internal resources. Water stress is expressed as gross abstractions in a percentage of total available renewable freshwater resources (including inflows from neighboring countries), or in a percentage of internal resources (i.e. precipitations - evapotranspiration).

According to our analysis, this indicator fully matches *sustainability impacts coverage*, *policy relevance* and *required data efforts*. In contrast, *LCA compatibility* is not matched, while *coverage of industries and industrial development* and *data availability* are partially matched.

Freshwater resources are of significant environmental and economic importance, with resources and pressures varying widely both within and between countries. Higher water abstraction rates and water stress can significantly impact all sustainability pillars – economic, environmental and social. Specific impacts include water shortages, salinization of freshwater bodies in coastal areas, human health problems, loss of wetlands, desertification and reduced food production.[33] Therefore, *sustainability impacts coverage* is fully matched.

Related policies and initiatives include Agenda 21 (UNCED, Rio de Janeiro, 1992), which explicitly considered the protection and preservation of freshwater resources and the World Summit on Sustainable Development (Johannesburg, 2002).[34] In addition, ensuring that rates of extraction are sustainable over the long term is an objective of the EU's Sixth Environment Action Programme.[35] Therefore, this indicator is highly *policy relevant*.

[33] OECD 2011
[34] OECD 2011
[35] EEA Indicators 2010

To calculate this indicator, data are needed on gross abstractions, population, total available renewable freshwater resources (including inflows from neighboring countries) and total internal water resources. Preparation and usage at a country level should be straightforward, although the challenges regarding data consistency and missing values should be taken into account. Collecting data at sub-national or sectoral level would be more challenging. Nonetheless, *required data efforts* are fully matched.

However, as this indicator refers to total abstractions, and is not industry or sector specific, LCA is not relevant. Therefore, this indicator does not match *LCA compatibility*.

Furthermore, though the UN estimates water withdrawal for the agricultural sector, municipalities (including domestic water withdrawal) and industries, as well as at the country and regional level, and the EEA compares irrigation, manufacturing industry, energy cooling and Public Water Supply usage in the Water Exploitation Index, "estimation of water withdrawal by sector is the main limitation to the computation of the indicator".[36] Thus this indicator only partially *covers industries and industrial development*.

One of the challenges regarding the usage of this indicator is related to data quality and availability. Beginning in 1992, the UN FAO has been collecting and analyzing data on water resources and their use through its AQUASTAT country surveys. To a certain extent, data is available for almost all countries, by continent, and by region. However, the periodicity and quality of this data creates limitations for its usage. For instance, data for developing countries is sometimes of lower quality or has gaps, and in many cases water use is only metered within urban areas, leaving gaps in the data regarding rural use. Data on withdrawals, especially in developing countries, is largely incomplete, particularly for agriculture. Furthermore, this indicator is typically based on country data, which may not reflect uneven spatial distribution of resources and thus mask water stress situations at the regional or local level. Therefore, *data availability* is only partially matched.

The water abstraction and water stress indicator is an essential indicator to gain insight into the key question of sustainable water usage, as it takes into account water resources available and the pressures specific to an individual country or watershed. However, its lacking LCA compatibility, limited coverage of industries and industrial development and limited data availability caused us to rank it only sixth.

Corporations' turnover, value added, and exports of the environmental goods and services sector

According to a Eurostat Handbook published in 2009, the environmental goods and services sector (EGSS)[37] is characterized by the four key variables:

1. Turnover (totals invoiced by the observation unit during the reference period),
2. Value added (the contribution made by these activities towards the income measure of gross domestic product (GDP),
3. Employment (see indicator table for employment in EGSS), and
4. Exports (consisting of sales, barter, or gifts or grants, of goods and services from residents to non-residents).[38]

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[36] UN Statistics MDG Indicators

[37] Eurostat 2009. Eurostat defines EGSS as "a heterogeneous set of producers of technologies, goods and services that:

- Measure, control, restore, prevent, treat, minimise, research and sensitise environmental damages to air, water and soil as well as problems related to waste, noise, biodiversity and landscapes. This includes 'cleaner' technologies, goods and services that prevent or minimise pollution.
- Measure, control, restore, prevent, minimise, research and sensitise resource depletion. This results mainly in resource-efficient technologies, goods and services that minimise the use of natural resources.

These technologies and products (i.e. goods and services) must satisfy the end purpose criterion, i.e. they must have an environmental protection or resource management purpose (hereinafter 'environmental purpose') as their prime objective."

[38] Eurostat Website http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Environmental_goods_and_services_sector, accessed 01 06 2012.

According to our analysis, this indicator fully matches *coverage of industries and industrial development*, *sustainability impacts coverage* and *policy relevance*. In contrast, *LCA compatibility* is not matched, while *required data efforts* and *data availability* are partially matched.

This indicator relates directly to EGSS, capturing trends in industries specifically within the environmental goods and services sector. Therefore, *coverage of industries and industrial development* is fully matched.

Furthermore, turnover, value added, and exports all provide information regarding economic trends in EGSS, such as its overall size and growth, and how that growth relates to the economy as a whole. Although products and services in EGSS "must have an environmental protection or resource management purpose (…) as their prime objective"[39], this indicator is not a measure of those impacts. While the indicator gives an important view on the development of the green sectors of an economy, it concentrates on the sectors defined as environmental goods sector. This implies that any movement towards greener practices in all other sectors is ignored. In addition, changes within the EGSS are not properly accounted for. If, for example, the industry for solar panels and photovoltaic systems is booming but uses lots of energy and produces substantial environmentally harmful byproducts, this would not be reflected in the indicator. Nonetheless, overall *sustainability impacts coverage* is considered fully matched.

The performance of the EGSS is related to a number of policy priorities and initiatives, including the Gothenburg strategy for a sustainable Europe and the Lisbon strategy for a competitive, dynamic and inclusive Europe. The value added and export level of environmentally friendly goods and services can be compared with total value added and total exports and hence give an idea of the extent to which the economy has transitioned to low-impact production methods and industrial composition. Therefore, this indicator is *policy relevant*.

In order to calculate this indicator, data on totals invoiced by the observation unit during the reference period, on the cost of production, on value of output and intermediate consumption as well as on exports are needed. Turnover and employment data are widely available and commonly used in assessments of performance and growth and the economic sector overall. Value added is also available, often used to compare income added by the EGSS to the national income. Export data is also widely available and frequently used.[40] However, the definition of EGSS may change depending on the type of data source used; it could prove challenging to collect harmonized data. Moreover, if the desired statistics are not already compiled by Eurostat or a similar entity, the preparation and use of the data will require additional time and resources, as each separate statistic in the indicator requires a specific methodology. There exist moderate to significant challenges in collecting, preparing, and using data in a meaningful way, and though these challenges will most likely be eliminated in the near future, *required data efforts* and *data availability* are currently only partially matched.

Capturing the monetary value added and export value of the EGSS can be used to evaluate the size and growth of these products, goods and sectors relative to the economy at large, but turnover and value added data are not captured by LCA methods. Therefore *LCA compatibility* is not matched.

This indicator is essential for measuring economic performance within sustainable industries but several aspects complicate its usefulness. The indicator is used almost exclusively for economic performance and cannot, for instance, effectively measure greening industries outside the EGSS. Moreover, it lacks LCA compatibility and often requires extra effort in cases where insufficient data exists, making it only marginally appropriate for the tasks at hand. For this reason the indicator ranked seventh.

Resource Productivity and Material Productivity

Resource productivity measures the total amount of materials directly used by an economy (Domestic Material Consumption DMC) in relation to the economic activity (GDP) through dividing

[39] Eurostat 2009
[40] Eurostat 2009

GDP (at constant prices) by DMC (GDP/DMC) or by Total Material Consumption TMC (GDP/TMC). Thus, Resource productivity enables aggregate measuring of the material efficiency of an economy.

According to our analysis, this indicator fully matches *coverage of industries and industrial development*, *policy relevance* and *data availability*. In contrast, *sustainability impacts coverage* is not matched, while *LCA compatibility* and *required data efforts* are partially matched.

Resource productivity successfully covers the performance of industries or sectors in two ways. First, it is based on DMC, which - in particular for complex products - requires aggregation to material categories, thus facilitating generalization to product categories or industry sectors. Furthermore, DMC addresses the three main categories (fossil fuels, minerals and biomass) and can, therefore, be applied to capturing specific industries or sectors within these categories. This indicator fully matches *coverage of industries and industrial development*.

Resource productivity can be used to indicate the progress towards decoupling of economic growth from the use of natural resources. Decoupling is an increasingly important policy issue, relevant to both the international and national level, that aims to reduce environmental impacts and degradation associated with primary production, material processing, manufacturing and waste disposal. Such issues are at the core of international agreements, including Agenda 21 and the 2002 World Summit on Sustainable Development Johannesburg Plan of Implementation, as well as European policies, such as the EUROPE2020 Strategy[41] or the Roadmap to a Resource Efficient Europe.[42] In the latter, resource productivity is even proposed as a provisional lead indicator, indicating that it is of high *policy relevance*.

Regarding data availability, GDP data is readily available for many countries and is provided by national statistical offices, European level databases (e.g., Eurostat) and international databases (e.g., WorldBank, OECD). For EU15 and EU27 level, Eurostat has collected data on material flows in the Environment database that include associated countries.[43] SERI provides access to global material extraction data at the national level at http://www.materialflows.net/. OECD provides data on material resources for the OECD countries in its Environmental Data Compendium.[44] *Data availability*, in this case, is fully matched.

However, since Resource productivity is based on DMC, which is not able to reflect the environmental impacts of the materials used, this indicator does not sufficiently cover the environmental dimension of resource and material consumption. It indicates that more value can be generated per unit of inputs, but it does not address resource scarcity or efficiency, or environmental impacts. *Sustainability impacts coverage* is therefore not matched.

In addition, Resource productivity includes materials input into the economy for further processing and consumption, so that different life cycle stages (from extraction to disposal) can be addressed. DMC is designed to measure materials extracted, used and also disposed of, so Resource productivity is able to address different life cycle stages. But because the different materials are calculated in terms of their weight, which does not sufficiently take into account the different environmental impacts of different materials, *LCA compatibility* is only partially matched.

Furthermore, in order to calculate the DMC for a complex manufactured product (e.g. consisting of a mix of materials), the product needs to be attributed to the “dominant” material category. This likely requires more efforts to establish conversion tables to arrive at a well-founded attribution of products and imports. Therefore, *required data efforts* are partially matched.

In spite of the high policy relevance of the Resource productivity indicator and its ability to measure resource quantities used within industries and industrial development, it remains

[41] European Commission 2010. EUROPE 2020 - A European strategy for smart, sustainable and inclusive growth. COM(2010) 2020, see http://ec.europa.eu/europe2020/index_en.htm.
[42] European Commission 2011. Roadmap to a Resource Efficient Europe. COM(2011) 571 final, see http://ec.europa.eu/environment/resource_efficiency/pdf/com2011_571.pdf
[43] See under environmental account, physical flows and hybrid accounts
[44] Available at: http://www.oecd.org/dataoecd/22/36/41878252.pdf

inadequate to consider environmental impacts and hidden flows, and it lacks LCA compatibility, rendering the indicator only partially relevant. As a result, it only ranked eighth.

Total Material Consumption (TMC)

Similar to Domestic Material Consumption (DMC), TMC measures the total amount of materials directly used by an economy (i.e. associated with domestic production and consumption activities), but it furthermore accounts for the effects of upstream hidden flows linked to imports of raw materials, semi-manufactured and finished products. TMC equals Total Material Requirement (TMR) minus exports minus indirect flows associated with exports.

According to our analysis, this indicator matches *coverage of industries and industrial development* and *policy relevance*. However, required data efforts are significant and *LCA compatibility*, *sustainability impacts coverage* and *data efforts* are only partially matched.

Similar to DMC, TMC is also material specific and linked to semi-manufactured or finished products. As a result, TMC also requires aggregation to material categories for complex products. This may facilitate generalization to product categories or industry sectors. Furthermore, because the three main categories - fossil fuels, minerals and biomass - are addressed, TMC matches *coverage of industries and industrial development*.

TMC is able to measure the absolute level of resources used within an economy and its associated upstream resource flows. Therefore, TMC could be used to indicate the progress towards decoupling of economic growth from the use of natural resources. Decoupling is an increasingly important policy issue at both the international and national level that aims to reduce environmental impacts and degradation associated with primary production, material processing, manufacturing and waste disposal. These are core issues of the Agenda 21 and the 2002 World Summit on Sustainable Development Johannesburg Plan of Implementation, as well as of European policies, such as the EUROPE2020 Strategy or the Roadmap to a Resource Efficient Europe. TMC hence is of high *policy relevance*.

There are, however, shortcomings that make TMC difficult to utilize effectively. TMC requires data on consumption and trade of all materials flowing in and out of an economy. In particular, calculating indirect flows poses great practical difficulties and significant *data efforts*.

In addition, TMC derives from MFA-type assessments. TMC is able to measure materials extracted, used (production and consumption) and disposed of, meaning that different life cycle stages can be addressed. However, because the different materials are calculated in terms of their weight, this indicator does not sufficiently take into account the different environmental impacts of different materials, and TMC only partially matches *LCA compatibility*.

Furthermore, though TMC is able to assess the hidden flows of imports and thus measure the "real" environmental impact (through indirect flows) of materials used for production and consumption, TMC may still only serve as a proxy for measuring the overall environmental pressure of resource use because different materials cause very different impacts on the environment (for instance, the impacts of 1 metric ton of mercury are doubtless much greater than those of 1 metric ton of gravel). Furthermore, the impacts linked to indirect flow associated with exports are not taken into consideration. Therefore, *sustainability impacts* are partially covered.

Concerning data availability, material flow data is available, e.g. through Eurostat's Environment database[45] or SERI's global material extraction data (at http://www.materialflows.net/). However, it is difficult to obtain a complete picture of all indirect flows. Therefore, *data availability* is only partially matched.

The lacking capturing of environmental impacts and deficient LCA compatibility render this indicator only partially useful in spite of the high policy relevance of the TMC indicator and its ability to measure resource quantities used within industries and industrial development. Therefore, we only ranked it ninth.

[45] See under environmental account, physical flows and hybrid accounts

The Ecological Footprint (EF)

The Ecological Footprint measures how much biologically productive land and water area is required to 1) meet resource consumption needs and 2) absorb the wastes generated by a human population, taking into account current technology. The methodology also includes a measurement of the annual production of biologically provided resources – called biocapacity. The Ecological Footprint and biocapacity are each measured in global hectares, a standardised unit of measurement equal to 1 hectare with global average productivity (yield obtained in a particular year from any land class with the locally prevailing technologies).

According to our analysis, this indicator matches *coverage of industries and industrial development*, *required data efforts* and *data availability*. In contrast, *LCA compatibility* is not matched, while *sustainability impacts coverage* and *policy relevance* are only partially matched.

The EF can be applied to studying the performance of specific industries. This has been done, for instance, by WWF concerning fine paper manufacturing (see http://wwf.panda.org/what_we_do/how_we_work/conservation/forests/news/?uNewsID=194141); by SERI focusing on the raw-materials producing industry in Austria (see http://seri.at/projects/completed-projects/ecological-footprint-industry/); and by Chen and Hsieh (2011)[46] regarding the hotel industry. As a result, this indicator matches the *coverage of industries and industrial development* criterion.

EF calculation covers six land use types: cropland, grazing land, fishing ground, forest land, built-up land, and the uptake of land to accommodate the carbon footprint. The calculations in the National Footprint Accounts are based primarily on international data sets published by the Food and Agriculture Organization of the United Nations (FAOSTAT, 2010), the UN Statistics Division (UN Commodity Trade Statistics Database – UN Comtrade 2010), and the International Energy Agency (IEA 2010). No primary data collection is required. Sufficient data has been available to calculate National EF accounts since 1961 for more than 150 countries. Therefore, *required data efforts* and *data availability* are fully matched.

However, though the EF can be applied to single activities, products, persons, enterprises or industries, National Footprint Accounts can reflect life cycle aspects only to a limited extent. For example, energy use will be monitored as such, but not attributed to any particular energy-using products. Furthermore, the EF does not capture most of the impact categories usually applied in life cycle analysis, such as ecotoxicity, acidification, ionizing radiation. Thus, the Ecological Footprint has poor *LCA compatibility* because it looks only at end-user consumption.

Furthermore, the EF measures primarily resource consumption. However, EF accounts do not contain spatially disaggregated data on actual land use and do not provide precise information on ecosystem impacts. Furthermore, the effects of resource consumption on climate change are not directly included in the analysis; neither do EF calculations explicitly address biodiversity or impact on ecosystems. The EF does not explicitly measure social or economic impacts. In fact, the EF was not designed to comprehensively measure overall sustainability. Many aspects of sustainability are missing from the calculation and need to be covered by complementary indicators. Nonetheless, the EF is one of the most ambitious attempts to provide one comprehensive indicator that would measure the entire spectrum of sustainability. Therefore, *sustainability impacts coverage* is considered to be partially matched.

In addition, though the EF is useful for assessing progress on the EU's resource policies because it is uniquely able to relate resource use to carrying capacity, it does not lead to immediate policy conclusions. Therefore, *policy relevance* is only partially matched.

In conclusion, while the EF has many advantages that favor its use as a sustainability indicator, it is not a best choice for measuring the sustainability of industries or industrial development due to its lack of LCA compatibility, restricted coverage of production issues and resulting policy relevance. It was therefore ranked 10th in the list of indicators reviewed.

[46] Chen, Han-Shen and Hsieh, Tsuifang 2011. An environmental performance assessment of the hotel industry using an ecological footprint. Journal of Hospitality Management and Tourism 2 (1): 1 – 11. Available at http://www.academicjournals.org/JHMT/PDF/Pdf2011/Jan/Chen%20and%20Hsieh%20pdf.pdf.

Resource Efficiency of Industry and the MDGs

In light of the upcoming review of the MDGs and the proposal to consider the development of SDGs, the selected indicators are reviewed with a view towards their applicability within the MDG setting. MDG 7 includes four targets and 10 indicators aimed at tracking progress towards reducing or even halting the loss of biodiversity as well as improving human health by removing environmentally mediated infections through improved drinking water and sanitation. However, none of the indicators addresses industries specifically or with the detail necessary to gain a complete and differentiated picture of the contributions of industry to resource extraction, use, waste, pollution, and environmental impacts.

Specifically, while the MDGs contain a number of indicators measuring resource stock (7.1, 7.6), resource use (7.4, 7.5, 7.7), and pollution (7.2, 7.3), there is no indicator addressing the scarcity of raw materials or their efficient use, nor do indicators exist for the management of waste and pollution that accompany industrial production related to resource exploitation. Thus, the indicators proposed in this study aim to address these identified gaps that exist in the current policy perspective of greening industry and making actors more accountable for resource depletion and pollution.

Following the collective review of the literature, data sources, and selected indicators, we recommend the following set of indicators to be integrated into the MDGs:

- Resource Productivity and Material Productivity
- Sustainable Process Index (SPI)
- Sector-specific or Resource-specific indicators
    - Energy Intensity by Sector
    - Water Consumption by Sector
    - Water Abstraction and Stress
    - CO_2 Productivity

These indicators should be supported by metrics revealing the extent of environmental impacts arising with from resource use. We therefore propose the following indicators:

- Environmentally Weighted Material Consumption (EMC)

Although the EMC has been identified as the most appropriate indicator established for measuring environmental impacts of resource use, the discussion of its limitations above shows a clear need to consider further indicators that are currently under development such as the **Overall environmental impact indicator** and the **Eco-efficiency indicator**.

Sustainability requires not only the generation and maintenance of sufficient economic activity within the ecological limits of the planet but also the consideration of social aspects such as equity, cohesion, and participation in decision-making. Not one of the 10 selected indicators is particularly well suited to reflect on the social dimension of industry. This is due to the current methodological focus of indicators as exclusively useful in measuring the 'greening' of industry. The social dimension of sustainable industrial development has not been the focus of this scoping study, but could be further developed in subsequent research.

Conclusions

The study has reached the following conclusions:

- LCA is a useful theoretical and practical framework for selecting and evaluating indicators for green industry and products. Its growing application is promising to bring greater clarity to the concept of "green industry".
- Resource efficiency and green production indicators exist but so far no single measure can capture all aspects of a "green industry", not to mention sustainability.
- Indicators that aim to combine LCA-type resource flow measures with environmental impact assessments have been proposed and are under development. It can be expected that 'second generation' indicators, e.g. the overall environmental impact indicator, will provide added value in studying industry's contributions to environmental degradation and allow for the identification of corrective policy interventions.
- A revised set of MDGs or SDGs can and should include resource efficiency and environmentally weighted impact indicators both from a consumption and production perspective. It is important that these measures, to the highest extent possible, consider the entire chain of resource flows.
- The social aspects of moving toward a resource efficient or sustainable industry have so far received little attention and should be considered in ongoing and future developments.
- Building on the set of indicators reviewed in this study we propose a basket of indicators as opposed to a single imperfect measure, with the objective to obtain a more complete picture of the efficiency and sustainability of industrial production.

Figure 2 visualizes the different dimensions of sustainable industries. An indicator basket should then be built to cover these dimensions with the minimal number of indicators.

Figure 2: Different dimensions of sustainable industrial development

Based on the reviews conducted in the previous chapters, the following indicators are proposed to be included in the basket:

- **EMC** (or eco-efficiency or overall environmental impact indicator) to capture *environmental impacts;*
- **Energy intensity by sector and production-based CO_2 productivity** to cover the *critical environmental areas* energy and climate change;
- **Water productivity by sector and water stress** to capture resource efficiency for a second *critical environmental resource; and*
- **Resource productivity (or TMC over GDP)** to capture *resource efficiency.*

According to the findings of the study, these indicators represent the most suitable indicators from the larger set of candidates that we evaluated. Industrial resource efficiency is gaining more traction not only in the environmental field but with a variety of actors, including the private sector, the climate community, and development economists. It can therefore be expected that investments will be made to further develop the indicators and data basis for calculating them.

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Appendix I

Resource Indicator:		
Brief description:		
Source/reference(s):		

Criteria	Qualitative assessment Question(s) to be answered by the criterion	score for criterion match (☺/😐/☹)*
LCA compatibility	*Is the indicator able to measure different life cycle stages? What aspects of the LCA chain does the indicator measure?*	
Coverage of industries and industrial development	*Is the indicator product-specific, or can it capture the performance of specific industries, sectors, and industrial development?*	
Sustainability impacts coverage	*Is the indicator able to measure environmental, economic, or social impacts?*	
Required data efforts	*How much data is required to establish the indicator? How much effort is needed to collect, prepare and use the data?*	
Consistency	*Does the indicator actually measure what it is intended to measure?*	
Avoiding double-counting	*Does the indicator preclude double-counting of resource use?*	
Compatibility	*Is the indicator derivable from existing measurement frameworks such as the System of Environmental-Economic Accounts (SEEA) or the Dutch National Accounting Matrix including Environmental Accounts (NAMEA)?*	
Uncertainties and data imputation	*How are uncertainties about data reflected in the indicator and how are missing data imputed? What errors of interpretation can be caused by the imputation method? Is the indicator robust against manipulation?*	
Scientifically verified	*Is the methodology for the indicator backed by scientific research and debate? Is it well documented?*	
Understanding and Acceptance	*Is the information directionally safe? Is comprehension of the indicator intuitive? Is the indicator accepted and used by different experts and non experts?*	
Policy relevance	*Does the indicator address and support policy priority issues by measuring progress towards political targets or thresholds? Does the indicator measure aspects which can be influenced by policy makers? Does it provide disaggregated information allowing the analysis of causal effects? Is it available to policy makers in short time frames?*	
Communication	*Can the indicator be visually illustrated?*	

* ☹ not matching the criterion 😐 partially matching the criterion ☺ matching the criterion

List of Abbreviations

AQUASTAT	UN FAO's global information system on water and agriculture
DMC	Domestic Material Consumption
EEA	European Economic Area
EF	Ecological Footprint
EGSS	Environmental goods and services sector
EMC	Environmentally weighted material consumption
GDP	Gross Domestic Product
GHG	Greenhouse gas
LCA	Life-cycle analysis
MDGs	Millennium Development Goals
MFA	Material Flow Analysis
NAMEA	Dutch National Accounting Matrix including Environmental Accounts
OECD	Organisation for Economic Co-operation and Development
SDGs	Sustainable Development Goals
SEEA	System of Environmental-Economic Accounts
SPI	Sustainable Process Index
TMC	Total Material Consumption
TMR	Total Material Requirement
UN FAO	United Nations Food and Agriculture Organisation
UNIDO	United Nations Industrial Development Organisation
WWF	World Wildlife Fund

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In the context of UNIDO’s process to establish a Green Industry Platform in 2012, this study’s purpose is to provide analytical support and to contribute to discussions on potentially relevant indicators for sustainable industries within the context of this Platform.

This Ecologic Policy Brief presents the main elements of the project in condensed form and is targeted toward an audience of policymakers and practitioners in the field of industrial resource efficiency and reporting.

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