Chemical footprint at micro and macro-scale
a life cycle based methodological framework

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“The mission of the IES is to provide scientific-technical support to the European Union's policies for the protection and sustainable development of the European and global environment”
JRC – IES - Sustainability Assessment Unit (H08)

mission and goals

Foster sustainability principles in EU policies through development/application of an integrated sustainability assessment framework for evidence-based decision support

- Facilitate systematic consideration of the social, economic, and environmental costs and benefits of EU policy measures based on life cycle thinking
- Support the development of new paths of growth focusing on a wider concept of green economy
- Boost the economic value of ecosystem services in a context of integrated and efficient management of natural resources
- Adopt a spatially resolved approach to sustainability assessment
- Increase the robustness and consistency of integrated sustainability assessment
II

(Non-legislative acts)

RECOMMENDATIONS

COMMISSION RECOMMENDATION

of 9 April 2013

on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations

(Text with EEA relevance)

(2013/179/EU)

THE EUROPEAN COMMISSION,

Having regard to the Treaty on the Functioning of the European Union, and in particular Article 191 and Article 292 thereof,

(4) The Conclusions of the Council on "Sustainable materials management and sustainable production and consumption" of 20 December 2010 (1) invited the Commission to develop a common methodology on the quantitative assessment of the environmental impacts of products throughout their life cycle, in
Link with international targets (and planetary boundaries)

Extraction of raw material

Manufacturing 1

Link with domestic/ EU targets

Manufacturing 2

Use phase

End of life

PRODUCT and TERRITORIAL POLICIES
Lca-based ecoinnovation for the product/sector

Green Chemistry - use phase but also supply chain
- Ecotoxicity and human toxicity but also other impacts
Integrated and life cycle based approach to chemical assessment: example of a pesticide

Application on the field

Fate in the environment

Assessment of ecological and human health impacts:

- Through evaluative scenarios
- Or increasingly accounting for spatial differentiation

What about:

- other life cycle stages of pesticide? E.g. production?
- other impact categories other than toxicity related ones?
WHAT IS THE CHEMICAL FOOTPRINT?

In theory, two approaches to chemical footprint may be possible:

1. Assessing the **intensity of chemical pressure**, in terms of release in the environment of chemicals, economic sector of use, typology of releases (point source or diffuse) and potential harm to the environment in a life cycle perspective

2. Linking the release in the environment with the carrying capacity of the system (ecological risk assessment, vulnerability analysis, Eco epidemiology).
Chemical Footprint: A Methodological Framework for Bridging Life Cycle Assessment and Planetary Boundaries for Chemical Pollution

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ABSTRACT
The development and use of footprint methodologies for environmental assessment are increasingly important for both the scientific and political communities. Starting from the ecological footprint, developed at the beginning of the 1990s, several other footprints were defined, e.g., carbon and water footprint. These footprints—even though based on a different meaning of “footprint”—integrate life cycle thinking, and focus on some challenging environmental impacts including resource consumption, CO2 emission leading to climate change, and water consumption. However, they usually neglect relevant aspects of biodiversity loss, i.e., species extinctions, genetic diversity loss, functional diversity loss, and ecosystem integrity loss, that are crucial for the current and future sustainability of the human society. This paper presents a chemical footprint that is able to capture both the ecological footprint and the footprint of human chemical use, including the direct and indirect consequences of chemical production, distribution, and use. The chemical footprint is designed to allow the assessment of the full-life cycle chemical impact sources, taken into account in the driver-responses impact assessment for the aquatic environment (direct water body type, diffuse and point sources) and the reference scenarios (direct, indirect, and diffuse sources). A chemical footprint provides a consistent assessment of impacts that supports integrated assessment of the full life cycle of chemicals.”
WHAT DOES IMPLY A LIFE CYCLE BASED APPROACH?

Chemical profile of emission over the life cycle of a product

- The masses of chemicals released during each phase of product life cycle, from raw material extraction to end of life are taken into account in the Life Cycle Inventory.

- Using Multimedia fate models such as box models (e.g. USEtox) or spatially resolved models (e.g. MAPPE) in order to calculate fate factors in different compartments.

- Through the Life Cycle Impact Assessment phase, fate factors for each chemical are multiplied by a characterisation factors derived from the chosen impact assessment model.
Inventory for Europe (27+3) – year 2010

**Airborne emissions**
- substances in E-PRTR
- NMVOC breakdown

**Soilborne emissions**
- E-PRTR for industrial releases (HM, POPs)
- HM emission from sludge and manure

**Waterborne emissions**
- industrial releases of HM and organics
- Urban emission of HM and organics, based on presence/absence WWTP

**Pesticide (and pharmaceutical) emissions**
Active ingredients (AI) breakdown
Chemical profile of emission related to EU 27 production and consumption

Production base vs consumption based approach

Emission * 
Fate * 
Effect factors = Characterisation factors

Updates ongoing
Prioritization of chemicals in the aquatic environment based on risk assessment: Analytical, modeling and regulatory perspective

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ABSTRACT
The extensive and intensive use of chemicals in our developed, highly technological society includes more than 100,000 chemical substances. Significant scientific evidence has lead to the recognition that their improper use and release may result in undesirable and harmful side-effects on both the human and ecosystem health. To cope with them, appropriate risk assessment processes and related prioritization schemes have
Building global inventories

- Extending coverage of substances and completeness of EU 27+3 inventory
- Testing different extrapolation strategies for calculating world emission factors


Figure 1. A map of residuals displaying the goodness of prediction of Hg emissions (UNEP, 2013) per country when using the GDP measure. The results shown are based on the residual difference between a model predicting an Hg emission in a single country using the GDP measure and the real value of Hg in that country. Following the color scale, the data in red refers to countries that were underestimated, the data in blue refers to countries that were overestimated, and the data in white refers to countries for which the prediction provides a good fit. Intermediate coloring corresponds to a variation in fitness (in the range ±2.3). No data was available for the countries shaded in black.
Inventories outside EU

**US**
US-EPA, 2010
Biggest coverage in terms of number of substances

**Canada**
Environment Canada, 2010
Pollutant releases (to air, water and soil), disposals and transfers for recycling

**Japan**
NITE, 2010
Included the percentage of facilities that reported emissions
No CAS number

**Australia**
AG-DEH, 2010
Inventory covering mostly metals
No pesticides
Chemical footprint and green chemistry?

Alleged ecoinnovation/ green chemistry options may lead to additional environmental burden if the perspective is on the substitution of the single substance and not a thorough assessment, including chemical-related, of the overall processing.

Key challenges:

- **Unmapped flows**
- **Groups of chemicals** (dioxins, PAHs, PCB’s, etc)
- **Metals**

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Ongoing scientific discussion related to chemical footprint

- Metrics for the boundary?
- Boundaries for toxicity/biodiversity/ecosystem services?
- Availability of data for >100,000 chemicals
- Role of mixture toxicity modeling
- Composite indicators? Accounting for different ecosystem’s vulnerabilities
- Bottom-up boundaries vs global boundaries → Global boundary for freshwater = Σ Bw1 + Bw2 + .... + Bwn?
- Spatial resolution of the boundary different for compartment of the emission and for clusters of chemicals?
- Reconciliating/ complement Risk assessment
How to set science-based thresholds

Thresholds based on Species Sensitivity Distribution (SSD) extrapolation

<table>
<thead>
<tr>
<th>Primary producers (A)</th>
<th>Invertebrates (anthropo) (B)</th>
<th>Fish (C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAF</td>
<td>Score</td>
<td>PAF</td>
</tr>
<tr>
<td>&lt;0.01</td>
<td>0</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>0.01-0.05</td>
<td>2</td>
<td>0.01-0.05</td>
</tr>
<tr>
<td>0.05-0.1</td>
<td>4</td>
<td>0.05-0.1</td>
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<td>0.1-0.2</td>
<td>8</td>
<td>0.1-0.2</td>
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<tr>
<td>0.2-0.4</td>
<td>16</td>
<td>0.2-0.4</td>
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<tr>
<td>0.4-0.6</td>
<td>18</td>
<td>0.4-0.6</td>
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<tr>
<td>0.6-0.8</td>
<td>20</td>
<td>0.6-0.8</td>
</tr>
<tr>
<td>0.8*</td>
<td>125</td>
<td>≥0.8*</td>
</tr>
<tr>
<td></td>
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</tr>
</tbody>
</table>

\[ \text{PAF}_{\text{SW}} = (A \times W_A) + (B \times W_B) + (C \times W_C) \]

PAFs are derived from SSD curves based on EUCLOS data
* A PAF higher than 0.8 indicates a dramatic disappearance of a component of the trophic chain. This must be assumed as extremely high risk (PAF_{\text{SW}} = 100) even if the score for the other components is low or negligible. In these cases only the highest score is used for the calculation.

Position of key species along the SSD distribution curve?

SSD-based biodiversity index.

Thresholds based on Ecoepydemiology, Trait-based ERA and Vulnerability assessment

Vulnerability analysis
Comparing contaminated and reference/natural site (e.g. on two rivers contaminated and reference site), highlighting the relative importance a number of single stressors and considering spatial differentiation of the impacts (Ippolito et al 2010)

Trait based ERA
Thresholds for effect of pesticide on macroinvertebrates and leaf breakdown trough meta-analysis of field study (Schafer et al 2012) and applying the trait-based SPEAR indicator (Liess et al 2008)

Ecological response and adaptation under multiple chemical and not chemical’s stressors?

Vulnerability analysis
Scale of assessment of the boundary could be set for clusters of chemicals, identified by key physical chemical parameters and persistence

Global vs local relevance

Input for discussion

• Increasing robustness in emission inventories
• Improving impact assessment
• Complementarity with risk assessment
• Fostering definition of science-based and related policy-based boundaries for chemicals

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