Methods and tools to account for Natural Capital in LCA

[Méthodes et outils pour prendre en compte le capital naturel dans l'ACV]
Projet n° 2021-04

Project Synthesis Report

Version No 1.0, released on 10/03/23

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Research context

Human well-being depends on several ecological goods and services provided by nature and derived from renewable and non-renewable natural resources. All this is "Natural Capital" (NC), or in other words the stock or the flow of elements resulting from ecosystems and that people may derive, use and/or manage from their functioning in the form of ecosystem services (ES) and associated benefits. ES can thus be interpreted as the "outputs" of NC, which needs proper conservation or restoration to maintain liveable conditions of clean air and water, to preserve nutrient regulation cycles, to ensure the supply of energy and food, and all the biotic and abiotic resources necessary to sustain human life on Earth. However, such sustainable management is only feasible if the complex cause-and-effect relationships between the processes of the anthroposphere and the natural cycles are known.

In this context the Life Cycle Assessment (LCA) approach can play an unprecedented role, as it has the unique ability to modelling the relationships among the biosphere and the technosphere. Nevertheless, LCA does not comprehensively consider all the elements of NC and the dependency of human systems from it, such as in the case of multiple ecosystem services of maintenance and regulation type (air purification, climate regulation, pollination, ...) and the cultural services. Furthermore, there is no consensus on how to define Natural Capital Accounting (NCA) and how to integrate NCA into decision-making either at the corporate level or in the public sector.

Objectives

This report summarises the work conducted over one year by the Luxembourg Institute of Science and Technology (LIST) within the framework of the SCORELCA project entitled "Methods and tools to account for Natural Capital in LCA", which started in December 2021. The end point of the project was to produce a clear and comprehensive roadmap for LCA practitioners, as well as natural capital managers, to perform NCA with a life cycle thinking perspective. The work details the extent to which, and under what methodological paradigm, NCA can benefit from LCA concepts, procedures, and tools, and how LCA in turn can expand its scope by covering these ES valuation gaps. Three specific objectives have been addressed in the project:

1. *Produce a state of the art of sustainability assessment methods currently used to account for natural capital* ➔ The idea was to identify and characterize existing methodological frameworks, as well as their gaps and opportunities for improving NCA at each level of market scale (product/service, industry/economic sector, entire country economy), governance (public and private) and territorial dimension (local, regional/national, international).

2. *Investigate the existing and potential links between NCA methods and LCA through a detailed assessment of the methodological compatibility aspects in each phase of LCA* ➔ This compatibility assessment was carried out following a "synthesis approach", starting from an analysis of existing literature cases, and finally trying to isolate the general trends for different economic sectors and scales of production.

3. *Provide recommendations on the use of LCA in NCA methods, in the form of a practical guide for industrial and institutional practitioners* ➔ Such a guide was conceptualised as a practical procedure provided with

specific examples, so to enable practitioners and stakeholders integrating LCA principles into the context and operational framework of the NCA.

Methodological approach

First of all, a global state-of-the-art on existing methods that consider the natural capital in environmental accounting and impact assessment was depicted by means of a systematic review of papers collected from the NCA literature (Figure 1). On top of that, the history of the main academic advances carried out worldwide on NCA, on the databases and guides produced so far, as well as on the current state of implementation of NCA methods in the private and public sectors at different geographical and economic scales were retraced. Focusing on the LCA methodological progress more specifically, a non-systematic review was also conducted (Figure 1) to harmonise those concepts and principles into an original definition of NC that can be representative and well interpreted by LCA practitioners. This reads as:

« *The Natural Capital, on which the life cycle of goods and services depend upon, is the heritage of ecological assets that encompasses all renewable and non-renewable, abiotic, and biotic resources existing on Earth, as well as the processes and functions that take place within and across ecosystems at different spatial and temporal scales. Those assets can be inventoried as environmental intervention flows, consumed by the life cycle activities of production systems in the form of intermediate or final ecosystem services, following their extraction from depletable or not depletable natural stocks (above- or below-ground)* ».

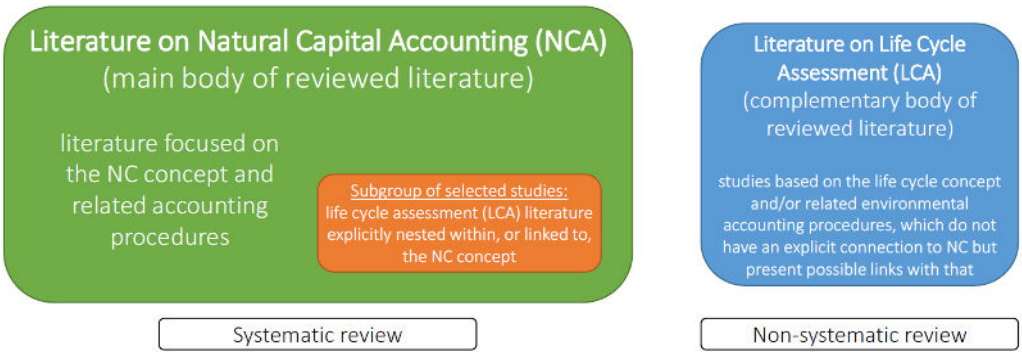

Figure 1 Diagram of the coupled systematic + non-systematic review conducted in this work (the box with green background on the left simplifies the critical review conducted on a final set of #120 studies, identified after a detailed screening of eligibility based on the PRISMA approach; the initial corpus of literature included more than 3,500 studies.

In other words, by coupling these systematic and non-systematic review analyses the Team achieved an extensive knowledge on the concepts and tools available to account for the detrimental (negative) and beneficial (positive) impacts due to the interaction between good and service life cycles at different economic and management scales (company, territory, country), the natural capital and the ES generated from it. Such a knowledge was capitalised by observing the trend of a series of qualitative and semi-quantitative indicators assessed across the selected NCA methodologies. These offered an in-depth view on the "use", number (if available) and type of applications across sectors, and the view on "scientific relevance", data sources and their representativeness and potential availability, as well as the flexibility and robustness of each methodology. An additional analysis of the relationship between LCA and NCA approaches was advanced by examining the NCA properties in comparison with the definition of the Goal and Scope in LCA, and by evaluating NCA requirements in relation to the Life Cycle Inventory (LCI), Impact Assessment (LCIA), and Interpretation phases. Once the state-of-the-art was determined and characterised,

the Team created a roadmap for integrating the LCA perspective into the NCA framework. To this end, a concrete proposal of ES accounting in LCA (ESA-LCA) was outlined building on current literature practices and commonalities between ESA and LCA. A few recommendations to decision-makers for business and territorial management were ultimately provided on how to assess NC impacts and dependencies based on the ESA-LCA methodological procedure.

Brief on the most relevant outputs

The review performed in this study clearly shows that several commonalities exist between NCA and LCA approaches. But most often there is a problem of terminology. For example, what in NCA is accounted for as a "dependency" flow, in LCA can be assessed as a positive impact due to, e.g., avoided emissions or decreased resource consumptions. Hence, in some cases it would be enough to adapt the taxonomy without performing any methodological improvement or integration, while obtaining a robust life cycle-based application to assess for NC dependencies. The analysis of existing NCA methods also suggests that the LCA method and its associated/complementary flow analysis and impact assessment approaches (such as environmentally extended input-output frameworks) are the most advanced in terms of capability to assess multiple and multiscale environmental impacts at the same time and harmonise them into aggregated metrics useful to support decision-making on nature protection and conservation. This is generally true when comparing LCA with other environmental accounting methods such as emergy, ecological footprint or spatial analysis of ES. Such methods rather provide complementary information to, and at territorial scales different from those typically considered in, LCA. On their side, LCA methods only fragmentedly cover an accounting for ecosystem services (and thus their benefits) derived from the dependency of technosphere systems to NC. Conversely this is a primary purpose that the most sophisticated NCA analyses attempt to address, adopting an ES assessment approach (i.e., biophysical and/or monetary valuations).

The project activity generated a synthetic fact sheet with several tables and literature mapping exercises to disclose the compatibility between LCA and NCA, with information and data grouped by "key issue" and by LCA methodological phase, using the terminology (and thus mainly for the use) of LCA practitioners. Results from this critical review allowed to identify the technical challenges associated with coupling LCA and NCA approaches. Five sets of recommendations can be offered for practitioners as summarised below:

1. *Definition of system boundaries and functional unit* ➔ Although LCA and NCA methods may have similar frameworks and approaches when defining objectives and scope (such as in the case of the Natural Capital Protocol), the LCA practitioner should be careful to avoid double counting when selecting the evaluation processes and phases, focusing on the most representative data and indicators. As data to account for ES in a format compatible with LCI and LCIA is difficult to retrieve, it is safer to focus on lesser indicators and items rather than expanding the boundary to include a larger number of ES flows for which only qualitative data can be provided. Additionally, it is worth reminding that the non-market valuation for most of ES generates less tangible and somehow more abstracted knowledge than the market-based knowledge on raw materials, energy, and products, which is instead largely accessible at the business scale of an organisation. Various techniques and tiers exist to account for ES, from expert-based qualitative judgements to quantitative statistical and literature surveys, up to very sophisticated remote sensing extrapolations or on-field sampling produced data. Practitioners may start from simplified ES accounting structures, where only a qualitative scoring of land use/land cover state and condition is needed, and then move to more complex modelling and assessment tools, especially if

quantitative ES data is available/accessible. In this regard, the European MAES guide for assessing ecosystems and their services within LIFE projects is just one example of powerful tool for getting familiar with ESA at different tiers of complexity, and to select and incorporate in NCA pertinent indicators.

2. *Use of life cycle inventory and ES databases* ➔ Sources and types of data available for conducting environmental impact assessments in LCA may not be necessary, functional, or immediately operational for the assessment of a wide number of ES and environmental externalities, whose accounting is instead very relevant for an exhaustive and representative NCA. Practitioners may be required to manipulate data, search for new data, or adapt certain datasets using specific assumptions (e.g., related to data nomenclature or classification systems), in order to align with the concept of NCA. In this regard, the ES literature is dramatically vast, and one can find abundant information to which referring for the analysis. Alternatively, existing ES valuation databases provide abundant set of data on ES flows either in physical or monetary units, which are worth to be explored as a source of data and references for conducting LCAs oriented to NCA. Examples are the open access databases Ecosystem Services Valuation Database (ESVD) and Environmental Valuation Reference Inventory (EVRI).

3. *Use of impact characterization methods and models* ➔ The present review proves that the current coverage of impact assessment indicators in LCA does not (yet) explicitly allow to assess the dependency of life cycle activities from the natural capital, if not for a narrowed set of resource and land use (change) flows. As mentioned above, several ES are not considered in LCA (either in LCI or LCIA cause-effect models), which necessarily limits the use of available LCIA best practices for the NCA. Practitioners may take advantage of the latest scientific advances that attempt to fill the current methodological gaps of LCA regarding ESA. The research studies listed below were selected amongst those most recent, advanced, and nowadays available in the ESA-LCA literature. Despite not certainly exhaustive, this selection represents a manageable sample of reference studies to guide practitioners into prospective opportunities to customize their NCA according to the most advanced LCIA frameworks that try to incorporate an ES accounting:
    - Babí Almenar et al. (2023), in: *Ecosyst. Serv*., 60, 101506
    - Babí Almenar et al. (2023), in: *Land*, 12, 70
    - Moore et al. (2023), in: *J. Environ. Manage*., 329, 117068
    - Alejandre et al. (2022), in: *J. Clean Prod*., 346, 131043
    - Cordella et a. (2022), in: *Proc. CIRP*, 105, 134-139
    - Oliveira et al. (2022), in: *Land*, 11, 2106
    - Larrey-Lassalle et al. (2022), in: *Land*, 11, 649
    - Xue & Bakshi (2022), in: *Sci. Tot. Environ*., 846, 157373
    - Chen et al. (2021), in: *Sci. Tot. Environ*., 773, 145018
    - VanderWilde & Newell (2021), in: *Resour. Conserv. Recy*., 169, 105461
    - Morales-Mora et al. (2020), in: *Appl. Sci.*, 10(2), 622
    - Rugani et al. (2019), in: *Sci. Tot. Environ*., 690, 1284-1298

4. *Data availability, accuracy, technological detail, and coverage* ➔ Database developers from the LCA community regularly update and improve the consistency and representativeness of their life cycle datasets of background activities. Therefore, the use of LCI results, for example in the form of "resource intensity" or "emission intensity" factors, provides an excellent data platform to fill potential gaps in the

databases used for NCA. The same holds for "impact intensity" factors derived in the form of aggregated LCIA outputs, where a precalculated amount of, e.g., embodied energy or carbon footprint (in MJ/unit of flow or kg CO_2-eq./unit of flow) from representative LCA studies might be used in NCA to convert unitary flows of product or service into equivalent resource or emission burdens. This is particularly true for the ecosystem accounts of SEEA (System of Environmental-Economic Accounting), one of the global NCA methodological references whose inventory data provision is typically based on national statistical sources. Without the use of LCI and LCIA, SEEA datasets may lose specificity, granularity, and accuracy for organisation and product scale NCA. But it also holds if one wishes to perform a NCA based on other approaches such as the Natural Capital Protocol, more focussed on the product level rather than the whole industry sector. In any case, practitioners should be careful in collecting data by choosing the appropriate dataset sources (if available), properly consult metadata information systems, and avoid double-counting that may occur when merging data from LCI processes into economic input-output systems (typically used in SEEA frameworks). This is even more important when applying the Natural Capital Protocol, which is oriented to supply recommendations to the product users and the organisation promoting the NCA study. The commercial ecoinvent database is the most extensive LCI database worldwide, and can ideally be used in a first instance to supply cumulative life cycle intensity factors compatible with NCA frameworks. Other LCA databases exist and can be found under different user licence agreements and functionalities, for example within the OpenLCA platform. While at the level of economic sector or region, homologous types of dataset (in terms of potential functionality and interoperability with NCA) can be retrieved for free in various sources such as the Exiobase platform, the World Input Output Database, or the Eora global supply chain database. In all these cases, uncertainty associated with derived intensity factors is generally higher, and granularity/detail lower, than with LCA tools. The advantage of using input-output related datasets is that factors can be retrieved in monetary unit (e.g., square meter of land use Y per euro spent in sector X), which is usually an information not or less frequent in cumulative LCI or LCIA databases. It is worth remarking that life cycle and input-output data frameworks provide a high technological and data granularity regarding resource extractions, emissions, land uses, and all related impact intensity factors associated with hundreds of technologies, services, and economic sectors. However, they do not disclose extensive information about ecosystem services. Data on ES may be collected from other sources as recommended at Point 2 above.

5. *Potential to use or converge impact assessment methods* ➔ While LCA suffers from not covering the full spectrum of natural capital impact assessment indicators (namely those indicators of ES supply), NCA methods do not offer a sufficient knowledge platform to fill this gap. Models used in the SEEA framework, for example, can cover only a limited number of ecosystem services, while the Natural Capital Protocol relies primarily on monetary valuation techniques for its natural capital assessments, which can be a source of considerable uncertainty. A joint effort needs to be made on both sides, but particularly by NCA practitioners, to identify the best available indicators and models for impact assessment (for both environmental benefit and cost assessments) of specific business cases where the dependence on natural capital may be unique, highly regionalized, and not transferable to other contexts. This also means that best practice research conducted so far (as outlined through the review analysis in this research) can be very useful to avoid starting from scratch: successful cases from the literature can be taken as a reference to establish a "baseline" on which the NCA practitioner can build new methods, coupling or integrating them with the best available knowledge and tools from LCA (e.g.,

with respect to indicators of biodiversity loss and resource depletion, for which there is a broader consensus in LCA than in NCA).

This literature review analysis ultimately suggests that merging LCA and NCA can be an effective solution to enhance the capacity of these two approaches to answer different questions in one unique methodological framework. Thinking in perspective one may consider a coupled LCA-NCA constituted by two methodological pillars (Figure 2). The first pillar, represented by a section for quantifying the "detrimental impacts" generated by life cycles to the natural capital, well depicted by applying LCA and related approaches; and the second pillar represented by a section to account for the "beneficial impacts" retrieved from such NC dependency, which can be characterised and valued with an ESA approach. Such a methodological combination would allow to advance the robust LCA-based approach with other methods of ES analysis in order to encompass both negative (using conventionally the LCI and LCIA tools) and positive (applying best available techniques of ES valuation) impacts.

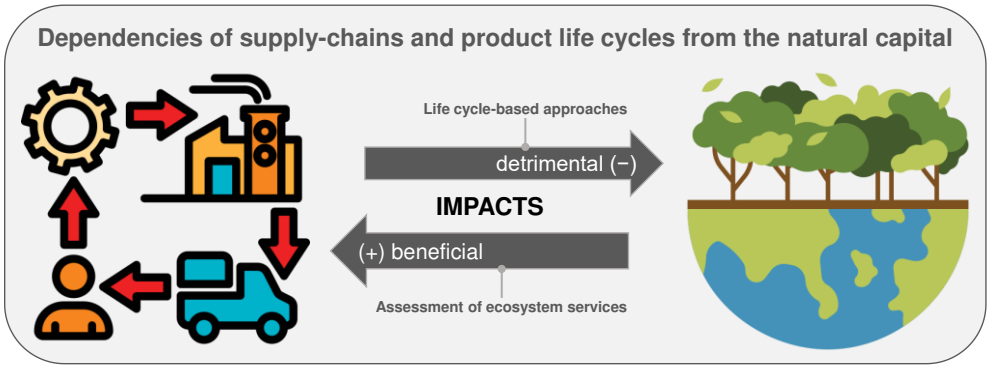

Figure 2 Simplified representation of the methodological pillars at the core of a coupled LCA-NCA approach.

Concluding remarks

One of the key actions of the European Commission within the European Green Deal, and as part of the 2030 Biodiversity Strategy, is to promote an international NCA initiative that aims to use the product / organization environmental footprint methodology (PEF / OEF), making use of life cycle and NCA approaches. It is therefore timely to build consensus and awareness on how to harness the power of LCA to improve NCA to support private and public goods, services, and land sustainable management. The systematic and non-systematic review analyses performed in this work have provided the ground for capitalizing on current LCA and NCA shared knowledge, and making it available to decision makers. Decision-makers across industries are particularly interested by the appraisal and deployment of a tool that, based on scientific evidence, can simplify, and make straightforward their decisional processes and opportunities to do business with nature.

The road towards a fully-fledged and operational life cycle based NCA, on one hand, and an LCA capable to account for NC dependencies, on the other hand, is plenty of challenges. As reported in the prospect below, the overall scientific results of the review were translated into a set of "take-home messages" for decision makers at organisational and industrial scale. Next to that, a simplified roadmap was produced outlining the methodological steps that any decision-maker, supported by an LCA practitioner and possibly other experts from the field of ES assessment, can roll out to scoping a NCA study and interpret its results. All the results and material produced in this project are included in the SCORELCA Full Report and within a Research Manuscript (critical review format) currently under review within a peer-reviewed journal.

Take-home messages

- **The dependency from natural capital of the supply-chains and product life cycles is determined by the combination of two categories of impact, i.e., the one generating detrimental effects on ecosystems, and the one providing direct and/or indirect benefits to human well-being** ➔ In natural capital accounting (NCA), life cycle-based approaches can be applied to quantifying detrimental impacts using specific characterisation models and negative environmental impact category indicators. Analogous (but opposite in sign) indicators of ecosystem service (ES) provisioning can be accounted for to assess the value of ES generated from the natural capital, either independently from, or with, the contribution of humans.

- **Applying a stepwise ESA-LCA based "mitigation hierarchy" to production systems allows to perform an extended, market-scale NCA** ➔ First, the application of lifecycle assessment (LCA) and related approaches creates opportunities to avoid and/or minimize environmental impacts on natural system; then, by applying an ES assessment it is possible to take a step further, promoting actions to restore the damaged system(s), offset residual and unavoidable impacts, and eventually bring to a net gain of benefits from increased services supplied by natural capital subjected to sustainable management.

- **In NCA, environmental accounting methodologies other than LCA (and similar approaches such as the environmentally extended input-output analysis) are also applied which allow to estimate the biophysical dependency of product life cycles and economic systems from the natural capital** ➔ It is worth mentioning that two well established methodologies can be used to estimate with physical and quantitative metrics the value of ES and natural capital assets provided by nature, i.e., ecological footprint and emergy analysis. Both methodologies are unique in offering a quantitative dimension of the environmental Supply of resources, land, and ES in general, which can be related to the Demand for those items made by the system analysed (the "demand", in this case, is also synonym of "negative impact", or "footprint"). As there is no one method for all, a combination of complementary approaches and tools seems in most cases preferable for addressing the multiple methodological challenges of a NCA study.

- **A novel definition of "natural capital accounting in LCA" has been proposed in this study, which originates from merging concepts and approaches from numerous other definitions available in the extensive literature on natural capital** ➔ No clear meaning, explications, or interpretations about the concept of natural capital have been offered so far by scholars of the LCA community. This has hampered to establish consensus on how to account for natural capital and its properties in the LCA framework. A priority task of the present work was to retrieve key information from the vast and variegated literature on ES, learn from different disciplines and build on former definitions of natural capital to create a first structured, explicit, and exhaustive understanding of what can be considered and assessed as "natural capital" in the LCA framework.

- **Because a multidisciplinary approach is crucial to perform NCA, there is a clear need to engage with experts outside the LCA community to build consensus on the development of a shared approach for NCA in LCA** ➔ While LCA practitioners may have appropriate competences and tools to perform very detailed NCA applications that consider one or more target ecosystem services, it is worth calling for contributions and cross-fertilisations from other scientific communities (e.g., ecology, economics, biology, …). This is especially useful if the NCA goal is broader in scope than LCA, and focuses on the creation of an overall methodological agreement about the collection and elaboration of data and indicators to account for ES and other natural capital assets (such as biodiversity).