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Deliverable 2.1:
Similarities and differences between EcoRA and LCA

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Report author: Jerome Payet

Project coordinator name/author: Jerome Payet
Project coordinator organisation name: SETEMIP-Environnement
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1 Abstract:

Life Cycle Assessment (LCA), and its impact assessment component Life Cycle Impact Assessment (LCIA), can be used to assess impacts due to contaminated sites. Nevertheless, so doing, the assessment can be compared to the assessment performed by Ecological Risk Assessment (EcoRA) for contaminated site. Furthermore, LCIA is know addressing the impact on ecosystems considering a change in biodiversity due to a change in environmental pressure in the media in a different way than what is done with ERA but with a similar question. It is the purpose of this report to first identify the similarities between the two approaches, but also the main differences. Nevertheless, due to the vast area of applicability of LCA, the work especially focuses on the impact of contaminated site on ecosystems. After describing the key properties of the two methods, the work is highlighting the common point between LCA and ERA for impact assessment on ecosystems. Afterward, the main sources of discrepancies are discussed under the perspective of the needs and objectives of each method. This discussion starts with the presentation of the notion of functional unit, and the implication of the choice of the system boundaries in the LCA of contaminated site. These two aspects are key discrepancies between LCA and ERA since they take place before the impact assessment step. Beyond this stage, even if the two approaches covered the same questions, the scope of the tools differs when LCA is used for comparison purpose while ERA is applying for conservative assessment. Afterwards, the work is discussing issues linked with the LCIA and ERA such as the time scale and the space scale issue, or the notion of biodiversity and the link with the biological organisation level and the “midpoint” and “endpoint” commonly used in LCA. As a conclusion, the work is discussing the tendencies of the two approaches in getting closer and closer, identifying possible limits to integration, and the methodological development that can be needed to increase the coherence between the two approaches in addressing the complex question of the impact on ecosystems, especially the change in biodiversity.

2 Introduction

2.1 Context

Life Cycle Assessment (LCA) and Environmental Risk Assessment (ERA) can be used in parallel for selecting the most appropriate land management strategy. Nevertheless, even if both approaches can now address impact on ecosystems and human health, the methodological background is very different and results can differ considerably. Furthermore, since both tools can not currently be applied in the same framework, some situation can occur where the environmental burden of the remediation can be higher than the impact of the site itself. It is the purpose of this work to identify the similarities and discrepancies of the methods and to propose a coherent common framework for applying LCA and ERA at the same time for selecting the most appropriate strategy in a contaminated land management perspective for terrestrial and aquatic ecosystems

2.2 Ecological Risk Assessment for contaminated site management

Ecological risk assessment is a process of collecting, organising and analysing environmental data to estimate the risk of contamination for ecosystems. Ecological Risk Assessment for contaminated site is rather different that EcoRA for substances regulation since it is focusing on pollutions already present in the environment. It is therefore more an impact assessment than a risk assessment. EcoRA for contaminated site is typically perform in phases or tiers. The tiered assessment for ERA starts with a simple screening at tier one, followed by a refined screening at tier 2 and then a detailed assessment at tier 3.

Ecological Risk Assessment method can be presented in 4 steps:

1- Hazard identification : identification of the capacity of the chemical to cause adverse effects
2- Exposure assessment: determination of the emission volume and the level of exposure
3- Hazard Assessment: determination of the dose response relationship for the chemical, estimating a level of effect for different exposure concentration
4- Risk characterization: comparison of the exposure and the effect assessment

These four steps are organised as presented below.

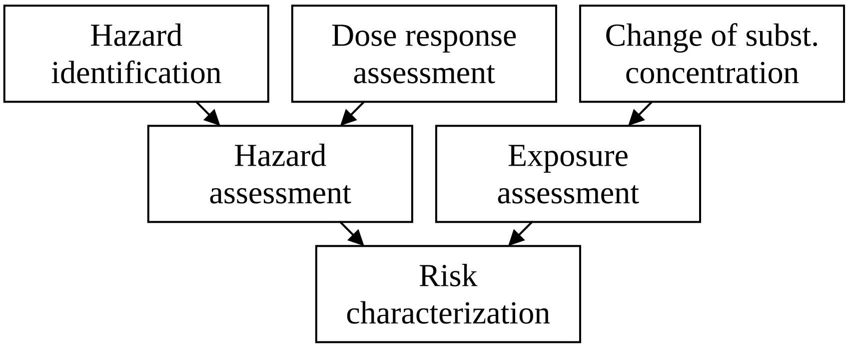

Figure 1*: Illustration of the risk assessment method (after Flemström et al. 2004)*

2.3 Life Cycle Assessment and Life Cycle Impact Assessment

Life Cycle assessment (LCA) is a method that aims at compares the relative environmental burden of different products (or services) satisfying the same service. The comparison is performed regarding different impact categories. The key point of LCA is the notion of equivalence of service which requires defining a functional unit, expressing the unit of service that as to be fulfil by the different products compared in the study. The functional unit is the basis of the comparison and is the basis of all environmental assessment "product oriented" such as LCA or eco-design. As describe in the international standard ISO 14040-44, Life Cycle Assessment is performed following 4 stages.

A- Definition of the scope and goal : build up the framework of the evaluation, defining the product or service evaluated, the alternatives compared and the purpose and limits of the evaluation
B- Life Cycle inventory: estimate the amount of resources that are consumed for achieving the product and the amount of substances emitted in the air, water and soil
C- Life Cycle Impact Assessment (LCIA): quantifies the environmental burden associated with the inventory emissions, covering different impact categories related for example to resources consumptions, global warming, human health and ecosystems quality. The LCIA can be done at the midpoint level considering a large number of impact categories somewhere in between the emissions and the final environmental burden, or at the damage (endpoint) level, considering a very limited number of impact categories (commonly four) that are very close to the Area of Protection or the Safeguard Subject that is of interest in LCA.
D- Interpretation: addresses the level reliability of the results of the LCA.

Among the 4 phases of LCA describes above, the Life Cycle Impact Assessment phase is very close to the environmental risk assessment procedure especially concerning impact categories such as impact on ecosystems or human health. Within this part of LCIA, several steps of the assessment can be distinguished:

1- Classification: identifying the substances that are likely to cause an effect in an impact category. This stage of the LCIA was very important when only a very small number of substances were characterized but now the tendency is to address the potential toxicity of all substances present in the inventory, considering very large substances dataset.

2- Fate modelling of the substances listed in the inventory: using an intermedia fate model, has the purpose of quantifying the fraction of the substance transferring from the media where the emission takes place to the target media (it therefore averages the concentration of substances over area covered by the space scale); and integrating the concentration of the substances overtime making it compatible with a steady state modelling.
3- Exposure modelling: Estimating the fraction of the substances that is causing adverse effects within the total amount of substance that is present in the compartment.
4- Effect assessment: based on a dose-effect relationship relating the increasing stressor occurrence and a increase in the intensity of the effects expected.
5- Damage modelling: That aims at facilitating the interpretation of the results; (1) Integrating together different stressors related to a single safeguard subject, it therefore ranks the different impact categories in terms of priority and reduce the number of categories considered typically from 15-20 to 4 damage categories; and (2) Facilitating the interpretation of the results, enabling the understanding of the impact in terms of absolute value (such as the DALY) and not in a relative assessment value (Like the substance equivalent).

The different stages of the life cycle impact assessment are presented below.

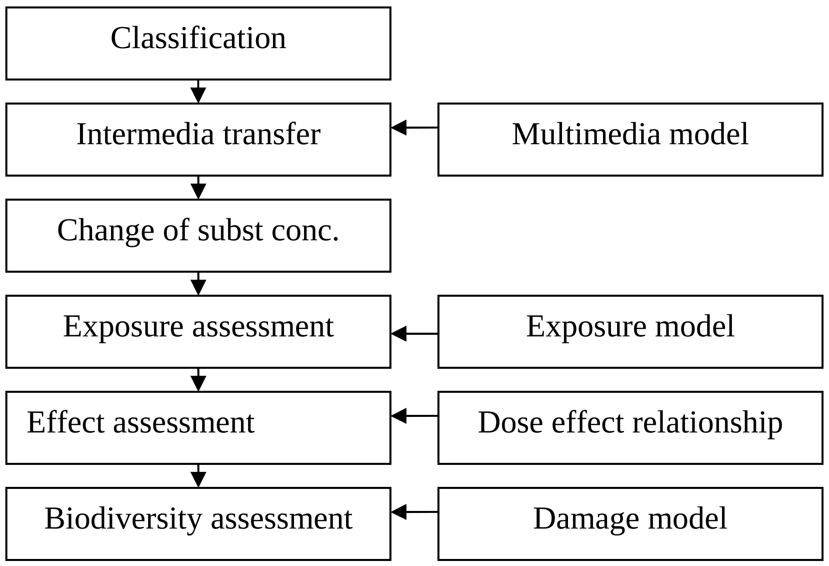

Figure 2: Illustration of the Life Cycle Impact Assessment method

As w can see in Figure 2: Illustration of the Life Cycle Impact Assessment method, the structure of the Life Cycle Impact Assessment process is rather different than the ERA. Furthermore, the terminology such as “exposure” does not cover the same reality in the two tools, and at the end, ERA comes out with the characterisation of a risk while LCA provide the quantification of a damage.

3 Comparison Ecological Risk Assessment and Life Cycle Assessment

3.1 Main similarities between the tools

Looking at the schematic description of the two approaches in Figure 1 and Figure 2 it helps understanding some differences in terminology between the two approaches. It must be first noted that the “classification” mention in LCIA have strong similarities with the “Hazard identification” of EcoRA. Then the “Exposure assessment” in EcoRA aims at quantifying an exposure concentration. This is therefore rather similar to the “Life Cycle Inventory & Fate modelling” of LCA that aims at calculating a change of concentration of a chemical in the environmental media for each inventory emission. Then the “Hazard assessment” mentioned in EcoRA can be viewed as the “exposure & effect modelling” of LCIA, since if enable the calculation of the impact on ecosystems, and then the “risk characterisation” step of EcoRA presents similarities with the “Damage modelling & interpretation” of LCIA. Even if the tools does not present similar structure, they appears to be quite coherent as soon as we consider carefully the term of “exposure” assessment which covers different things whether we are in LCIA or EcoRA.

In terms of management of the tools, EcoRA for contaminated site management is a tiered approach commonly applied in three tiers. LCA is commonly presented as a one tier assessment, nevertheless, LCA is commonly manage with different level of details which presents some similarities with the EcoRA procedure as presented below.

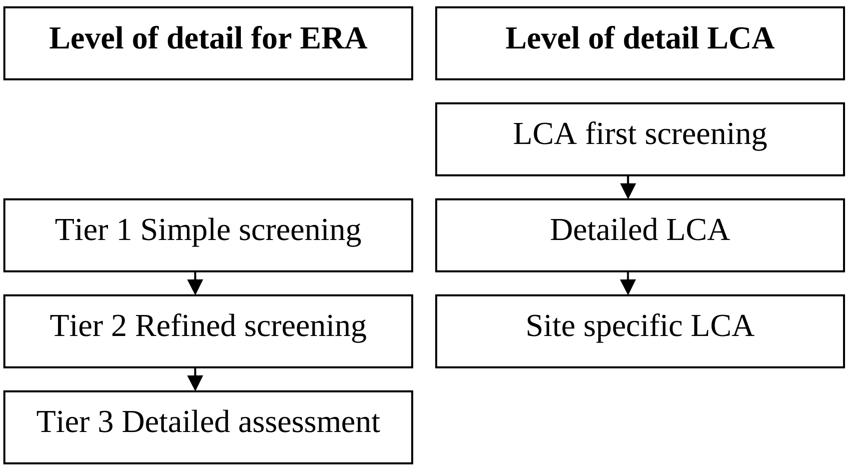

Figure 3: Comparison of the tiered ERA approach and the different level of details of LCA

As presented above, both EcoRA and LCA can be considered as tiered approaches. This is commonly accepted for EcoRA, but LCA is not thus describes. Nevertheless, efficient management of LCA studies requires to start with a “First Screening”, enabling the identification of the key environmental aspects, and then to focus on those points for the detailed LCA. Nevertheless, “Detailed LCA” is typically performed with tools already available in commercial softwares that are generic assessment tools. The development of a site specific LCA requires the collection of environmental data form the site itself and therefore requires a considerable effort. This can therefore be considered as a refined LCA study. Furthermore, in between the generic LCA and the site specific, a regional LCA can be performed with a spatial resolution at the watershed scale.

Finally, the main similarity between the two approaches is their overall purpose to quantify environmental burden of human activities. Concerning impact on ecosystems, questions addressed by the Life Cycle Assessment and Ecological Risk Assessment are aiming at quantifying the impact on biodiversity. Nevertheless, beyond this similarity, numerous discrepancies can be observed. It is therefore important to check if the tools are compatible. Indeed the two tools will be more and more used in parallel and we shall ensure they will not give opposite conclusions as presented in figures 4 and 5.

After considering the similarities between tools, discrepancies can now be addressed.

3.2 Comparative LCA versus absolute EcoRA

LCA was first designed for comparative assessment purpose. The tool enables a comparison between several alternative and identify their relative impact for each impact category considered. EcoRA is applied to assess if a site is at risk or not. This can be assessed considering threshold of effects which corresponds to an acceptable level of effect. For site remediation, threshold are defined in a first tier assessment (such as Target or Intervention values), but detailed assessment therefore has to consider a reference site. This specificity of EcoRA has some implication for LCA. Indeed, LCA is working in a comparative way to assess impact associated with different scenarios. This strategy can be viewed as a "less is better" where the environmental optimum is the zero emission level. ERA is commonly working with a threshold level (typically for substance regulation) or with a reference site (for contaminated site remediation). Dealing with contaminated site management, LCA has to consider the site itself as a part of the technosphere tending to a zero level emission. The alternative would be to consider the site itself as a part of the ecosphere, thus taking into account its own intrinsic value; nevertheless, this is not compatible with a 0 level emissions for all substances concerned by a natural background. In that case, the reference site used in ERA can be also used as a reference scenario in LCA, therefore the downstream impacts associated with this scenario could be considered as residual impacts. This could be of major importance for contaminated sites occurring in areas affected by a high level of background concentration of pollutants. In that case, the residual impact could be high and the environmental efficiencies of the remediation strategies shall be put in perspective with this residual background.

3.3 The Functional Unit, a key difference between the tools

The unique fundamental difference between LCA and ERA is the notion of functional unit which is a key aspect of LCA and where no equivalent can be found in ERA. All the other specificities mentioned below are due to the models, databases or the framework of the methods and are likely to change with the evolution of methods. It must be noticed that all part of the methods that corresponds to EcoRA is the Life Cycle Impact Assessment (LCIA). We will therefore now focus on that part of LCA.

3.4 System boundaries, in-between technosphere and ecosphere

In the Definition of the Scope and Goal of the LCA, the boundaries of the system under study are defined. For contaminated site remediation, it is important to decide whether the site itself belongs to the technosphere or the ecosphere.. In the first case, the site is considered as a reservoir of pollutants (such as a landfill) but not as an ecosystem itself, in the second case, it is considered as an ecosystem. Nevertheless, in that case, LCIA need to be adapted to take it into account especially in terms of site specific differentiation for fate and effect modelling. As presented in the table below, as soon as the contaminated site has an intrinsic value as a landscape, ecosystem, or species composition, it has to be included in the ecosphere and not the technosphere.

Tableau 1: Intrinsic value of the site

Site with intrinsic value	Site without an intrinsic value
Landscape or ecological value must be considered in the management strategy	Impact resulting from the site has to be considered disregarding the modifications of the site itself
The site is to be considered as a terrestrial ecosystems and its value shall be considered in the corresponding impact category in LCA	The site is only considered in LCA as an industrial system releasing pollutants and transferring it to other media
Ronde Venen is used in the MuSA project to represent this sort of sites. This site is a polder composed by a peat soil contaminated mainly by Cd, Cu, Pb, Zn.	Recent industrial contaminated area without historical values and strong contamination corresponds to this sort of sites

It is important to distinguish from the early evaluation of contaminated site those that have an intrinsic value such as landscape or ecological value and the sites that simply require a remediation. The first group will be addressed as terrestrial ecosystems and the possible remediation perspectives will have to take into account their intrinsic value, while the other group will just be addressed as a storage or pollutant progressively released in the other environmental media

3.5 Characterization factors in LCA versus dose/effect relationship

LCA is using characterization factors for quantifying the impact of a given substance on the ecosystem. The impact is obtained simply multiplying the emission of a substance in an environmental media (such as air, water or soil) by the characterization factor corresponding to the substance, the emission media, and the target ecosystem. The overall impact on ecosystems in LCA is resulting from the association of a life cycle inventory table and a characterisation factors table. In its experimental perspective, ERA is mainly developing or using concentration/effect curves experienced in the field or in laboratory with an interpretation of the possible consequences of this relation considering the concentration in the field and the sensitivity of the ecosystem or of some of its components. Thus, while LCA is simply using one value to assess the impact of a substance emitted in a media or present in it, ERA is dealing with more qualitative information that are relevant for the site and which could not necessarily be extrapolated to other site.

3.6 Differences in assessment scale between the EcoRA and LCIA

Historically, LCA was addressing impact at a large scale such while ERA was mainly focusing at small scale. It was the case for time and spatial scale. This issues of spatial scale, time scale, and biological organisation level are addressed in more details below.

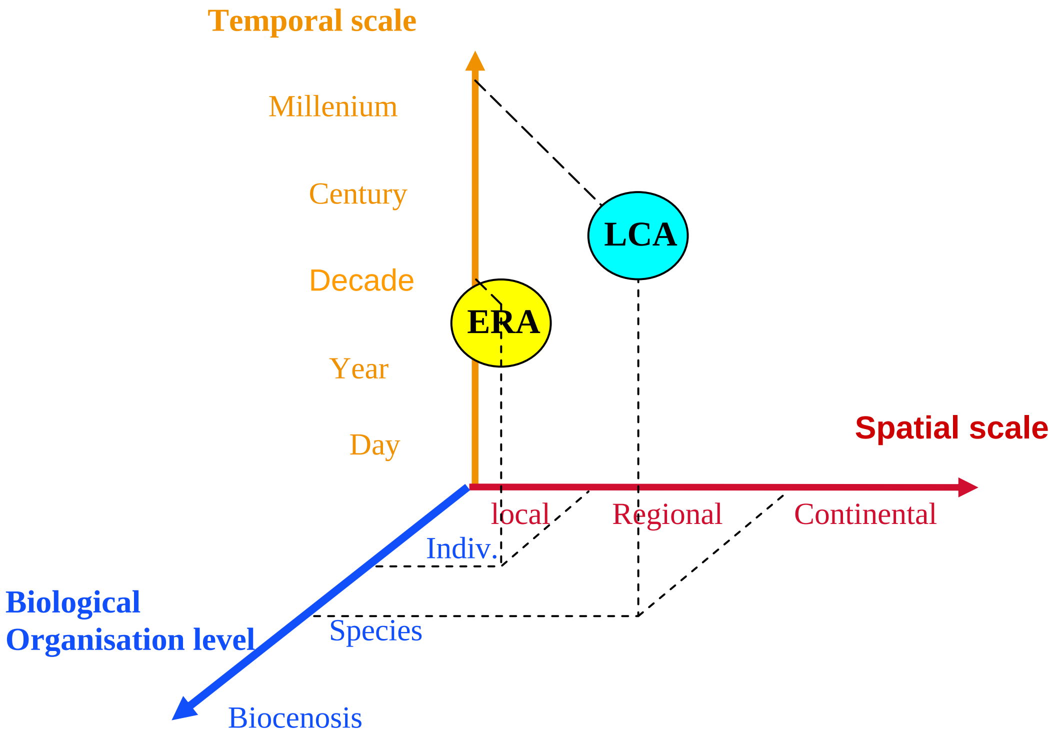

Figure 4: Comparison the EcoRA and LCA in terms of assessment scales

As presented in the figure above, ERA is designed for assessing hazard at a local scale while LCA deals mainly with continental scale. Concerning Time scale, ERA aims at estimating the hazard in a short term perspective, while LCA mainly addresses a long term perspective (100 to 1000 years). And finally concerning biological indicator, ERA is working on a small dataset of well known biological indicators, LCA estimates a percent of change of biodiversity in the ecosystem on the basis of laboratory test species.- Reference value: ERA is based on the notion of an acceptable risk define by a threshold value (the target value) while LCA is based on the “less is better” method. These questions of spatial and time scales are discussed in more details below.

3.6.1 Spatial scale and spatial differentiation

The spatial scale issue is a key problem for the integration of LCA and ERA. Using spatially differentiated models in LCA is a possible response to help resolving this problem.

Managing spatially differentiated modelling in LCA requires to apply it at three different level in the Life Cycle assessment process; at the inventory level (considering spatially differentiated emissions); at the fate model level (including site parameters for a given location in the multimedia transfer model); at the exposure and effect level (considering the actual bioavailability of substances and the actual specie biodiversity composition of the site).

Spatially differentiated Life Cycle Inventory

Practically site remediation is interesting in LCA since we can consider among scenarios the alternative of a “Doing nothing” scenario. In that case, all the emissions are from the site itself and we have therefore a highly spatially differentiated inventory. In all other situations in LCA, working with spatially differentiated emissions has been done for some illustrative studies (such as paper mills for example) but can not be done as routine studies.

Spatially differentiated multimedia modelling
As presented in the table below, ERA is mainly working at a local scale and LCA has been first developed for impact categories that produce impact at a global scale.

Tableau 2: Presentation of different spatial scale for LCIA and ERA

Scale	Local	Regional	Continental
Indic. Km^2	0.0001	2 500	25 000 000
LCA	Site	Watershed	Generic
ERA	Site	Intermedia	No

Generic LCA gives results at the continental or global scale while ERA mainly works at the site scale. Regionalization of LCA models gives a promising perspective in assessing impact at a coherent scale with ERA.

Spatially differentiated exposure and effect models
Generic exposure and effects models are based on an average exposure at a continental level, and effect modeling is based on the calculation of the HC50 (Hazardous Concentration of substances affecting 50% of the organisms above their chronic EC50) for laboratory organisms that are compatible with the area considered. The use of spatially differentiated models of exposure and effects requires the calculation of exposure concentration based on local or regional media parameters, and calculation of HC50s compatible with the organisms presents in the site, or some groups of organisms that can be of specific interest in the considered area.

3.6.2 Time scale and dynamic modelling

Tableau 3: Comparison of time scale issue for impact assessment in LCA and ERA

Years	10	100	1 000	10 000	60 000 to inf.
Persp.	Management	Human life	Civilisation	Ecosystem	Geological
ERA	Yes	No	No	No	No
LCA	No	LCI Short term	No	No	LCI-LCIA

Developing a single decision support tool for LCA and ERA requires working at a coherent time scale. It is possible to develop impact assessment methods for ecosystems working at 100, 1000 and 10000 years for LCA. Nevertheless, the highest time scale considered in ERA is 10 years (for considering intermedia transfer of pollutants for example) while in LCA, the shortest time scale manageable with current models is the century. It clearly demonstrates the gap we have in terms of time scale between the tools. This problem is mainly due to the underlying assumption of steady state modeling that we are using in LCA. Under this assumption the integration of the concentration over time suggests an exposure to constant concentration of chemicals. Promising works have been done for the development of dynamic modeling in LCIA, nevertheless, such modeling requires considering a considerable number of media parameters which makes it unfeasible at this time in an industrial case study.

3.7 Notion of midpoint and endpoint in LCA

The notion of midpoint and endpoint is a key issue in LCIA. Indeed, LCIA was first focussing on global impact such as resources consumption and global warming, and therefore midpoint indicators were developed to address these impacts. Nevertheless, the evolution of the tool lead to address now impact categories such as human health or ecosystems, and it was therefore necessary to assess impacts closer to the area of protection level (AoP). For that purpose, endpoint (also called damage) modelling has been proposed by developers in order to better support the understanding of the impact. Practically, climate change is currently considered as an endpoint indictor even if impact is assessed as the midpoint level. The main reason for that is the limitation of the impacts assessment methods which does not allowed to provide a link between the midpoint level and the consequential impacts on ecosystems and human health.

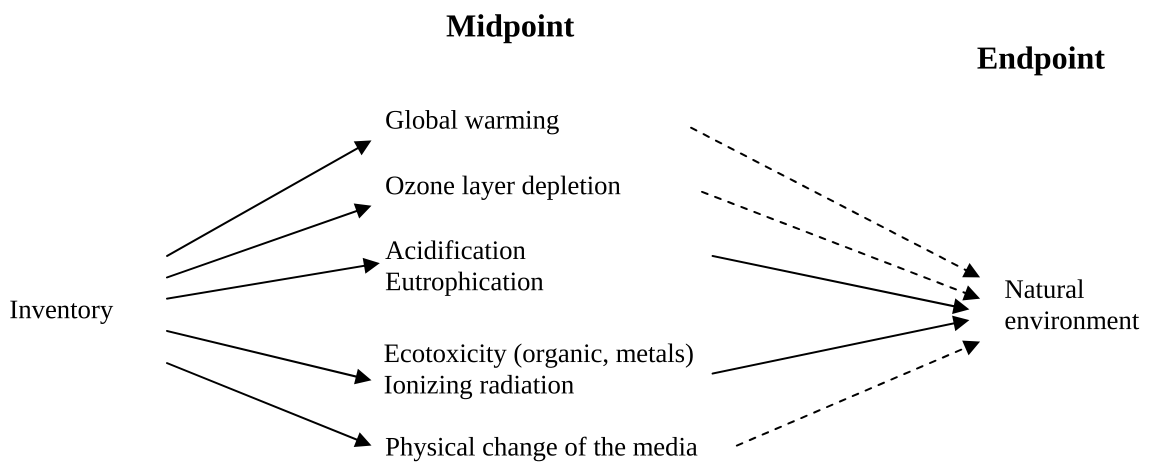

Figure 5 : Integration of environmental stressors in LCA

ERA does not address this issue of midpoint and endpoint. Indeed, the method is assessing damage occurring at the site scale regarding an existing biodiversity. Therefore, midpoint level assessment is not relevant for ERA methods. Furthermore, ERA approaches are assessing anthropogenic stressors separately linking the stressors with the different target that can be of concern in the site. In comparison, LCA is using endpoint modelling to add impact of each stressor on a single final target.

3.8 Biodiversity issue and related parameters

Both LCIA and ERA aims at assessing impact on ecosystems, and both tools can provide information related to the quantification of impact on biodiversity due to the presence of toxic substances in the field. Nevertheless, the impact indicator for biodiversity is the fraction of affected species (PAF) for LCIA while ERA can address individual species in the field. At the same time, LCIA can address impacts in soil and water considering intermedia transfer of pollutants, but change in biodiversity occurring in the site itself due to the presence of toxics is not considered. As a contrary, ERA is addressing only (or mainly) impacts occurring in the site itself and not the impacts in the other media.
A second point in biodiversity is the definition of biodiversity addressed. LCA is addressing first population diversity (under the assumption that each population which is not present in the field can

recolonized the area as soon as the stressor disappears. ERA can focus on species diversity, considering for example the question of endangered species, or can also use indicators of ecosystems functioning.
As a third important aspect of considering biodiversity, LCA is addressing damage on biodiversity under the assumption of a direct concentration/effect relationship between each substance concentration and a certain level of fraction of diseappeared species. ERA can go far beyond, considering aspects such as trophic chain, foodweb structure, keystones species, etc.

3.9 Differences in input data

Fate Modelling

Substances parameters considered in a first tier assessment of EcoRA and a LCA study are mainly Kow, half life of substances, Henry's constant, solubility, Kds, BAF and BCF. Nevertheless, media parameters such as the fraction of clay, organic matter, the pH, etc can be considered in the EcoRA but are not considered in the generic LCA.

Exposure modelling

Bioavailability for metals needs to be considered in both cases when dealing with site contaminated with metals.

Effect modelling

Until now, first tier studies ERA where mainly using ecotoxicity data based on No Observed (or Lowest observed) Effects Level instead of Effect Concentration levels, while LCA has decided to use EC50s (Effect concentration affecting 50% of the individuals in a test) as data input for impact calculation. Nevertheless, in both cases chronic data from laboratory testing are used in priority.

Differences between data collection for impact assessment

In terms of data collection, the tools also differ considerably. EcoRA is historically based on field observations and field or laboratory experiments. As a difference, LCA is always based on modelling, for quantifying the intermedia transfer, the exposure, and the effect. Furthermore, models used in LCA can not be validated as a whole, it is only possible to validate some part of each model. Nevertheless, for such a purpose, connection with EcoRA works can be of strong help since we should be able to compare the prediction of impact performed with LCA models, with the impact assessment based on EcoRA experiments antd the observations performed in the field.

4 Conclusions:

4.1 Possible evolution of LCA and ERA

Historically, even if LCA and ERA have been developed separately, there was always a tendency to become closer and closer as soon as the impact categories addressed were similar. It was also for this reason what impact assessment methods used for LCA were directly derived from ERA methods such as the PNEC method or the HC5 method.

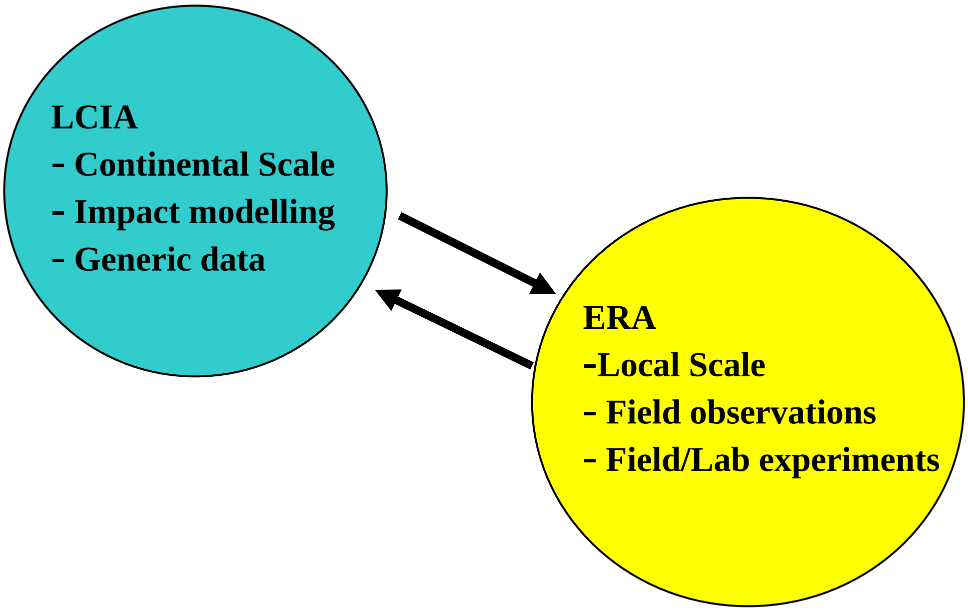

Figure 6: LCIA and ERA can be considered completely different tools

Further these developments, LCA as comparative methods was affirming its specificity developing its own impact indicators, but the tools tend nevertheless to be closer and closer especially concerning the time and space scale addressed.

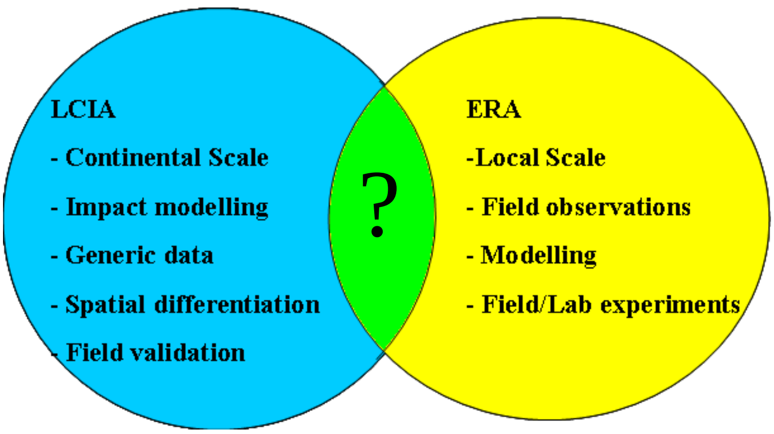

Figure 7: A partial integration of ERA and LCIA

Addressing now partly the same question but with a different view, the question of how far it is possible to integrate the two tools is open. Even if the complementarities of the tools is obvious, it is important to consider the issues that are covered by the two tools on a similar basis in order to ensure we will not have opposite response to the same question.

4.2 Ensuring coherence between tools

As highlighted by Udo de Haes, it is possible to ensure the coherence of the methods while considering their specificities at three different levels, the mathematical formula level (use in the impact modelling), the input data and the application (case-study). In the area of site remediation, it is important to bear in mind that LCA is mainly based on models while ERA is based on experimental data (only little modelling is used for intermedia transfer for example). Therefore for impact assessment on ecosystems, we have to ensure the coherence between tools at two levels: (1) the assumptions supporting the models such as the time or spatial scale needs to be coherent with the field observations; and (2) the input data in the model must be coherent with the data observed (or tested) in the field. It is the case for data such as substances concentration, Kd values, Kow, soil composition, biodiversity composition, etc). Considering the coherence at these two levels, it will be possible to ensure the outcomes of the LCA are coherent with the one from ERA. Furthermore, in terms of research perspectives, it would be then possible to make a partial validation of the models, relating for example the predicted change in biodiversity with the one observed in the field, or validating the intermedia transfer of substances.

4.3 Perspectives in the improvement of LCIA and ERA

The MuSA project highlights some clear discrepancies between LCA and ERA at the conceptual level and also in terms of input data. Nevertheless, both decision support tools address similar targets and shall give coherent results. The development of regional model in LCIA is a promising perspective. Nevertheless, the uncertainty on the data input in the model are important and measured (or observed) data from the site itself should be compared with model output in order to ensure a reliable modeling at least for the first results obtained with regional models. In terms of perspectives, the priority issues are (1) the variability of the soil composition shall be addressed for developing more accurate soil model and (2) target organisms and biodiversity indicators used in LCA must be consider in parallel with organisms diversity from the site or this area to ensure a coherent assessment at the local, regional and continental scale.

The learning from ERA highlights the need of tiered approach for costly environmental evaluations. For contaminated site management, it is always the case for the site characterisation, and therefore, the tiered approach is now well described in TRIAD for example. LCA is usually seen as a simplified assessment tools which could be considered as a one shot assessment tool. Nevertheless, even in a typical LCA study, 2 step assessments are preferred with a first screening followed by a detailed study. Based on our experience in the comparison between LCA an ERA applied to contaminated site, it seems a third step with a site scale LCA would be relevant for complex systems in order to ensure the coherence between the conclusions of the ERA and the LCA studies. Learnings for Ronde Venen case study highlight that the data collected for a second tier assessment in ERA are rather similar to those required for a site specific LCA, therefore there is no important over cost expected to such an assessment, as soon as the LCIA models enabling site specific assessment for fate, exposure and effect modelling are available. It is therefore a priority to develop such models for LCA in order to support coherent use and partial integration of LCA and ERA. Furthermore, due to their ambiguous status between the ecosphere and the technosphere, and their scientific interest, it seems contaminated site assessment is a good basis for developing case studies on that point.

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