Ecological Accounting : How to organize information for biodiversity conservation decision and action at the national, business and ecosystem levels?

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Input paper to the NGFS-INSPIRE study group on Biodiversity and Financial stability

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Outline

Introduction

Multiplication of approaches for measuring the "value of nature" and social and economic interdependencies with biodiversity - Approaches aimed at modelling and assessing the impacts and dependencies between society and economic activities on the one hand, and biodiversity and the proper functioning of ecosystems on the other, have multiplied over the last decade. These are based either on biophysical modelling work or on methods for the economic and monetary valuation of ecosystem services (or "nature's contributions to people") (Chaplin-Kramer et al., 2019; Swiss Re Institute., 2021; Svartzman et al., 2021). These approaches have now taken a prominent place in the biodiversity conservation agenda as shown by international and national studies such as the Millennium Ecosystem Assessment (MEA, 2005), the TEEB reports (TEEB, 2010, 2012) or more recently the Dasgupta study (Dasgupta, 2021) or the work of Johnson and al. (2021).

Recognizing the important contributions of these "valuing nature" approaches – The fundamental rationale, the theory of change, underpinning most approaches to measuring and assessing biodiversity impacts, dependencies and risks is that: (1) by revealing the value of ecosystems and their multiple contributions to societal well-being, which were previously invisible; (2) by translating and communicating these values in monetary terms or in a spatially explicit manner; (3) then these will have a greater chance of being taken into account in cost/benefit decision-making processes, risk analysis, public policy making and investment choices that are more favorable to nature conservation and restoration (Kareiva et al., 2011; Laurans & Mermet, 2014; Levrel et al., 2014; Mermet et al., 2014, p. 23). This has so far raised a lot of hope about the possibility of "*making conservation mainstream, attractive and commonplace worldwide*" (Daily et al., 2009, p. 21). The development of this research agenda has brought some results to the world of nature conservation (Helm & Hepburn, 2012; Laurans and Mermet, 2014): analysis of environmental trade-offs in the context of public policy development or implementation; study of incentive structures ; raising awareness, advocacy and warning of the economic and financial benefits and risks associated with ecosystem degradation (e.g. Swiss Re Institute., 2021; Svartzman et al., 2021). This has also fueled the development of a certain type of "business case for biodiversity" discourse and to the development of a number of *ad-hoc* tools for helping businesses to better assess and manage their impacts, performances and risks related to ecosystems (Lammerant et al., 2019; NCC, 2016; TEEB, 2012; Winn & Pogutz, 2013).

Acknowledging their limitations when turning to the actual use of ecosystem-interdependencies information in decision-making and action – A growing body of work, however, points to an "implementation gap" and emphasizes that revealing the economic values of biodiversity and generating new information about the interdependencies that bind us to it is not *by itself* sufficient to produce the expected transformative effects in diverse decision-making contexts at the business, policy or ecosystem governance levels (Levrel et al., 2017 ; Recuero Virto et al., 2018; Ruckelshaus et al., 2015; van den Burg & Bogaardt, 2014). In order to progress towards a real consideration of these assessments and this knowledge, and to have the policy and decision-making impact expected, a number of studies have pointed to the importance of analyzing and taking better account of the real contexts of decision and action in which these metrics are actually used (Berghöfer et al., 2016; Feger et al., 2017b; McKenzie et al., 2014; Mermet et al., 2014; Posner et al., 2016; Rosenthal et al., 2014; Winkler et al., 2021).

Issue addressed in this input paper – In order to contribute to the multiple efforts for the transformation of our economy into a system that effectively maintains and restores biodiversity, we introduce a proposal aimed at going further in the integration of ecosystem-interdependencies information at the heart of organizational processes and decision-making procedures at different

levels. These methods also aim to take into consideration the great variety of decision-making and action contexts that characterize the realm of biodiversity conservation. We argue that such an endeavor requires to turn to the field of "ecological accounting", both on a conceptual level and on a practical level, to put forward concrete methods and tools for collective decision and action. The paper hence addresses the following question: **what kind of ecological accounting concepts and methods can be sense-making and scientifically sound, to support the management of biodiversity-related risks and reorganize our economic system towards the achievement of biodiversity conservation/restoration goals ?**

Outline – The first part of this paper will discuss our reasons to turn to the academic and practical field of ecological accounting at different levels of decision and organization (national, business and ecosystem); and our choice to adopt a strong sustainability and maintenance cost-based approach. Based on these foundations, we will then present three complementary ecological accounting methods at the national level (the Unpaid ecological costs approach); at the business level (the Comprehensive Accounting in Respect of Ecology model) and at ecosystem management level (the Ecosystem-centric management accounting approach). We will conclude by highlighting the need to continue to progress towards the interlinking of these methods.

1) Accounting for organizing biodiversity conservation: three starting points

1.1 Adopting an accounting paradigm

Historically, most approaches that have been developed in the past decades to quantify the impacts and dependencies with ecosystems and their services as well as the risks associated with their degradation have built on interdisciplinary alliances between environmental sciences and economics (Daily, 1997; Gómez-Baggethun et al., 2010). In order now to address the issue of "measuring nature" not only for making its value more visible and build awareness, but *for actively using information to organize* its preservation at different levels of decisions and action, we argue that one needs to turn to accounting as the adequate disciplinary and conceptual paradigm. This calls for the development of new alliances between conservation science and accounting research and practice (Bebbington et al., 2021; Cuckston, 2018, 2021; Feger et al., 2018; Feger & Mermet, 2017).

Turning to the field of accounting research is indeed an invitation to move away from an understanding of the very notion of "accounting" – such as in the term "natural capital accounting" – as being only the craft of producing economic or biophysical figures related to nature. Indeed, beyond its calculative nature, and in its broadest sense, "accounting" has to be understood as being "*the preparation and the framing of information (qualitative and quantitative) to assist specific organizing and decision-making processes (Jollands, 2017)*" (Feger et al., 2018, p. 973).

More than four decades of qualitative and critical accounting research have indeed focused in studying the detailed use of multiple types of accounting systems and methods in concrete and contextualized decision-making settings, and analyzed how they generate intended or unintended organizational changes and wider governance transformations (Ahrens & Chapman, 2007; Chapman

et al., 2009; Hopwood, 1983; Miller & Power, 2013). This academic field has now firmly established that :

- Accounting systems are the fundamental language of all organizations and institutions, as they serve as a basis for multiple concrete human practices which are in and of themselves *constitutive of* any kind of organizational functioning: defining performance(s), distributing responsibilities, demanding and discharging accountability, decision-making, planning, debating, negotiating, adjudicating, justifying, controlling, etc. (Miller & Power, 2013).
- These practices and the systematic exchange of diverse kinds of "accounts" among individuals within organizations as well as between organizations are key in gradually building and stabilizing "systems of accountabilities". Systems of accountabilities are a key aspect of all kinds of human organizations and for the achievement of collective performance goals (Burchell et al., 1980; Roberts & Scapens, 1985).
- Accounting research and practice recognizes the very political nature of choosing and using a given accounting framework and method over others, as they are all deeply embedded in (often implicit) underlying worldviews (Cooper et al., 2005; Gray, 2010; Kuasirikun & Constable, 2010; Milne, 1996). The political nature of accounting is even more tangible when it comes to accounting conventions and norms that are the object of real-world collective negotiations held in well-identified decision-making instances (Chiapello, 2008; Richard, 2005; Richard et al., 2018).

Accounting systems, procedures and norms are thus key aspects of the way institutional and economic actors can respond, coordinate and concretely operationalize responsibilities and action for biodiversity conservation and restoration (Feger & Mermet, 2021).

1.2 Three main levels of ecological accounting innovations

Since 1990s, "*researchers have revealed and criticized the lack of consideration of sustainability issues in existing accounting systems (e.g., Milne 1996) and advocated the development of new accounting approaches inspired by ecological thinking at and beyond the corporate level (e.g. Bebbington & Larrinaga, 2014; Birkin, 1996; Russell et al., 2017)*" (Feger et al., 2019, p 973). The issue of biodiversity is still nascent in accounting research (Jones, 2014; Jones & Solomon, 2013; Thomson, 2014). It is however rapidly gaining ground and the number of new "accounting for biodiversity" methods and tools increases rapidly. Feger and Mermet (2021) propose a typology of the main domains of accounting for biodiversity innovation at the national, business/private organizations and ecosystem management levels. The authors stress the need to progress in the interlinkages of accounting methods at these three levels in support of different set of actors and driving forces for change.

Indeed, at the level of public authorities and institutional actors, the development of national ecological accounting innovations has the potential to support the regular assessment of a country's overall ecosystem quality and to define public policies, budgets and economic instruments aimed at protecting them (Bérard, 2019; Hein et al., 2020). At the level of a given business or a private organization, innovative ecological accounting methods have the potential to help managers and CEOs define biodiversity commitments and operate subsequent concrete changes in their business models and the firm's governance. It can also support stakeholders and civil society to hold the organizations accountable for these biodiversity commitments (Addison et al., 2019; Adler et al., 2018; Boiral, 2016). At the ecosystem management level, new shared accounting systems can help support the definition and delivery of conservation strategies by multiple stakeholders who impact and depend on the same ecosystem. They can thus serve as an accounting basis for the collective governance of ecosystems and environmental commons (Feger & Mermet, 2017, 2021).

In each of these levels of accounting for biodiversity innovations, there are active controversies regarding the conceptual basis of the methods and frameworks proposed, shedding light on the deep differences between them regarding : the definitions and ways of measuring biodiversity and their value(s); the adoption of a weak or a strong sustainability approach; the choice of the relevant accounting perimeter ; the need to integrate new metrics within existing systems of accounts or rather the need to develop new ad-hoc tools and systems of accounts, etc. Acknowledging these controversies is crucial in the realm of ecological accounting, since choosing one way or another to account for nature can ultimately have important (expected or unintended) consequences on how and on what basis decisions are made, actions are conducted and justified, and environmental performances are reached (or not). When promoting and developing a given ecological accounting method rather than another, one thus needs to be as clear and explicit as possible about its conceptual and normative underpinnings. That way, the accounting methods along with the worldview on which they are based remain open for debate, critiques and improvement.

With these elements in mind, the authors of this paper suggest that it is now possible to develop and connect ecological accounting innovations that have deep transformative potential for biodiversity at the national, business and ecosystem levels, and that are based shared conceptual foundations. Before introducing the three complementary methods, the next section aims at making more explicit important aspects of these shared conceptual foundations.

1.3 Defending a strong sustainability and a maintenance cost-based perspective

Strong and weak sustainability

Strong sustainability (SS) is foremost the opposite of weak sustainability (WS). WS is defined by the fact that the total capital stock from which a society benefits must not be decreasing, but that the contents of this total quantity of capital is secondary. This concept is based on an objective of intergenerational well-being (Hartwick, 1977; Solow, 1974, 1993). It is thus entirely accepted that an increase in physical capital can offset a loss in natural capital, the important consideration being that the total amount of capital does not decrease. The above is the definition of sustainability adopted by the Brundtland Report (World Commission on Environmental and Development, 1987). The aim of SS is to move beyond these conventional definitions of sustainable development by considering that it is necessary to adhere to the constraint of maintaining natural capital, whether for ethical or technical reasons. There is therefore in this concept of SS a conscious refusal of the principle that physical capital can be substituted for natural capital, to the point that SS is defined as the non-substitutability paradigm (Neumayer, 2003).

While the debates on SS versus WS took place mainly in the 1990s, there has recently been renewed interest for several reasons: an inability to propose monetary values for natural capital that are sufficiently robust or even admissible before courts of law (Thompson, 2002); the growing recognition of the rights of nature which goes against the idea that any destruction of nature can be justified by the simple fact that it leads to an increase in a country's wealth (Cano Pecharroman, 2018); the adoption of much stricter environmental normative reference systems than those of the 1990s, and which offer a legal and social basis for the tacit recognition of the SS principle as a guide to public policy-making (Feuillette et al., 2016; Levrel et al., 2014; Quétier et al., 2014); the emergence of tools

to support public policies that aim to move away from the welfare equivalence towards equivalences 'in kind', but also the appearance of a detailed determination of the debt incurred to non-human living entities (Rambaud and Richard, 2015; Scemama and Levrel, 2016).

Total Economic Value and maintenance costs valuation approaches

Virulent debates animate the world of financiers and accountants on the best way to measure the erosion of natural capital. There are two opposing views:

- The first aims at calculating monetary valuations of the ecosystem services provided by nature (and the "natural capital" it represents). This leads to calculating the erosion of natural capital by measuring the associated losses of economic benefit. This method for assessing the cost of environmental degradation is founded on the Total Economic Value (TEV) of benefits forgone because of the depletion of ecosystem services delivered by marine biodiversity.
- The second approach is to consider that we need to comply with a normative principle of no net loss of natural capital components, or to maintain the proper ecological state of an ecosystem. This second criterion leads to proposals of accounting methods based on a biophysical reference system in which economic valuation has only an instrumental role, that is to say to measure how much it costs to maintain the proper ecological state of the ecosystems (here we will use maintenance costs and conservation/restoration costs interchangeably) (Levrel et al., 2014).

From the point of view of standard economic theory, the first approach is more robust since it is in accordance with the welfare optimization analysis (Mäler, 2008). However, there are at least four major practical issues which have to be addressed when considering monetary valuation of non-use values, indirect use values, and even simple non-market use values such as recreational activities (Barbier et al., 2009; Heal, 2000; Pearce, 2007; Wallace, 2008): the lack of data on interactions between biological entities, ecological functions, ecosystem services production, and changes in well-being (Costanza et al., 2007; Naeem et al., 2009; Carpenter et al., 2006, 2009); the high level of uncertainty regarding some of the values based on support services or cultural services (Ludwig, 2000; Toman, 1998); the controversies around the benefit-transfer method for extrapolating local values to a regional or national scale (Spash and Vatn, 2006; Braat and ten Brink, 2008; TEEB, 2010); the controversies around the stated preferences analysis for capturing non-use, indirect use, and non-market use values (Kahneman et al., 1990; Kahneman and Ritov, 1994; Horowitz and McConnell, 2002); ethical issues regarding the commensurability and monetization of nature (Espeland and Stevens, 1998; Rutherford et al., 1998); the limits of the TEV to give a relevant information when the analysis is used in a policy frame where some strong sustainability goals are fixed (Pearce et Atkinson, 1993; Bithas, 2011).

And more is the complexity of the natural capital (e.g., for biodiversity), stronger are the limits mentioned above. This is the reason why most of the attempts of capturing the TEV of biodiversity, and the ecosystem services it delivers, failed. Recognizing these limits, some authors like David Pearce (2007) have proposed paying attention to the real costs borne by society to provision and maintain ecosystem services – that is, the costs of conservation policies. These can be divided into two categories, the opportunity costs of ecosystem conservation and the management costs of conserving biodiversity and provisioning ecosystem services. Bartelmus (2009) and other specialists of the System of Ecosystem and Economic Accounting (SEEA - at the level of national accounting)

went further and suggested paying attention to the maintenance costs of a given environmental state[1].

The increasing success of the maintenance costs approach

The maintenance costs approaches have been more and more used in the recent years. In Europe, the cost of degradation of the marine environment, which is reported by member states for the Marine strategic framework directive, uses cost-based approaches in most of countries (see for example Levrel et al., 2014). In France, the tutelary value for carbon that informs decisions (including-cost benefit analysis) on climate and energy policies as well as the tutelary value of the biodiversity are respectively based on the costs to be in a situation of neutral emissions by 2050 and the costs to respect a no net loss goal of biodiversity (Quinet, 2013, 2019). Even in the United States, where welfare-based valuations were first developed to inform liability cases in courts, court decisions finally preferred cost-based approaches and in-kind equivalencies in practice when it is necessary to give some evidence regarding the assessment of environmental injuries (costs of primary restoration and costs of compensatory restoration) (Thompson, 2002; Roach and Wade, 2006). In Switzerland the value of biodiversity integrated in the tax for trucks transport, developed to internalize the environmental externalities of this sector, is also based on the costs of restoration. In fact, when valuation concerns biodiversity components, the only easily implemented, sense-making and scientifically sound methods are the cost-based approaches. The basis of this approach is accounting for historical costs, and not in anticipation of future benefits which allow the calculation of the updated net value. In addition, Nature is treated as an entity distinct from and outside the economic system.

Concretely, in these contexts, the maintenance costs can be understood as the real expenditures needed by a socio-economic system to maintain the level of natural capital required to deliver a certain amount of ecosystem services it benefits from. This method does not take into account the economic welfare theory and is based on accountability theory. Maintenance costs can therefore be disproportionate as regard with the benefit provided by the investment in the natural capital (EPA, 2009, Table 1). It is clearly one of the main limits of this method.

However, it is also one of the strengths of the maintenance costs approach. Thus, maintenance costs assessment makes sense only in a policy frame where some environmental standards have been adopted, reflecting the level of natural capital that a society agreed to maintain through a specific level of investment. This policy frame is a product of some compromises regarding the formulation of the environmental problem, the norms and rules which are necessary to tackle this issue, and the effort (measured in terms of changes in use and/or restoration programmes) required to achieve them. This complex management system includes a clear environmental normative reference, reflecting a strong sustainability goal, which is the product of a number of negotiation processes and political trade-offs. It does not make sense to give a TEV, based on individual aggregated

[1] "Maintenance cost is applied to environmental degradation. The SEEA reviews maintenance costing critically as the hypothetical cost of avoiding pollution or restoring the polluted environment (United Nations et al., 2003, ch.10D). Maintenance cost can be seen, however, as the weights for actual environmental impacts 'according to society's obligation and capacity for dealing with environmental concerns'" (Bartelmus, 2008, p.145); "Such costing is indeed more practical than the assessment of elusive damage effects from environmental impacts" (Bartelmus, 2009, p.1851).

preferences[2], which is based on another normative principle: the maximum of welfare. But it seems possible to consider that it makes sense to know how much more it will cost to reach biodiversity conservation goal.

2) Three complementary strong sustainability accounting methods at the State, business and ecosystem-management levels

We will now proceed by presenting three ecological accounting methods at the national, business and ecosystem-management levels. These three methods are supported by a community (scientists, academics, professionals, NGOs, etc.) federated by the "Ecological Accounting" research chair[3]. They are currently being experimented in concrete decision-making settings through multiple research-action programmes (PhDs or others). All three methods have in common a strong sustainability and cost-based approach, making them consistent with one another, and opening the path for their future interlinkage.

3.1 The Unpaid Ecological Costs approach : transforming national accounting to better guide public investments in nature restoration

At the national level, the System of Environmental and Economic Accounting (SEEA) sets the ground for the development of a comprehensive, comparable, and reliable statistical framework on the environment and its relationship with human activities. It was first released in 1993 to respond to the societal demand for sustainable development. The rationale guiding this effort is that **"***individual and society decisions concerning the use of the environment will be better informed through the use of information set that are developed based on a recognition of the relationship between ecosystems and economic and other human activity***"** (UNSD, 2014). After several iterations, the Central Framework of the SEEA (SEEA-CF) was adopted as a statistical standard in its 2012 version by the United Nations Statistics Division (UNSD, 2014). This statistical framework is aligned with the System of National Accounts of 2008. It includes a series of accounts recording stocks and flows of environmental assets and is already implemented in 80 countries (UNCEEEA, 2019). To go further on the inclusion of ecosystems, the UN published in 2021 a dedicated framework for Ecosystem Account (called SEEA EA). The biophysical ecosystem accounts ("extent" and "condition") have been adopted as a statistical standard by the UNSD (Figure 1).

[2] Assuming that it is impossible to set an aggregation rule that would allow to sum individual preferences inside a TEV in a way that would respect the norms that society as whole agree as essential, as mentioned long time ago by Kenneth Arrow (1950), the maintenance cost assessment seems to be more suited when some environmental normative goals have already been adopted.

[3] https://www.chaire-comptabilite-ecologique.fr/?lang=en

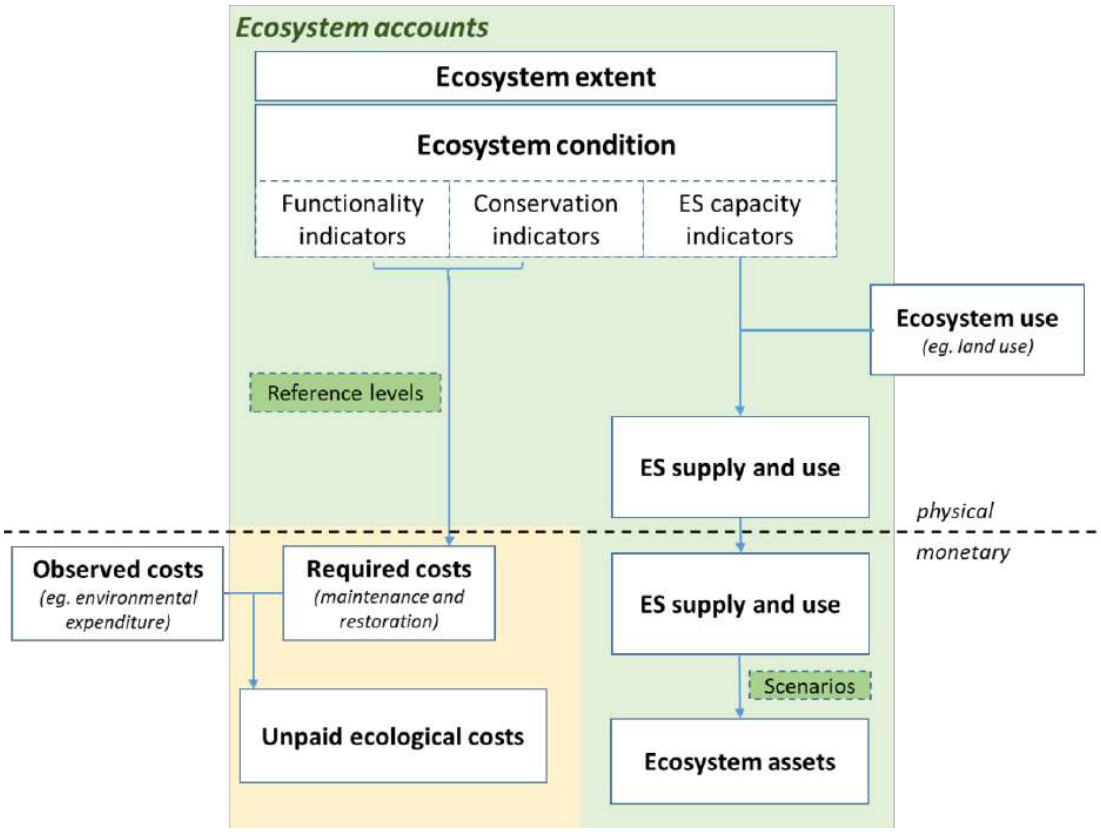

Figure 1: Structure of ecosystem accounts (Source : *Comte, Kervinio, Levrel, 2020, p. 22*)

The economic accounts of measuring ecosystem services flow and assets are "recommendations", while other approaches, including unpaid ecological costs, have not been qualified in these terms and are still being experimented. The "Unpaid ecological costs" represent the value, in terms of avoidance or restoration costs, of the degradation of ecosystem assets in a given period due to economic activities (Vanoli, 2017, p.244). It corresponds to the concept of "imputed maintenance cost" in the SEEA 1993.

Our general proposal in this framework is to not consider nature as an asset in production processes but as an institutional sector, like the firm sector and the household sector, which takes part in this process by providing its productive force. Consequently, the economic system that uses nature's force of production incurs a debt to nature, at the least if this is done to the detriment of nature's capacity for renewal. We call it the "Ecological Debt", which is the debt of the Economy towards Nature. To specify this debt, it is necessary to use some ecological standards and targets to achieve or to maintain. These standards can be based on legal norms or on scientific recommendations. The legal norms provide the decisive advantage of resulting from a political process which gives them a strong legitimacy. It is possible to mention the good ecological status (GES) of the marine and terrestrial waters in the Marine Strategic Framework Directive (MSFD) and the Water Framework Directive (WFD), the no net loss of biodiversity in the Environmental Impact Assessment or the Good Conservation Status of the endangered species.

All these "ecological goals" are explicitly mentioned in European directives. The gap between the current states and the environmental targets mentioned in these directives can be defined in economic terms from the concept of unpaid ecological costs. These unpaid ecological costs can be assessed through the following steps. The first step is to link the observed costs, recorded in different

official documents such as the Economic and Social Analysis of the MSFD or the WFD. Then it is necessary to estimate the financing needs (required costs) to reach the GES. Finally, the difference between the financing needs and the observed costs corresponds to the unpaid ecological costs of the descriptor studied. This method is suitable because it requires minimal economic modelling: it is indeed based on observable market prices. It is therefore the closest to the SNA standards.

Thus, starting from observed costs implies that there is no need to use fictitious markets that internalize the ecological costs of activities. The financing needs to reach the GES is calculated with a dose-response model. The application of a dose-response model allows to estimate the change of the environmental state associated to the stimuli to the investments made in environmental protection/restoration measures. It enables us to calculate how much it will cost to reach the GES. This requires to have data and models of interactions which allows to assess the ecological responses to pressure changes.

Next, it is possible to write the payment of the debt to nature in the production accounts if the Nature is compared to a producer (providing ecosystem services which can be written as intermediary consumption for the economic sector). But it is also possible to write the payment of the debt to nature in the exploitation accounts if the Nature is compared to a worker (providing labour force which can be written as wages for the economic sector). If there is no payment, then the debt must be written in the financial accounts.

It is possible to give an illustration of the unpaid ecological cost with the new French law named "climate and resilience" which has been adopted in 2021. It is mentioned in the article 191 of this new law that a no net loss of Natural-Agricultural-Forested (NAF) lands must be reach by 2050 and that the level of NAF land destruction must be divided by two in comparison with the 2010-2020 period. There are two ways to apply this new law. Stopping urbanization or restoring previous urbanized areas to offset the conversion of NAF in built areas. The cost of ecological restoration of an urbanized area is estimated between 90 and 390 € for one square meter. In 2019, 235 km^2 of NAF lands have been converted in urbanized lands. Restoring 235 km^2 would cost between 23 and 90 billions $ (CGEDD, 2019). If we use the same types of methods for the following ten years, which should lead to the decrease of 50% of the rate of urbanization, it means that we estimate that the cost would be between 154 and 632 billions $ for the economic sector (Gonon, Surun et Levrel, 2021). 154 billions $ is approximately the total return revenue of the building industry in France… These amounts are not some costs coming from fictive market but from the application of the law. They can be reduced if this industry invests in new techniques and processes for avoiding the impacts of new buildings or if the State decides to socialize these costs (in this case the institutional sector where these costs will be written in the administrative one).

Table 1: *Simulation of the maintenance cost for the building industry resulting from the application of the new French Climate and Resilience Law*

Accounts	**Institutional sectors**	
Production accounts	*Building industry*	*Nature*
Production value	128	No net loss of NAF Habitats
Intermediary consumption	11	
Maintenance cost of NAF habitats	**91**	
Total intermediary consumption	102	
Added value	26	

3.2 The Comprehensive Accounting in Respect of Ecology (CARE): integrating « natural capitals » at the heart of business financial accounting

The CARE model (Rambaud & Chenet, 2021; Rambaud & Feger, 2020) is established at the level of business accounting (e.g. balance-sheet, income statement, management accounting, dashboards and control systems, etc.). It is developed, theorized (Rambaud & Richard, 2015) and tested since 2013. It is the subject of several recommendations in France and internationally (Bhattacharya et al., 2021; Notat & Senard, 2018) and experimented in the context of large companies as well as Small and Medium Enterprises.

The theory on which this model is based comes from several scientific analyses (of financial accounting; of accounting economic models; of accounting models combining financial and non-financial issues on the basis of ecological sciences and bioeconomic models), from which three observations follow:

- The notion of "capital" is, historically and in "classical" business accounting (historical cost accounting), a *debt* and not a set of assets. This is in opposition to the vision of capital in economics and in so-called (fair) "value" accounting (Nobes, 2015; Richard and Rambaud, 2022). Classical financial accounting is thus conceptually based on the monitoring of financial advances provided to the organization (by shareholders/owners, banks, suppliers, etc.), through their uses and consumptions in the organization's operating cycle. It is based and on the guarantee that these advances will be refunded in the long term: these constitute the organization's financial capital, which therefore represents all of the organization's debts.
- (Fair) "value" accounting favors shareholders/owners at the expense of other stakeholders (Rashad Abdel-Khalik, 2011; Richard, 2015);
- Business accounting models based on a neoclassical approach, i.e. on the "value" created by nature and humans (including ecosystem services, benefits rendered by nature and humans, internalization of externalities, sustainability as value creation, intangible capital, etc.), are incompatible with science-based and collectively accepted ecological conservation issues, and thus with an ecological strong sustainability approach (Clark, 2010; Pearce, 1976; Rambaud & Chenet, 2021).

CARE as a conceptual accounting framework - As a result of these findings, CARE is first and foremost a conceptual accounting framework, rejecting (fair) "value" approaches and scientifically exploring the convergence between "classical" (historical cost) accounting and ecological conservation issues: CARE is thus not a simple measurement system or a management tool, but a complete accounting system, ensuring a global (re)framing of the activity of organisations. It is a language adapted to a reconceptualization of organizations on a basis of an ecological and integrated thinking .

CARE extends the definition of financial capital as advance/debt to non-financial issues. In CARE's sense, a "capital" is an "entity" (material or non-material, human or natural) – as a forest, a river, biodiversity, a human being, *etc.* - , employed and consumed (by the organization) in its business model, whose existence is independent of the organization's activity (including its utility/productivity), and recognized as having to to be preserved. A capital is therefore a "capital (that is "paramount") entity", a matter of concerns. CARE is then based on a systematic extension of the monitoring of the uses and consumptions, in the organization's activity, of these capitals as well

as the guarantee of their "reimbursement" (preservation) in the long term, implying the implementation of adapted biophysical accounting systems, management dashboards, etc.

CARE is in line with strong ecological sustainability: each natural "capital" entity (e.g., a river impacted by the company, a soil used by the company, etc.) must be preserved in its integrity, *one by one*. CARE leads to the restructuring of the business model: in order to exploit the capital entities and thus create value, CARE leads to questioning from the outset how to preserve the capitals used for this value creation (thus, beside the business "operating function" a "preservation function" is highlighted).

CARE as an operational accounting methodology **-** Operationally, CARE is also a practical methodology, logically deduced from this conceptual framework, divided into 8 phases. This methodology evolves over time to be refined while remaining framed by the conceptual framework.

Methodologically, CARE restructures the dashboards, indicators, business model, understanding of value creation, turnover and value chain, balance sheet/ income statement and organizational performance assessment. It does so by articulating biophysical accounts and monetary accounts, finally integrated within the balance sheet and the income statement of the organization. Natural capitals used by the company during its production/operating cycle are captured through the definition of good ecological states on a scientific and collectively accepted basis. The CARE model then incorporates the costs of conserving (preventing or restoring) these natural capitals over time into the company's balance sheet and income statement (Figure 2).

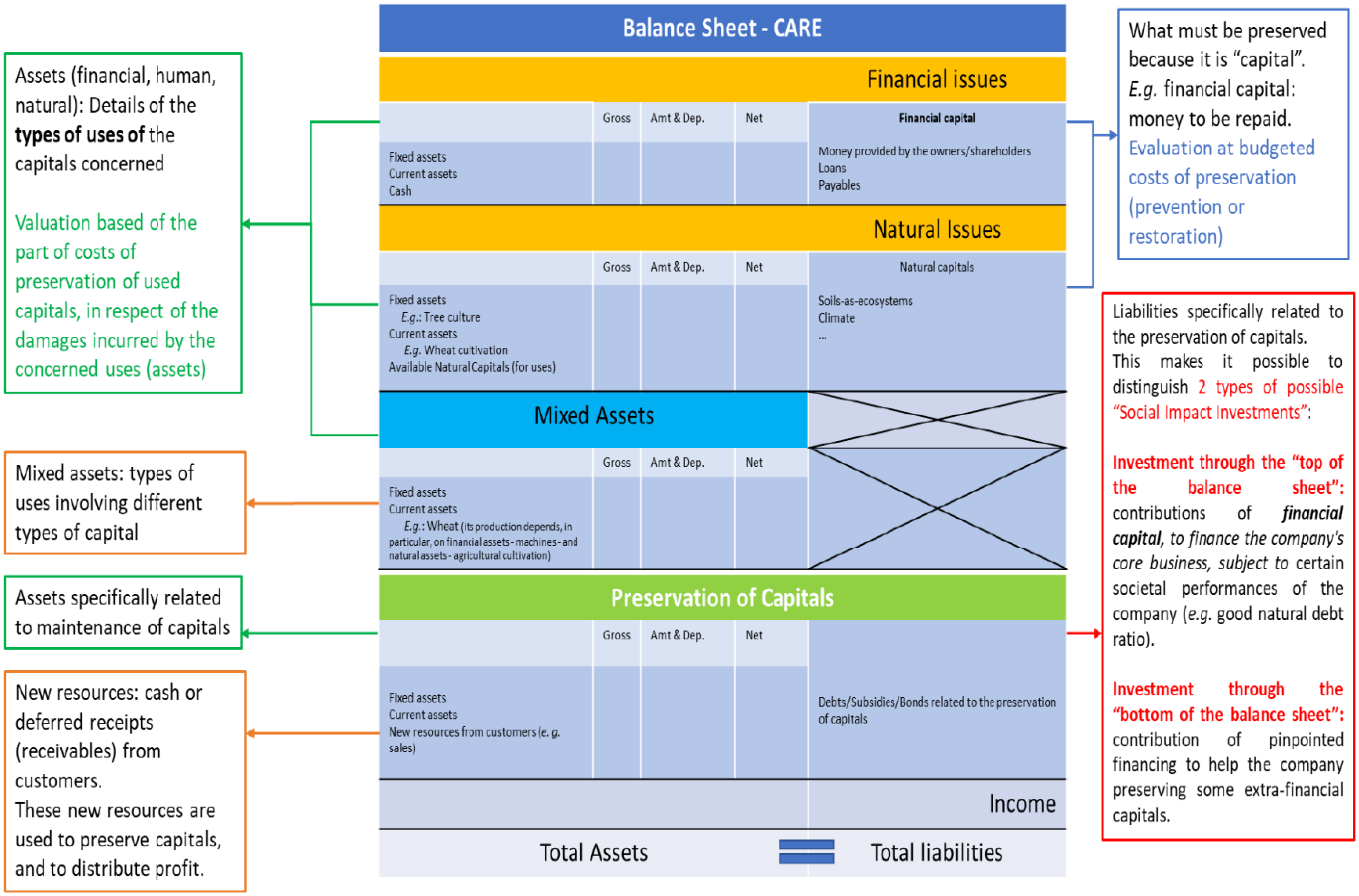

Figure 2: *A company's balance-sheet with the CARE model (source: Rambaud and Feger, 2020).*

3.3 The Ecosystem-Centric Management Accounting model: an accounting method for the strategic and collective management of ecosystems

The Ecosystem-centric management accounting model has been developed specifically to support the strategic management of a given ecosystem or biodiversity issue, and collective dialogue and negotiations between stakeholders that have joint interdependencies with this ecosystem (Feger et al., 2017; Feger & Mermet, 2018, 2021). The development of this approach responds to calls to put accounting at the service of conservation work and of the design and use of innovative information systems in the realm of ecosystem management (*Ibid;* Cuckston, 2018, 2021). This needs to happen via exceptionally diverse ecological, human activity and power relation situations, e.g. Nature-Based Solutions initiatives (Vigerstol et al., 2021); the collective restoration of a wetland complex in a given agricultural context ; the negotiation of the boundaries of an ecological corridor for fauna migration, etc.

The Ecosystem-centric management accounting model aims at monitoring the ecological condition of a particular ecosystem as well as the various pressures deriving from diverse stakeholder operations. Central in this framework is scrutiny of the various steps taken by different stakeholders to reduce impact or to contribute to restoration. Monitoring also comes in the form of evaluation of collective ecosystem-level environmental performance data and agreement from each stakeholder to offset labor and costs (Feger and Mermet 2018).

The main aspects of this ecosystem-centric accounting framework are summed up here (Figure 3)**:**

(a) Accounting for ecological results and progress in ecosystem conservation/restoration (biophysical): There is first a need to establish structured accounts of ecological results and performances obtained at the ecosystem level (in biophysical and ecological terms, based on environmental sciences) to serve as a collective reference to organizations involved in its management. These accounts are shared collectively by the organizations that interact with the ecosystems and can be made public. They are defined both by environmental regulations and standards when they exist, and by the actors themselves when agreement is reached on given collective ecological targets. They can build on existing science-based indicators or ecological information systems and indicators already in place and already used by concerned stakeholders. They serve as a common reference for assessing collective progress in ecosystem conservation/restoration.

(b) Accounting for ecological impacts and contributions (biophysical and monetary): structured accounts need to be established to assess how specific activities and operations from different public and private actors are impacting negatively the overall ecological quality of the ecosystem at hand (*e.g*. a given ecosystem functioning; a given species habitat, etc.). In addition, accounts need also be established to track and measure how the actions undertaken by the different organizations add up and combine to contribute to the sound management of the ecosystem and to the achievement of ecological results (Feger & Mermet, 2018). Three main types of contributions are distinguished in three different "contribution accounts": concrete conservation, impact reduction and restoration actions; financial contributions; governance and data/information contributions. The different actors interacting with the ecosystem share these contribution accounts. They use these accounts to define and discuss the respective and relative responsibilities of the different organizations concerned by the same ecosystem or biodiversity issue; and negotiate the relevant level of efforts and costs to be borne by each of them that would optimize the provision of relevant contributions and the realization of the agreed-on ecological targets.

(c) **Accounting for each stakeholder's relative contributions, costs and benefits:** a third layer of accounts is then established in order for each (public or private) organization involved in the collective ecosystem management initiative to assess whether or not its own individual efforts and costs are effective in terms of contributing to the ecological results and to what degree. For public institutions who invest in biodiversity restoration, it is useful to determine whether the public money spent has effectively led to progress towards the expected ecological targets. For individual private actors and companies, it will allow them to assess whether and how their actions *really* contribute to obtaining ecological results, and to evaluate the costs necessary for providing these efforts and other benefits and compensations negotiated with the others. It helps them assess whether the costs they have budgeted for natural capital maintenance activities are used effectively in regards to other stakeholders and to the overall ecological results collectively obtained. When reconnected to the CARE accounts, it ultimately allows to measure whether their individual ecological debt (incurred when using ecosystem for their industrial and producing activities) is being effectively repaid (Rambaud and Feger, 2020).

The Ecosystem-centred management accounting approach recognizes the great diversity of ecosystem governance and management contexts and does not promote ready-made solutions. Defining how the accounts can be used for negotiation and long-term management between actors requires in-depth analysis of the realities of the collective action dynamics, strategic interactions, and institutional structures at play in each given ecosystem. The main accounts (ecological results, pressures, contributions) however have the same general structure, which then allows for comparability despite this heterogeneity of situations. This accounting model can thus serve as a conceptual and practical basis for a structuration and pre-standardisation of ecological accounts at the ecosystem scale, across this diversity of contexts, that can be supported by law and regulations. It is also key in the development of "business models for ecosystem management services" by environmental sector firms that develop natural capital regeneration activities and nature-positive services (Feger & Mermet, 2020).

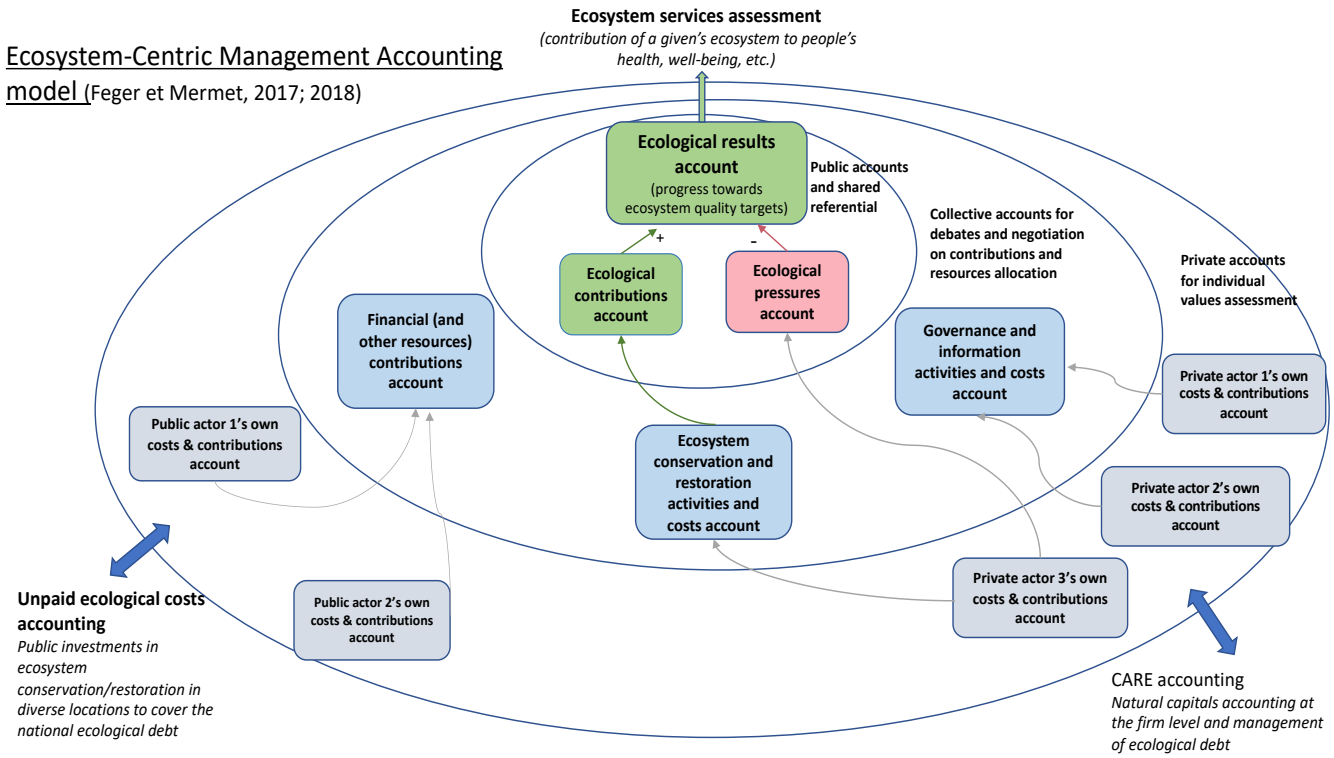

Figure 3: *Schematic representation of the three levels of accounts of the ecosystem-centric management accounting model, designed to be used by several (public and private) actors in strategic interactions*

3) Towards a multi-level approach in strong sustainability accounting for nature

Reducing the impacts of the financial system on biodiversity, and in turn, the risks of biodiversity loss on the financial system stability requires to be able to invest into *concrete actions* that do actually maintain or restore biodiversity and natural ecosystems integrity. In other words, beyond awareness raising, the challenge is ultimately to be able to redirect and track how public or private money effectively translates into tangible and measurable ecological results in a great variety of socio-environmental contexts.

We have argued in this paper that this calls for the development of ecological accounting methods and tools at three complementary levels: States and public institutions; businesses/private organizations; collective ecosystem management initiatives. We have put forward three methods that are currently the object of both conceptual and field research, and that have in common a shared conceptual underpinning, i.e (1) the adoption of a strong sustainability approach where ecological entities/natural capital have intrinsic value and are to be preserved at levels defined by the best available scientific knowledge and on the basis of collectively negotiated and agreed on environmental legal frameworks and targets ; (2) a focus on maintenance and conservation costs needed to achieve these ecological targets rather than on the economic valuation of ecosystem services.

To conclude, we point out why we believe it is now essential to progress in the interlinking of the Unpaid Ecological Costs, the CARE model and the Ecosystem-centric management accounting approaches proposed in this paper (Figure 4). This interlinking work is central to the research agenda currently undertaken by the "Ecological Accounting" Chair.

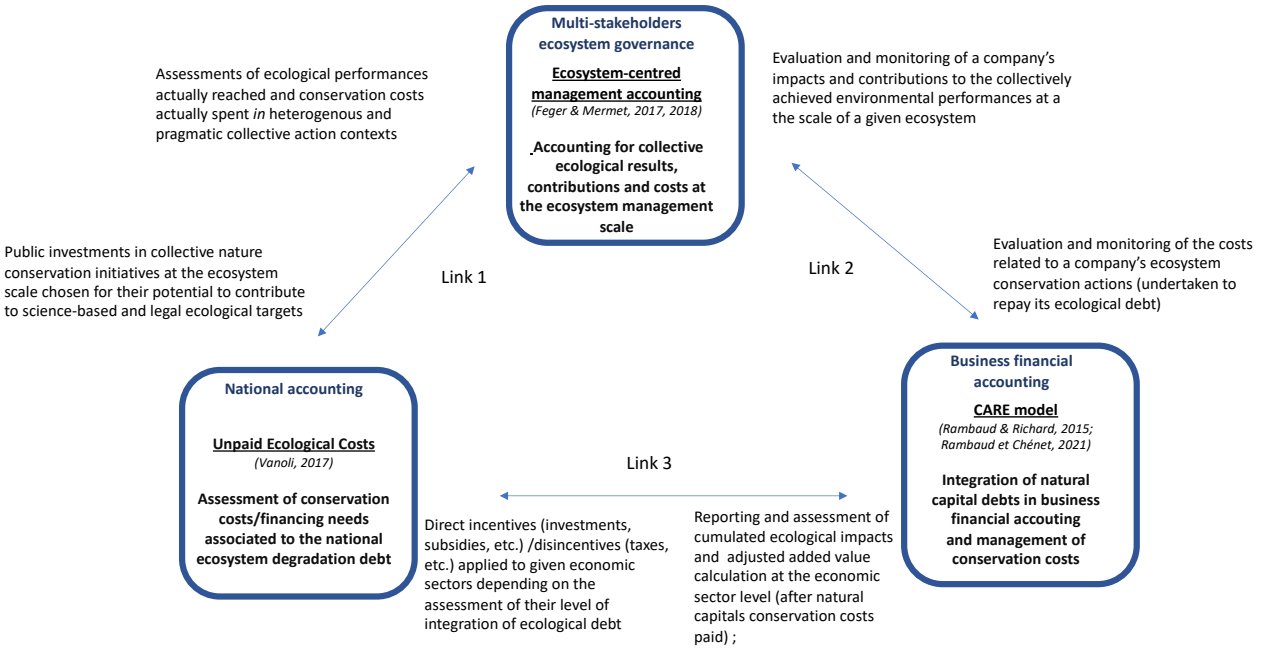

Figure 4 : *Stakes and research perspectives for the interlinkage of national, business and ecosystem accounting levels (Source : adapted from Feger and Mermet, 2021, Figure 3)*

Accounting for ecological results obtained through public investments in multiple nature conservation initiatives (Figure 4, link 1) – Unpaid ecological costs are based on normative standards of strong sustainability which are mentioned in legal texts (coming from citizen preferences and not consumer preferences). They hence reflect a kind of collective willingness to pay for restoring the good ecological states of waters, soils and biodiversity. Next, public policies must define how to allocate these potential payments (which represent an ecological debt since they are not actually based on expenditures). Part of these payments can be allocated to various economic sectors to support their ecological transition and impact reduction efforts (cf below description of *Link 3*). Another part of these payments can be allocated to local stakeholders who are responsible for and have the actual agency and power to act strategically at the ecosystem scale (a given river, a given lake, a given species habitat) in order to implement concrete conservation/restoration. For instance, investments can be made into Nature-Based Solutions (Vigerstol et al., 2021), that then needs to be used for different concrete management activities for the protection/restoration of the natural areas targeted, and undertaken by a diversity of stakeholders who need to coordinate. Unpaid ecological costs accounting thus need to be interlinked to Ecosystem-centric management accounting approaches that can be applied in context-specific collective ecosystem governance settings, where quantitative biophysical results about the improvement of a given ecosystem's condition can be assessed as well as the multiple contributions brought to it by different stakeholders and the costs of these contributions. The evaluation of the ecological results obtained (e.g., how much have the biodiversity habitat and water filtration services of such wetland increased in the past year?) for a given amount of public money invested in ecosystem maintenance/preservation thus becomes ultimately possible.

Acknowledging and managing the collective essence of most natural capitals used by companies (figure 4, link 2) – The CARE model is established primarily at the company level and proposes deep transformations of firms' financial accounting systems to integrate the costs of conserving natural capitals. As we have seen, in CARE, a work of definition and description of natural capital entities with which the firm interacts has to be done at the level of the firm. However, this cannot suffice, since in most cases, the ecological quality of these natural capitals (biodiversity in a given area, a given river, a given soil, etc.) that the firm impacts also depends on the interactions that other public or private organizations have with these natural entities and how they impact them. In other words, a company's impacts on a given natural entity and the conservation/restoration actions it puts in place using the CARE model are only one part of the wider ecosystem protection issue, that is also conditioned by other actors' decisions and actions in the perimeter of this given ecosystem. Hence, the level of ecological impact due to the firm's operations as well as the ecological performances of the conservation/restoration actions that the firm puts in place to repay its uses of natural capitals are relative, and cannot be assessed independently from the assessment of other actors' interactions with the ecosystem concerned. Hence, the company also has to get involved in a work of collective dialogue and negotiation that needs to be conducted at the ecosystem management scale regarding the very definition of this natural entity; the ecological quality targets and thresholds that need to be maintained or reached collectively; and the individual actions that are relevant to be implemented by the firms and other actors. The CARE model thus requires to be intimately linked to the Ecosystem-centric management accounting method, established at the level of the strategic and collective management of a given ecosystem.

Building biodiversity accountability and supporting the ecological transition of productive economic sectors (figure 4, link 3) – The implementation of the CARE model at the company level helps to measure and report how, with what effectiveness, and at what cost a given business actually conserves or restores the natural capitals it uses in the process of creating its own economic value. It

can then prove useful for public institutions (and more widely, civil society) in their efforts to assess whether or not companies respect their biodiversity-commitments and in gradually building public accountability frameworks on this issue. If applied widely (in association with Ecosystem-centric management accounting), this also makes it possible to calculate cumulated impacts of companies from a same economic sector on biodiversity and ecosystem integrity. More profoundly, CARE provides an integrated definition of the firm's financial results and therefore of financial profit also, the calculation of which could be carried out only once expenses for the uses of natural capitals (i.e., conservation costs) are effectively taken into consideration. Adjusted added values (i.e., after natural capitals conservation costs are paid) could then be calculated at the level of whole economic sectors (agricultural sector, fishery sector, cosmetic sector, etc.). Such information can then be instrumental for public institutions to identify sectors that need support from the State in their transitioning towards (strong) sustainable activities. It is also key in defining the levels of incentives (public investments, subsidies, etc.) or disincentive (taxes, etc.) that can then be applied to different sectors depending on their level of integration of their ecological debts. The amounts of public budgets necessary to invest in the ecological transformation of diverse industrial sectors can be assessed based on the Unpaid Ecological Costs approach.

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