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Towards a common conceptual framework for chemical footprint bridging Risk Assessment and Life Cycle Assessment: Short review and way forward

Extended Abstract and Oral Presentation at SETAC EU Annual Meeting, 11-15 May 2014, Basel (CH)

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This report has been reviewed and approved in accordance with IVL's audited and approved management system.

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Foreword

This report consists of three parts pertaining to the same scientific contribution to the SETAC Europe Annual Meeting held May 11-15. 2014, in Basel Switzerland

1. Short abstract
2. Extended abstract
3. Oral presentation slides

A full reference to this publication should be written as follows:

Rydberg T., Sala S., Bjørn A., Molander S., Payet J., Posthuma L., Sörme L., Vighi M., Zijp, MC. (2014) Towards a common conceptual framework for chemical footprint bridging Risk Assessment and Life Cycle Assessment: Short review and way forward, Extended Abstract and Platform presentation, SETAC Europe Annual Meeting, Basel 13-16 May, 2014. Available as Rydberg T; *et al*, IVL Report C0031, Stockholm, Sweden, 2014. www.ivl.se/publications

Short Abstract

Several studies have been presented recently, applying the chemical footprint (ChF) concept trying to address a variety of questions, often, but not always, to aggregate pollution of many chemicals to one or a few indicators. Furthermore, the possibility to link chemical pollution to the concept of planetary boundaries, e.g. through the ChF concept, has also been discussed in recent publications. While the planetary boundary concept is pointed out as very difficult for chemical pollution, because of its local or regional nature, there is a need for an integrated chemical assessment and management approach on the regional and global level.

This paper provides a short review and conceptual analysis regarding ChF, and suggests a way forward towards a common science based Conceptual Framework for Chemical Footprinting methods, bridging Risk Assessment (RA) and Life Cycle Assessment (LCA) science and methods.

Although varying, the approaches reviewed typically are rooted in the knowledge basis of both RA and LCA. Questions for further elaboration are, e.g.: (a) Is a ChF assigned to an object in the technosphere: point source, value chain, sector, or the whole economy, and if so, on what scale (Sub-national to Global), (b) Is a ChF assigned to an object in the biosphere: specific location, or a specific organism (man?), (c) Is the number of chemicals involved one, several, all?, (d) Are chemicals treated as individuals, or grouped, or aggregated by means of toxicity related summation (TCDD-TEQ, UseTox, else), (e) What position to indicate in the cause-effect chain: from occurrence in the technosphere, to the “n-th” order effect in the environment? (f) Are also metabolites included?, and (g) What are relevant impacts, i.e. human health, or ecosystem integrity (only), or also e.g. photo chemical oxidant formation, among others?

Given the apparent versatility of the concept and its potential use in chemicals management, a substantial motive to collate the initiatives exists. A SETAC-Working group would be a functional way forward with the goal to e.g.: 1) frame the existing methodologies according to applications and 2) evaluate and fill gaps and weaknesses of proposed methodologies. Input from both the RA and LCA communities are necessary to reach sound and versatile methods which are useful for chemical risk reduction and management, and to underpin development towards the definition of a planetary boundary, or boundaries, for chemical pollution.

Sammanfattning

I flera nyligen genomförda studier som tillämpat konceptet ”Chemical footprint” (kemiskt fotavtryck) har man försökt hantera ett antal frågor kring detta, till exempel hur man kan aggregera miljöpåverkan från många kemikalier till en eller ett fåtal indikatorer.

Även möjligheten att koppla miljöpåverkan av kemikalier till konceptet planetära gränser, till exempel genom konceptet kemiskt fotavtryck, diskuterats i den senaste litteraturen. Trots att konceptet kring planetariska gränser har ansetts vara alltför komplicerat för kemikalier, till exempel för att påverkan ofta är lokal eller regional, så finns behov av ett integrerat angreppssätt för bedömning och hantering av kemikalier både regionalt och globalt.

I denna rapport görs en kort översikt och konceptanalys av begreppet kemiskt fotavtryck. En väg framåt för ett gemensamt vetenskapligt baserat konceptuellt ramverk för metoder föreslås, där kunskap och metoder från såväl riskbedömning som livscykelanalys används.

De olika angreppssätten är oftast baserade på kunskap inom riskbedömning och/eller livscykelanalys. Frågor som bör studeras ytterligare är till exempel: a) Ska kemiskt fotavtryck syfta på objekt i teknosfären: punktkälla, värdekedja, sektor, eller hela ekonomin, och i så fall i vilken skala (subnationell till global); b) Ska kemiskt fotavtryck syfta på objekt i biosfären: specifik plats eller specifik organism (människan?); c) Ska antalet inräknade kemikalier vara en, flera eller alla; d) Ska alla kemikalier behandlas individuellt, grupperat eller aggregerat på toxicitet relaterat till summation (TCDD-TEQ, USeTox, annat); e) Vilken länk ska indikeras i orsak- och verkanskedjan: från förekomst i teknosfären till den ”n:te” effekten i miljön; f) Ska metaboliter inkluderas; g) Vilka effekter är relevanta: mänsklig hälsa, ekosystemets integritet (bara).

Det är väl motiverat att sammanföra de olika initiativen, på grund av konceptets potentiella användning inom kemikaliehantering.

En arbetsgrupp inom SETAC skulle kunna vara en fungerande väg framåt, med målet att till exempel: 1) klargöra förutsättningar för och samband mellan de existerande metoderna i relation tilltillämpningsområde; 2) utvärdera och komplettera luckor och svagheter i de föreslagna metoderna.

Bidrag med kunskap från forskningsgrupper inom både risk- och livscykelanalys är nödvändig för att nå metodik som är användbar för riskreducering och hantering av kemikalier, samt för att stötta utvecklingen mot planetära gränser för miljöpåverkan från kemikalier.

Extended Abstract

1. Introduction

The chemical footprint (ChF) concept has gained increased attention over the past couple of years, as highlighted in an open meeting during SETAC Europe Annual Meeting 2011 [1]. The concept is formed by analogy to the often used "carbon footprint", "ecological footprint" and "water footprint". Drawing on this analogy, a ChF aims to serve as an indicator for chemical pollution. Several case studies have been presented recently, applying the concept in a variety of ways and thus trying to address a variety of questions, see e.g. [2,3,4,5,6], often, but not always, to aggregate pollution of many chemicals to one or a few indicators. Furthermore, the possibility to link chemical pollution to the concept of planetary boundaries, e.g. through the ChF concept has also been discussed in recent publications [7,8,9]. Chemical pollution is one of the nine "Planetary Boundaries" listed by Rockström et al. [10] however the authors did not suggest an indicator or boundary level for chemical pollution. Scheringer et al [11] as well as other authors [8,9] confirmed that it is difficult to define a single global "tipping point" that could be reflected by a planetary boundary, because of the local or regional nature of many chemical impacts due to, e.g., varying emissions, fates, ecosystem sensitivities and effects. Nevertheless, the need for an integrated chemical assessment and management approach on the regional and global level is highlighted. The aim of this paper is to provide a short review of scientific approaches until now regarding ChF, and to suggest a SETAC working group on the topic to be the preferred way forward towards a science based Conceptual Framework for Chemical Footprinting methods.

2. Materials and methods

In this paper we combine two approaches in that we perform a conceptual analysis of the ChF concept, based on differences in its application observed in a short review of various studies.

3. Review of applied approaches

Sala and Pennington [2] and Sala and Goralczyk [7] proposed a conceptual framework in two steps for ChF, adopting Life Cycle Assessment (LCA) and Risk Assessment (RA) principles, and applied it to a case study for Europe: 1) assessing the intensity of chemical pressure in terms of: release of chemicals into the environment in different compartments; economic sectors of use, and typologies of releases, and 2) linking the releases and potential harm for the environment with the carrying capacity of the receiving ecosystems.

Sörme et al [3] used data for emissions to water and air from the E-PRTR (European Pollutant Release and Transfer Register) together with the USEtox models [12] to calculate a ChF from point sources, covering impacts on human toxicity (cancer and non-cancer) and ecotoxicity. A consumption perspective was retrieved by adding an Input-Output analysis on the emissions by industry sector.

Bjørn et al [4,8] focuses on freshwater ecotoxicity and converts USEtox impact scores into "the occupation of a (theoretical) fresh water volume needed to dilute a chemical emission to the point where it causes no damage to ecosystems in the volume during its presence". The ChF is compared with the availability of freshwater at scales relevant for the object under study

Zijp et al [5] and Posthuma et al [9] defined the ChF concept for emissions of landscape-level emission of chemical substances, and provide case study data for organics and agricultural chemicals, and derived the footprint using (chosen) policy boundaries for chemicals management and natural 'tipping' point boundaries. The ChF for aquatic systems was defined as the volume of water in a geographical area that is needed to dilute the expected impact of environmental concentrations of separate chemicals or a mixture to a level below such boundary. Main footprint contributing chemicals were finally ranked.

Rydberg [6] calculated the ChF as total use-phase emissions of a few hundred organic additives contained in the societal stock of plastic materials and also tried out, with limited success due to lack of availability so far, on the option to apply characterisation factors such as USEtox factors, for further assessment on significance of the emissions.

Maillard, et al [13] developed a model and tool for the ChF (focusing ecotoxicological footprint) calculation of cosmetic and detergent ingredients based on the USEtox ecotoxicity model, in an LCA/Environmental footprint context. Major effort was put into data collection for ecotoxicity assessments.

4. Results of comparison and conceptual analysis

Although varying, the approaches reviewed typically are rooted in the knowledge basis of both risk assessment and life cycle assessment. The partial review and the related conceptual analysis may at this early stage indicate aspects (dimensions) to be further elaborated into a common conceptual framework for defining and using ChF-s. A non-exhaustive list of questions for this elaboration is: (a) Is a ChF assigned to an object in the technosphere: point source, value chain, sector, or the whole economy, and if so, on what scale (Sub-national/National/EU/Global), (b) Is a ChF assigned to an object in the biosphere: specific location, or a specific organism (man?), (c) Is the number of chemicals involved one, few, several, many, or all?, (e) Are chemicals treated as individuals, or grouped, or aggregated by means of approaches based on "scoring" or toxicity related summation (TCDD-TEQ, UseTox, else). (f) What position in the cause-effect chain to indicate: anywhere from a substance's existence in the technosphere, to the "n-th" order effect in the environment? (f) Are (only) produced chemicals of concern, or also metabolites?, and (g) What are relevant impacts, i.e. human health, or ecosystem integrity (only), or also photochemical oxidant formation and global warming, where "chemicals" are part of the problem?

5. The way forward

Evidently, several parallel approaches have been published on chemical emission stress, referring to the concept footprint, with or without reference to boundary conditions. Given the apparent versatility of the concept and its potential use in quantitatively assessing alternative chemical production and management strategies, and evaluating impacts of policy measures taken, a substantial motive to collate the initiatives exists. A SETAC-Working group would be a functional approach to organise such a collation and optimisation process. The goal of that is not to propose one chemical footprint methodology, but to: 1) frame the existing methodologies according to the answers/ applications they may provide and 2) evaluate and fill gaps and weaknesses of proposed methodologies. Input from both the RA and LCA communities are necessary to reach sound and versatile methods which are useful for chemical risk reduction and management, and to underpin development towards the definition of a planetary boundary, or boundaries, for chemical pollution.

6. References

[1] http://globe.setac.org/2011/april/april-14-2011.html

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[3] Sörme L, et al, 2012, Oral presentation, SETAC Annual Meeting, Berlin, 20-24 May 2012

[4] Bjørn A, Birkved M, Hauschild MZ In: Proceedings SETAC 18th LCA Case Study Symposium (November 2012), Copenhagen, Denmark. p. 60-61.

[5] Zijp MC, et al, 2013, Oral, SETAC LCA Case study symposium, Rome, 11-13 November 2013.

[6] Rydberg T. 2013. Oral, SETAC LCA Case study symposium, Rome, 11-13 November 2013.

[7] Sala S, Goralczyk M. 2013. Integrated environmental assessment and management, 9(4), 623-632.

[8] Bjørn A, et al. 2013. Proceedings SETAC Europe 23rd Annual Meeting, Glasgow, Scotland p. 399.

[9] Posthuma L, et al. 2012 Poster at Planet under Pressure, march 2012, London.

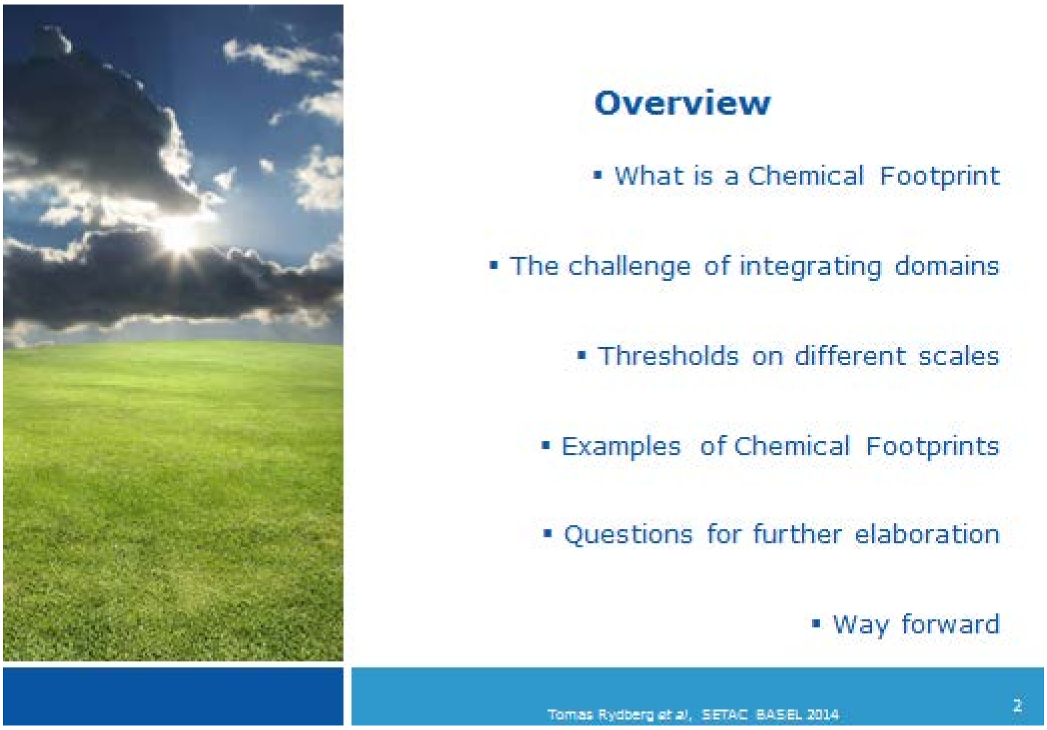
[10] Rockström J, et al. 2009. Nature 461: 472-75

[11] Scheringer M, et al, 2012. Dioxin 2012 - 32nd International Symposium on Halogenated Persistent Organic Compounds, Cairns, Australia, 26-31 August 2012.

[12] Rosenbaum RK, et al, 2008. The International Journal of Life Cycle Assessment 13:532-546.

[13] Maillard E, et al, 2013. Poster at LCM 2013, Göteborg, 26-28 Aug, 2013.

Oral presentation slides



What is a Chemical Footprint?

- Aims to serve as an indicator for chemical pollution
- Term is formed by analogy to ecological footprint, carbon footprint, water footprint
- Various interpretations are possible and also available
  - Use oriented
  - Emission oriented
  - Concentration oriented
  - Impact oriented

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Two parallel & interlinked paths Chemical footprint

Indicator(s) for Chemical Footprint

Sustainability threshold(s)

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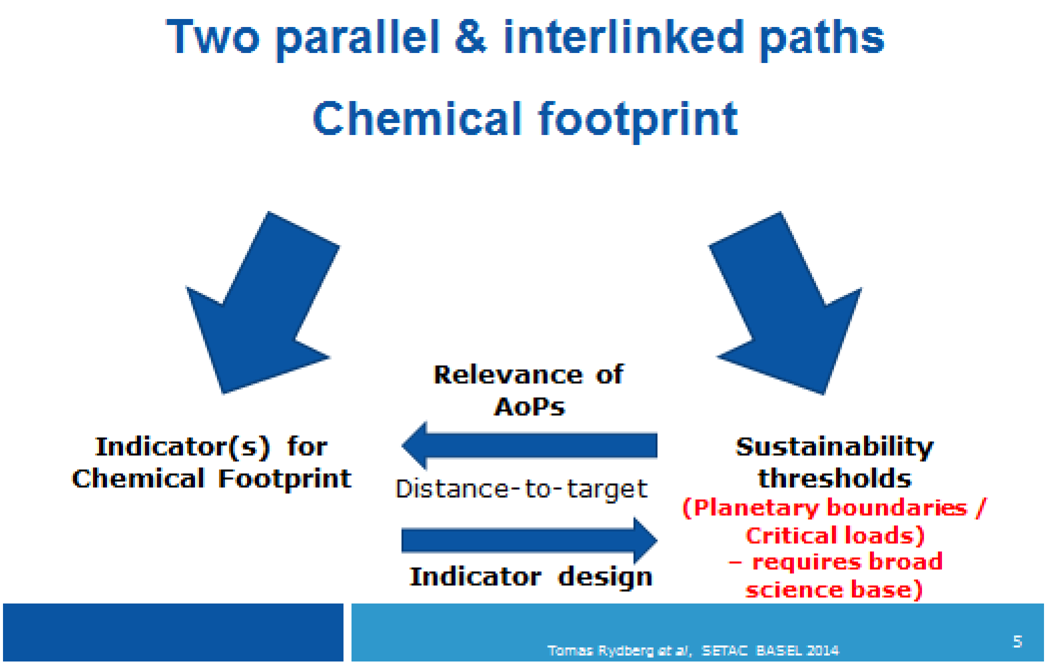

What to indicate by a Chemical Footprint?

Indicator target	Use	Emission	Concentration	Exposure	Effects	Damage
Single chemicals	Use amount of commercially available chemicals (production, stock, etc.)	Annual emissions	Environmental concentration	Daily intake Concentration in tissue	PDI/ADI PEC/PNEC Toxic units Critical volumes	DALY Potentially Damaged Fraction of species (PDF) Loss of populations or species
Multiple chemicals					Additive PDI/ADI Additive PEC/PNEC Toxic units Critical volumes Potentially Affected Fraction of species (PAF)	

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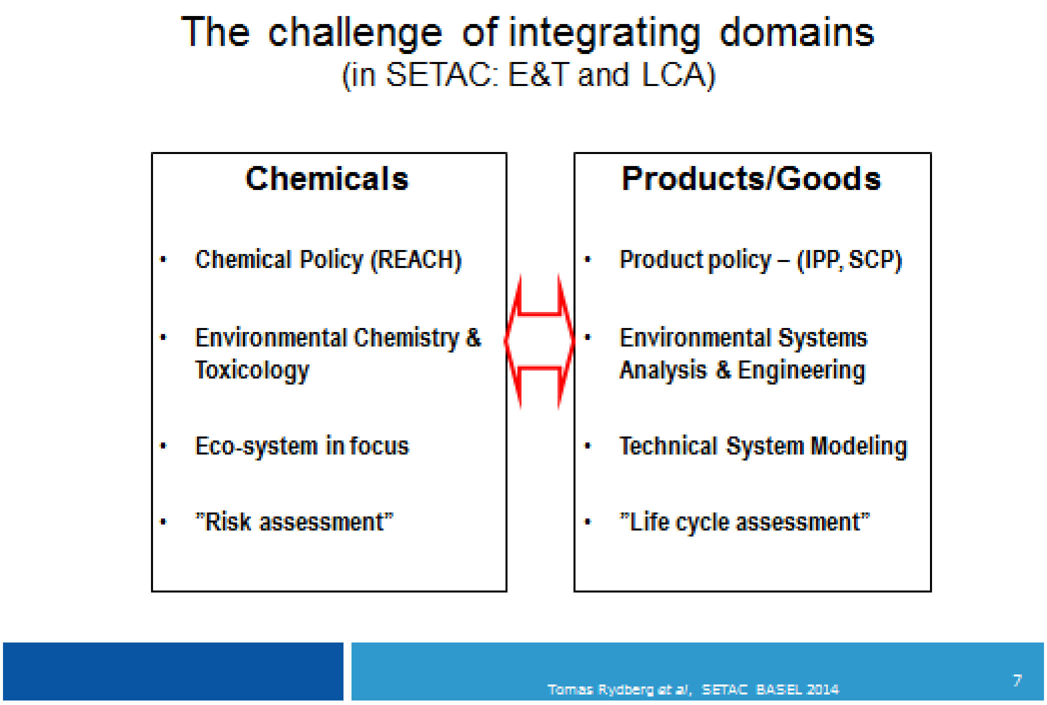
The challenge of integrating domains
(in SETAC: E&T and LCA)
Chemicals
Chemical Policy (REACH)
Environmental Chemistry & Toxicology
Eco-system in focus
"Risk assessment"
Products/Goods
Product policy – (IPP, SCP)
Environmental Systems Analysis & Engineering
Technical System Modeling
"Life cycle assessment"
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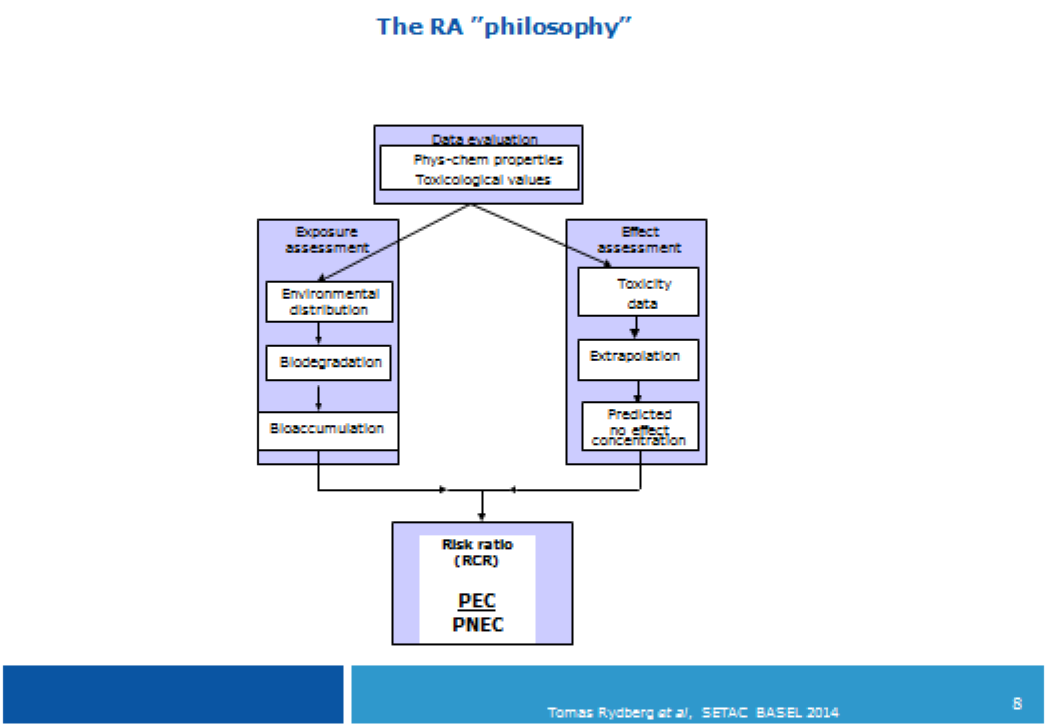
The RA "philosophy"
Data evaluation
Phys-chem properties
Toxicological values
Exposure assessment
Environmental distribution
Biodegradation
Bioaccumulation
Effect assessment
Toxicity data
Extrapolation
Predicted no effect concentration
Risk ratio (RCR)
PEC
PNEC
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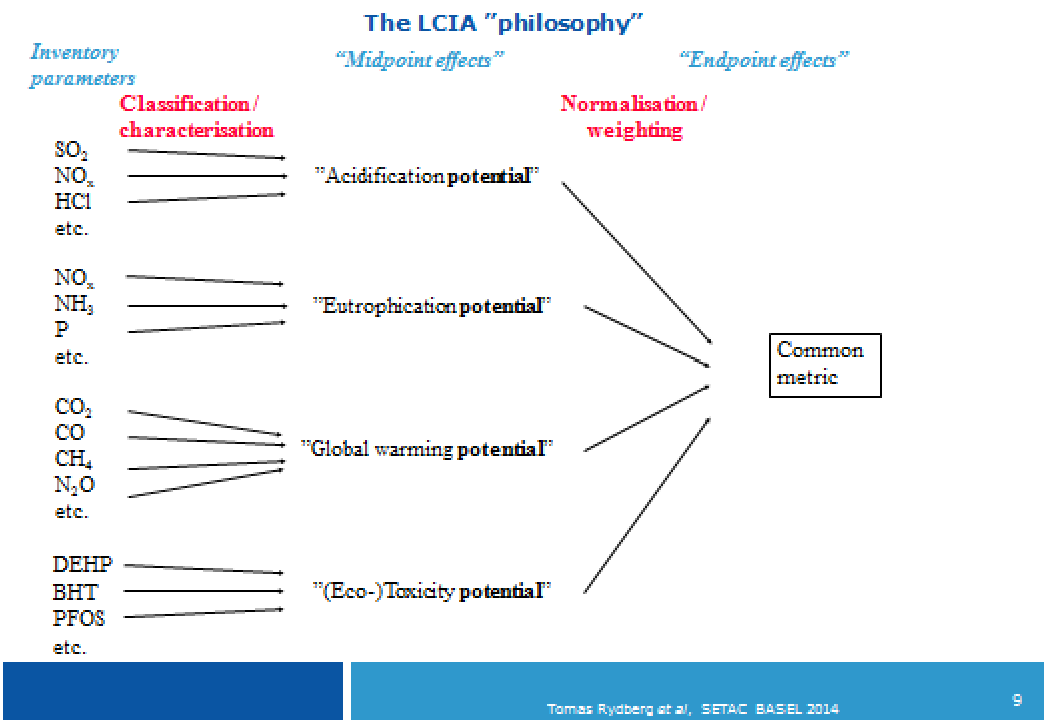
The LCIA "philosophy"
Inventory parameters
"Midpoint effects"
"Endpoint effects"
Classification / characterisation
Normalisation / weighting
SO2
NOx
HCl
etc.
"Acidification potential"
NOx
NH3
P
etc.
"Eutrophication potential"
CO2
CO
CH4
N2O
etc.
"Global warming potential"
DEHP
BHT
PFOS
etc.
"(Eco-)Toxicity potential"
Common metric
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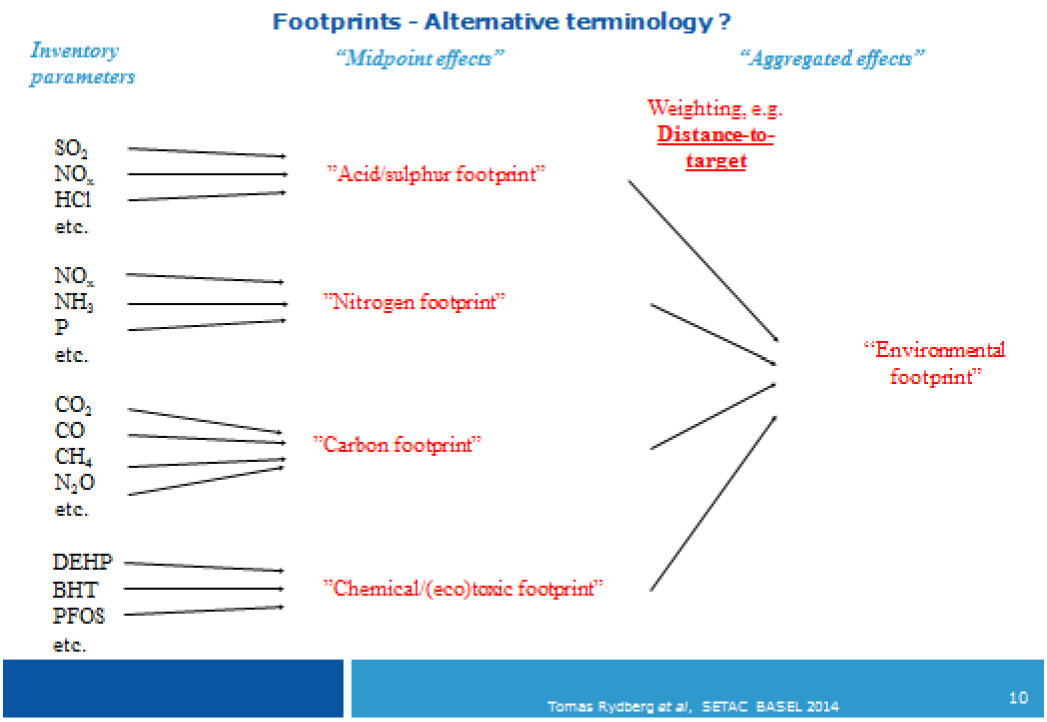
Footprints - Alternative terminology ?
Inventory parameters
"Midpoint effects"
"Aggregated effects"
Weighting, e.g. Distance-to-target
SO2
NOx
HCl
etc.
"Acid/sulphur footprint"
NOx
NH3
P
etc.
"Nitrogen footprint"
CO2
CO
CH4
N2O
etc.
"Carbon footprint"
DEHP
BHT
PFOS
etc.
"Chemical/(eco)toxic footprint"
"Environmental footprint"
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Thresholds on different scales

Site-specific	Regional	Global
PNEC	Critical load	Planetary boundary

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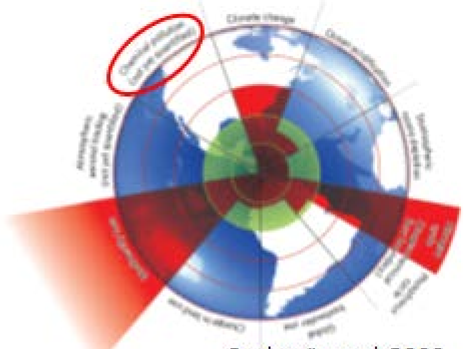
CRITICAL LOAD

1. Introduction

Johansson et al, 1991

Two decades of evolution (?) from critical load (left) to planetary boundaries (below)



Rockström et al, 2009

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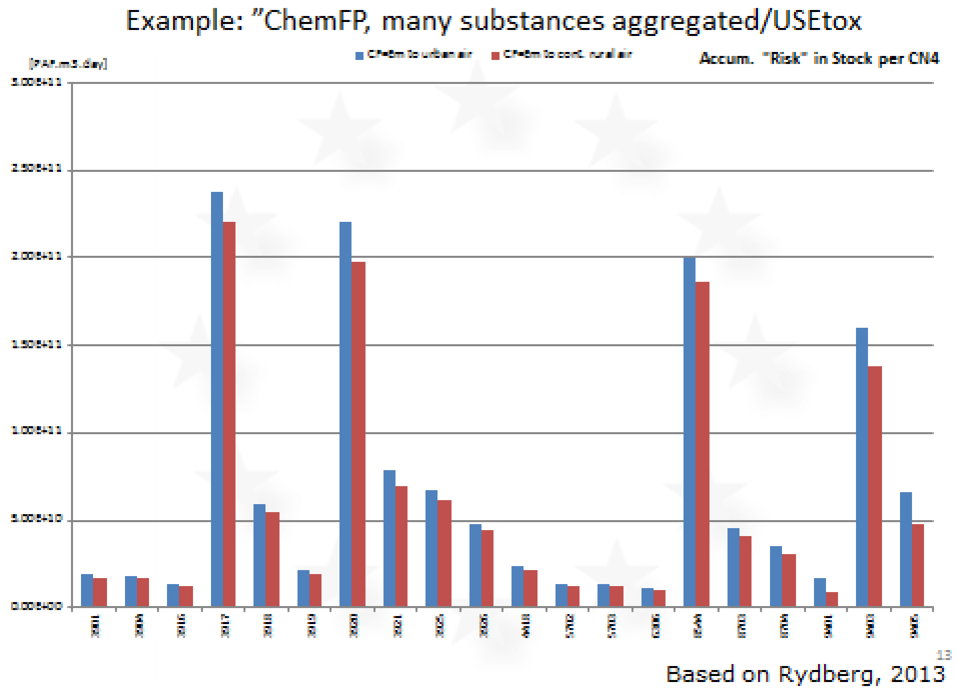
Example: "ChemFP, many substances aggregated/USEtox
Accum. "Risk" in Stock per CN4
Based on Rydberg, 2013
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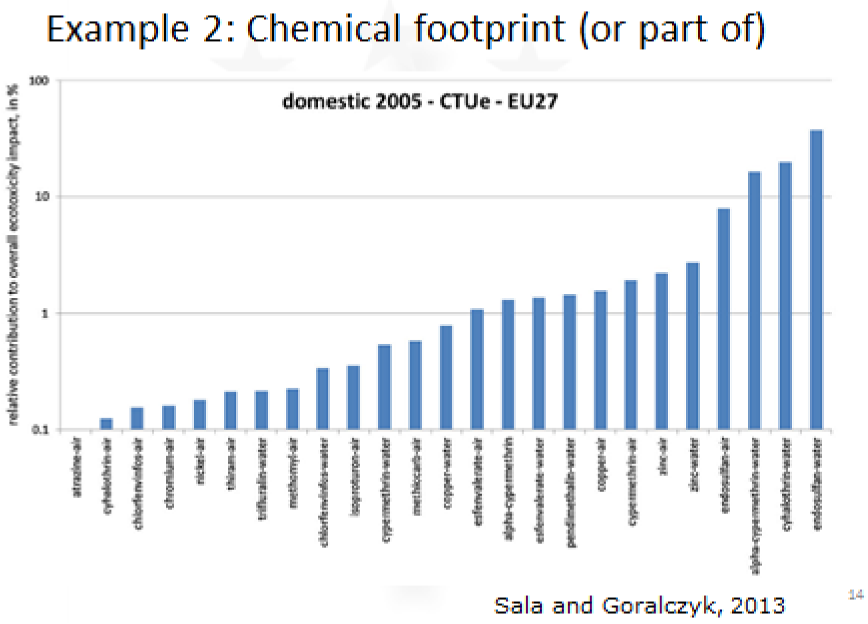
Example 2: Chemical footprint (or part of)
domestic 2005 - CTUe - EU27
relative contribution to overall ecotoxicity impact, in %
100
10
1
0.1
atrazine-air
cyhalothrin-air
chlorfenvinfos-air
chromium-air
nickel-air
thiram-air
trifluralin-water
methomyl-air
chlorfenvinfos-water
isoproturon-air
cypermethrin-water
methiocarb-air
copper-water
esfenvalerate-air
alpha-cypermethrin
esfenvalerate-water
pendimethalin-water
copper-air
cypermethrin-air
zinc-air
zinc-water
endosulfan-air
alpha-cypermethrin-water
cyhalothrin-water
endosulfan-water
Sala and Goralczyk, 2013
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Questions for further elaboration

a) Is a ChF assigned to an object in the technosphere: point source, value chain, sector, or the whole economy, and if so, on what scale (Sub-national/National/EU/Global),

b) Is a ChF assigned to an object in the biosphere: specific location, or a specific organism (man?)

c) Is the number of chemicals involved one, few, several, many, or all?

d) Are chemicals treated as individuals, or grouped, or aggregated by means of approaches based on "scoring" or toxicity related summation (TCDD-TEQ, UseTox, else).

e) What position in the cause-effect chain to indicate: anywhere from a substance's existence in the technosphere, to the "n-th" order effect in the environment?

f) Are (only) produced chemicals of concern, or also metabolites?, and

g) What are relevant impacts, i.e. human health, or ecosystem toxicity/health/integrity (only), or also photochemical oxidant formation and global warming, where "chemicals" are part of the problem?

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Way forward

- 1) frame the existing methodologies according to the answers/ they may provide for their respective applications
  - assessing alternative chemical production and management strategies
  - evaluating impacts of policy measures taken
  - etc
- 2) evaluate and fill gaps and weaknesses of proposed methodologies.

Input from both the RA and LCA communities are necessary to reach sound and versatile methods which are useful for chemical risk reduction and management, and to underpin development towards the definition of a planetary boundary, or boundaries, for chemical pollution.

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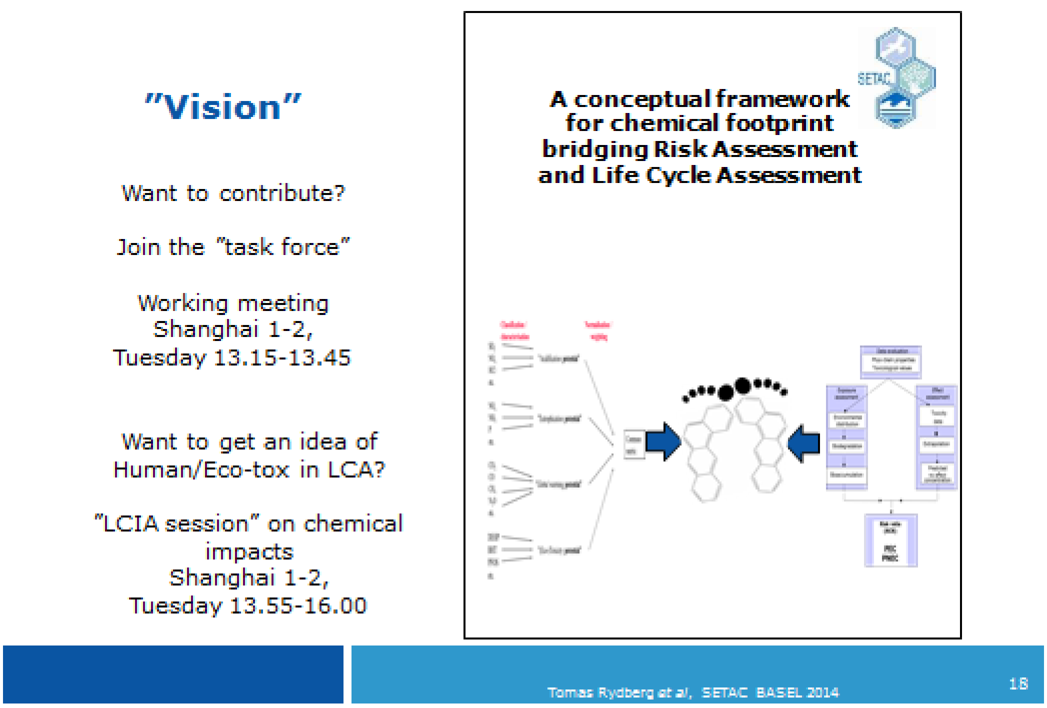
ID	Title	Presenter	Abstract	Extended Abstract	Session Room	Time (asc)
TU261	Assessing chemical footprint of Europe to support chemical policies for products	Dr Serenella Sala	In the last few years, environmental footprint (EF) concept has o...		Exhibition Hall	Tue May 13 08:10
TU256	COMPARING METHOD AND DATA AVAILABILITY FOR CALCULATION OF CHEMICAL FOOTPRINT	Dr. Jerome Payet	The increase of chemicals use and applications has led to a decre...		Exhibition Hall	Tue May 13 08:10
TU309	Devils in the tails - Assessing mixture toxic pressure (msPAF) and chemical footprinting for emerging chemicals	Dik van de Meent	The EU FP7-project SOLUTIONS aims to provide management perspecti...		Exhibition Hall	Tue May 13 08:10
219	Towards a common conceptual framework for chemical footprint bridging Risk Assessment and Life Cycle Assessment: Short review and way forward	PhD Tomas V. Rydberg	Several studies have been presented recently, applying the chemic...		Delhi	Tue May 13 08:15
330	Chemical footprint assessment: presentation of method and application to a case study involving different spatial scales	Anders Bjorn	Expressing Life Cycle Impact Assessment (LCIA) results as footpri...		Shanghai 1/2	Tue May 13 14:00
WE269	Tiered decision framework for the development of sustainable chemical products and processes - Application to the biobased economy	M.Sc. Akshay Patel	Designing benign chemicals is not an easy task, given production ...		Exhibition Hall	Wed May 14 08:10



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[4] Bjørn A, Birkved M, Hauschild MZ In: Proceedings SETAC 18th LCA Case Study Symposium (November 2012), Copenhagen, Denmark. p. 60-61.
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[12] Rosenbaum RK, et al, 2008. The International Journal of Life Cycle Assessment 13:532-546.
[13] Maillard E, et al, 2013. Poster at LCM 2013, Göteborg, 26-28 Aug, 2013.

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Thank you for your kind attention

And thanks to all the hard working colleagues!

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