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Nature and the Wealth of Nations

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Quality of growth and ecological transition

What exactly are we talking about?

Measurement attempts

Integration into economic choices

Department for the Economics, Assessment and Integration of Sustainable Development

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Editorial by the General Commissioner for Sustainable Development

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Today, no-one doubts that damage to nature poses a threat to the future prosperity of our economies. However, sufficient account of natural capital is not taken in economic choices, due to the lack of a consensus regarding a methodology for its measurement. Consequently, whole segments of this rich asset are not taken into consideration and are likely to be irreversibly wasted.

Several initiatives have, however, been launched in France on this topic. As far back as 2009, a report drafted by the Commission on the measurement of economic performance and social progress (Stiglitz, Sen and Fitoussi) proposed possible courses of action. Since then, initiatives have been taken by the MEDDE's statistical services and work has been carried out by commissions supervised by France-Stratégie on the reference values and the value of ecosystem services. The new wealth indicators, published by France Stratégie in October 2015, are intended to supplement GDP in order to give a more comprehensive vision of well-being. The carbon footprint and land take are examples of these indicators.

This edition of the CGDD (General commission for sustainable development) Review thus aims at presenting the current state of knowledge concerning "natural capital". While it is widely acknowledged that GDP is an imperfect indicator and that green capital is a vital component of growth, the improvement of national accounting and the creation of an indicator that can rival GDP remain open research questions. Attempts at measurement – on both accounting and biophysical levels – have been made but there is currently no "doctrine" or "shared vision" of nature's contribution to the "wealth of nations".

The urgency of the situation argues in favour of a rapid stabilisation of the measurement conventions – even if they remain imperfect – so that environmental policy instruments can be calibrated on the basis of the missing values of natural capital. However, such a need must overcome our lack of knowledge, which must be developed before we can improve our measurements of nature. It may also be confronted with a certain reluctance to ascribe a monetary value to nature, with the risk of making nature a type of capital like any other and corrupting its intrinsic value.

Through its assessments of environmental policies, the CGDD has, on many occasions, raised the question of the risks inherent to the monetisation of nature. To understand the wide range of standpoints concerning the value of nature and in response to these warnings, the CGDD has been running a series of monetisation seminars since 2010 in order to improve the awareness of the complexity and nature of this exercise. Monetisation cannot, under any circumstances, be said to reveal any intrinsic value of nature. On a more modest level, it reflects the social preferences that exist in favour of the conservation of nature.

It is essential to settle the misunderstandings between disciplines and clarify the technical disputes over environmental accounting. Such thinking should allow the research findings to be converted into a core of robust arguments that can be used to prompt public and private decision-makers to take better account of the good management of natural environments in their decision-making. The key issue is to develop economic and other types of tools that are capable of triggering investments in energy transition.

This edition of the CGDD Review is of a resolutely multidisciplinary nature. It thus allows the issue to be considered from different standpoints, in the following order:

– it firstly covers the conceptual framework, which is simultaneously philosophical, economic and biological, of the debates concerning the polysemic term of "natural capital";

– it then reports on the status of the proposals and the methodological controversies concerning the measurement of natural capital;

– it finally examines the economic, accounting and financial instruments that must be developed in order to transfer the value of natural assets into real economic choices.

The aim is to incorporate the research findings into a guide that is both conceptual and operational, based-on high-level expertise. I hope this publication will constitute a core of arguments that can support the positions adopted at both national and international levels and develop public policies for green growth.

Introduction: Quality of growth and ecological transition

Michel Aglietta,
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The quality of growth has become the key issue of this century. Taking the urgent need for inclusive and sustainable growth seriously requires a profound change in the ways of thinking that guide economic policies. The ensuing new social contract must define social well-being according to a principle of justice as equity and encompass the preservation of the ecological foundations of human activity.

Such an aim leads us to re-examine the principle of value far beyond the utilitarian and individualistic foundations of the term that apply to market exchanges. The principles of market organisation do not apply to public goods and shared assets, but they still have a social value.

These social evaluations must not be confused with market prices. They are the results of political processes, i.e. reasoned public debates among stakeholders bringing together collective competences. This conception leads to a significant broadening of our perception of the capital that constitutes the wealth of nations (particularly to include the climate and biodiversity).

This article argues for the replacement of GDP-based national accounting with a generalised accounting method based on social well-being. This is only possible if economic theory and the analytical tools that it develops are reintegrated into all of the social sciences.

But isn't it an indulgence to be discussing the quality of growth and, above all, threats to the climate, right now when Europe is suffering from profound economic stagnation? This is, of course, the immediate concern of the people in charge of the budget, having vowed to reduce budget expenditure under duress from Brussels. This is also the equally pressing argument used by the powerful energy and transport lobby, whose current state of mind is clearly shown by the Volkswagen scandal, involving the industrial giant of a country that prides itself on being a paragon of ecological virtue. First of all, let's increase the amount of growth. Then we can worry about improving its quality. But the repeated failure of the policies that claim to be inspired by this priority is causing more and more people to have doubts.

If transforming the growth regime can provide a way out of economic stagnation, what should be done? Taking the urgent need for inclusive and sustainable growth seriously requires a profound change in the ways of thinking that guide economic policies, and consequently in the underlying frameworks of analysis and measurement and in the instruments used to implement them. We must also avoid the illusion of the radical about-turn proposed by certain ecologists: the repayment of the "ecological debt" to nature would become an absolute imperative instead of the growth of GDP.

Let's consider what has happened since 2010. The recession, followed by the decline in growth, have slowed down the rise in CO_2 emissions and even reduced them in 2011. The benefit derived by society depends on the value that it ascribes to the reduction of an additional ton of CO_2. At the same time, and for the same reason, unemployment has increased and productive investment has plummeted. This has incurred a significant social cost. A sustainable growth-oriented policy requires an accounting and analysis framework that is capable of comparing the social benefits and costs within a single measurement reference framework. GDP-based national accounting must therefore be replaced by a generalised accounting method based on social well-being. This is only possible if the economic theory and the analytical tools that it develops are reintegrated into all of the social sciences.

Well-being and the wealth of nations: the need for an integrated analytical framework

The United Nations are the focal point for the successful creation of a consistent, universal agenda that can be applied by all countries, as this organisation hosts both the panel for the drafting of the new Millennium Development Goals which have been adopted in 2015 and the Framework Convention on Climate Change from which the Conference of the Parties originates, which will was held in Paris at the end of 2015.

To succeed in making sustainable development the primary objective of public policies, it must also be the long-term criterion that acts as a driving force for private investment policies, and can thus be incorporated into the benchmark of profitability. This cannot occur without profound changes in corporate governance and in the manner in which private accounting defines and measures capital. The advances that we shall be describing in the national accounting system must be supported by private accounting so that economic policy instruments can act as incentives for the private sector, ensuring the compatibility of societal objectives and corporate profitability.

The theoretical approach to sustainability implies the adoption of a principle of social justice

Sustainable growth is a new form of growth, incorporating ecological constraints and pursuing the goal of social equity. Intergenerational social well-being constitutes the theoretical framework. Any development trajectory on which intergenerational well-being does not decline is sustainable. The economic theory of growth does not form part of this framework for fundamental reasons.

First of all, social well-being is not an aggregate of individual preferences. Indeed, Arrow's impossibility theorem demonstrates that for any procedure of social choice in a democratic society, it is impossible to aggregate heterogeneous individual choices conclusively in a function of social well-being. It follows that any claim to eradicate poverty and reduce inequalities must originate from a criterion of social justice that cannot be provided by the utilitarian principles of "orthodox" economic theory. Indeed, equality must be defined in such a way as to facilitate interpersonal comparisons, not only by calculating empirical indices, but also with regard to the principles that legitimise public choices. Representative democracy is no more helpful because the majority rule, which is a non-substantive procedural rule, is incapable of establishing a fair form of social sharing. It underestimates shared assets, such as nature, and tramples the interests of politically under-represented minorities, just as the market excludes people without access to money.

Only an ethical principle can break the deadlock in which liberal democratic societies are currently languishing. Threatened by the dramatic deterioration in shared assets at the social level, in which democracy remains excluded from the corporate sector, and at the environmental level from the local to planetary scale, the human communities of the 21st century may or may not be ethical. We must therefore move towards political philosophy. In this field, the Rawlsian principle of social justice is of paramount importance.

By defining justice as equity, Rawls proposes a principled solution to the problem of the social contract set out by Rousseau. By placing equity at the heart of justice, Rawls brushes aside Bentham's utilitarian theorem. Human beings have moral faculties that define the meaning of the shared asset. It follows that reason is a human aptitude of a higher order than rationality, because reason means the freedom to exercise public reasoning in social evaluation. This liberty is not solely formal. It can only be exercised through access to primary goods of which no-one should be deprived if compliance with the principle of justice as equity is ensured.

Primary goods define the actual liberties against which inequalities must be measured. These are the material, educational and institutional resources underlying individual opportunities. They form a much broader set of resources than income alone. To these must be added the quality of public health, primary education, basic freedoms, and the absence of impediments (particularly financial and due to connivance) to the powers and prerogatives associated with social functions and environmental assets. It follows that inequalities are only fair if they improve the situation of the most underprivileged people with regard to access to primary goods.

These principles do not allow us to create a well-ordered classification of public policies from the standpoint of equity, and thus do not allow for the definition of a social optimum in terms of well-being, which is intrinsically out of reach. However, they do define the terms of a comparative process, on the basis of which it is possible to declare certain social situations unjust and to come to agreements of shared justice on which the inclusive nature of development depends.

From the principle of justice as equity to the model of inclusive and sustainable wealth

From the above, it follows that intergenerational social well-being surpasses private consumption, even when adjusted for inequalities of income, in order to incorporate the public services participating in primary goods and which are intensive consumers of intangible capital, and the environmental services originating from natural capital.

The criterion of sustainability makes use of the theorem of equivalence, which allows the constituents of well-being to be replaced by its determinants, i.e. the components of the total social capital of nations. This vector of types of capital forms the productive basis of the nation. These are the components of capital which are subject to a generalised accounting of the wealth of nations. It is the evolution of the social capital thus defined that allows for the assessment of whether or not a nation is engaged on a sustainable trajectory and provides

information about the policies to be conducted, i.e. whether it is preferable to invest in such and such a component of the total capital.

This approach has the benefit of being inclusive and progressive. On the basis of the principles, methods and advanced estimates provided by the United Nations in the different reports on inclusive wealth, it is incumbent upon the nations to use them to make changes to their national accounting system, starting with the creation of satellite accounts for categories of capital which are not considered as such by the standard accounting system.

Economic policy and reform of national accounting

The national accounting system is an economic policy instrument. The system that we have inherited (the GDP accounting system) is completely at the service of the management of demand in the economic cycle that is supposedly independent of long-term growth. With the theoretical apparatus of the production function based on an extraordinarily restricted definition of capital and on the premise of independence between supply and demand in the long term, the question of growth is not subject to any macroeconomic policy. Why have the gains in productivity been constantly reduced in Europe in national accounting measures since the start of the 21st century? Why did Solow, at the start of the 1990s, comment that increases in productivity could be observed everywhere except in the national accounts of the United States? These questions remain unanswered in the framework of the theories of growth that are currently in force.

The transformation of the growth regime, which the aim of the criterion of sustainability, requires more than incentives given to private stakeholders. It needs to be guided by a long-term policy. The instruments of this policy must be based on a broader national accounting system and on a wealth accounting system.

Sustainable growth is intergenerational. Societal wealth (material, cultural and cognitive) is bequeathed by previous generations, maintained and accumulated by the active generation and passed on to future generations. The counterpart to this wealth is the debt (which is inalienable as it is impossible to pay back to the generation that bequeathed the wealth) of the living members vis-à-vis society in general in the form of a collective that is perpetuated over time. However, this collective capital includes public goods whose accumulation cannot be delegated through incentives. It is under the direct responsibility of the State as the tutelary power of society. Primary goods, to which access is characteristic of a principle of justice, are largely dependent on public policies and require sufficient investments, both material and human. These are investments in education: covering pre-school infancy, pre-primary and primary education developed and organised in such a way as to compensate for the inherited discriminations, a range of post-secondary training courses to ensure that no young adults are abandoned without social ties, and the organisation of life-long learning. The eradication of gender discrimination, which wastes vast amounts of human capital in broken and devalued women's careers, requires much more than the statement of legal principles. Social equality for access to health services, although unrivalled in its excellence, requires massive public investments.

A national accounting system for social wealth, which is extended and pragmatically improved in line with the deployment of a public policy of long-term growth, is essential to the choice of public investment priorities. This accounting system must be decentralised at the regional levels of public responsibility. It must be capable of stimulating the public's commitment to public affairs, provided that it is associated with an improvement in lifestyles. It is in this association that wealth accounting encounters the practice of public reasoning.

The question of prices and the practice of public reasoning

In the criticisms of the inclusive wealth approach, there is some confusion between prices in general and market prices. A price is a shared value resulting from a social contract whose scope depends on the size of the group of participants that are directly or indirectly involved in the agreement. If this agreement falls outside the market organisation because it concerns public goods, shared assets or inter-relationships which are market externalities, it still has a social value. Indeed, resources have been consumed, goods have been produced (in this way, a quantity of greenhouse gas eliminated is a commodity produced) and services have been provided (cleaning up a river or recycling waste are services provided).

The theoretical prices of these assets are their marginal contributions to intertemporal well-being. Stating that these prices cannot be known does not invalidate the estimates proposed through the gathering of information, reasoned debates and agreements, any more than the differences in market prices due to the unknown prices of perfect competition can be said to invalidate the existence of markets.

These social evaluations are the results of political processes in the broadest possible sense, i.e. of reasoned public debates among stakeholders bringing together collective competences. Their creation is a furtherance of democracy according to the principle of justice as equity. The estimation of these prices requires a common conception of well-being, an understanding of the social and natural processes leading to the estimates and

quantified information about these processes that allows for the creation of hypotheses about the degrees of substitutability among types of capital.

Such a development of evaluation practices, which is essential to organising the decentralised productive basis for sustainable growth, has a major impact on corporate governance. Firstly, the holders of skills whose productivity is achieved through complementarities and cooperation are stakeholders in the value produced. Therefore, they are partners in the strategies that must be developed concerning the corporate sector's contribution to social well-being. Furthermore, the economic boundaries of the corporate sector no longer coincide with the legal codification of the private company in the presence of externalities. Groups of companies forming industrial systems are stakeholders in collective decision-making entities concerning the production of shared assets.

Shared valuations must overcome two additional distortions due to situations that the market is unable to correct. In the first place, the market has a tendency to under-produce goods and services that provide positive externalities because the social return is greater than the private return. Secondly, the market overproduces goods and services that jointly generate negative externalities because the private cost is lower than the social cost. A collective agreement on the social value is a preliminary condition for the provision and calibration of economic policy instruments designed to close the gap and thus encourage companies to act in the interests of sustainable growth. This organisation of interdependencies that exceed and supplement commercial relationships is particularly relevant to the interrelationships between the economy and the environment.

Taking account of natural capital: biodiversity and climate

Biodiversity and climate change are the two main environmental fields that resemble public goods and therefore cannot be substituted for forms of capital produced according to incentives provided by the market. However, they pose very different problems for sustainable development policies.

Indeed, climate change is a measurable and global phenomenon. There is great uncertainty concerning how it will evolve. Nevertheless, accumulated scientific research shows that the composition of the atmosphere may be linked to the increase in temperature and the ensuing damage can be analysed or otherwise accurately quantified. A precautionary principle may give rise to an agreement on an acceptable limit for the temperature rise. Policies may be defined on the basis of a value assigned to carbon, the investments committed to countering the rise in GHG emissions and the financial instruments deployed that form part of the known tools of economic policy.

Biodiversity is certainly also a public commodity from the standpoint of the services provided by ecosystems. But it defies analysis due to its heterogeneity and dependence on specific contexts. Rather than being a single public commodity, it consists of groups of public goods that partially overlap and may be conflicting. Moreover, some of them are renewable while others are not. It can be said that biodiversity is a series of public goods that overlap from the local to global levels. In addition, biodiversity does not respond to the way in which standard economic models treat natural capital. It does not seem to respond to economic conceptualisation. But is it unsuited to any type of valuation? This is a key question for the definition of pertinent means of action.

Climate change: value of carbon, investments and financing

The successive failures of Conferences of the Parties on the climate have given rise to a conviction: policies that aim to limit the temperature rise can only be effective if they are integrated into investment strategies for sustainable growth. Their proper meaning only becomes apparent in the conceptual framework of the quality of growth. However, development policies are specific to countries or to integrated groups of countries, such as the European Union. It follows that carbon valuation in support of these investments is a political decision intended to provide incentives for corporate projects, as is mentioned in detail in this volume.

In the framework of a general agreement committing countries to long-term trajectories in which GHG emissions are brought down before being reduced in absolute terms, the countries can define five-year plans in which they announce guaranteed reductions of a certain amount in such a way as to direct investments towards a gradual dissociation of growth and energy-intensity. To this end, governments are defining a social value for carbon that applies to the calculation of the internal return on new, low carbon-oriented investments. However, this is not sufficient to trigger the desired investments. The gap between private returns and the social return must be closed in order to encourage companies to make investments that contribute to the positive externality that is the reduction of emissions. This is the role of a certification scheme for the reductions made by companies and of a financial mechanism that socialises the risk inherent to this certification. Companies could be given carbon certificates that are approved by financial bodies in order to realise the proportion of the value that they have created but which cannot be realised on a market until the carbon externality has been completely absorbed into a market price.

The investments to be made are heterogeneous and require appropriate financing: some of them are public while others are private, some are financed by banks and others by institutional savings. But all of them could apply for the risk socialisation scheme that combines certification by independent agencies with the acceptance of carbon certificates by the central bank in the form of carbon assets against the creation of money.

In principle, four types of investments cover much of the field of transition towards a low-carbon economy: increasing the share of renewables in the energy production capacity, creating smart electricity distribution grids, both for the connection of local electricity generation sources and for regulation interconnections among regions and countries, improving the energy efficiency of buildings by renovating public, commercial and residential buildings, and developing means of transport that can completely redefine urban mobility, thus transforming the use of space, which in turn determines the value flows in towns and cities.

Proposing a separate carbon valuation for new investments focusing on the reallocation of capital and for the pricing system that counterbalances the supply and demand for consumer goods is an operational way of overcoming the handicap of the carbon externality without running into crippling political obstacles. This proposal is a practical illustration of the approach that seeks to move the concern of sustainability forward by extending the scope of value.

The certification scheme and its monetary validation apply to four types of investments. But the financing methods are differentiated. The first two categories – new energy sources and distribution networks – lend themselves to financing with a high level of public involvement in the framework of the European funds managed by the EIB and relying on private savings through mandatory issues. This is the standard financing used in the Juncker plan. On the contrary, improvements to the energy efficiency of buildings and means of urban mobility are investments of a more diffuse nature situated in the regions.

The building sector must therefore offer good incentives to SMEs. The funding is credit-based. The loans may be subsidised by a public development bank, as in Germany. The granting of subsidies to home owners for the renovation of private housing and the provision of loan guarantees to local authorities for public housing renovations will probably be required.

Urban mobility requires investments in infrastructure. These investments and their financing are primarily public. Urban transport is much more homogenised than the building sector. It prioritises means of public transport and the sharing of a public mobility service via fleets of vehicles that are pooled to make drastic reductions in the use of private vehicles. These investments – bringing into play the effects of increasing returns associated with the amalgamation of resources – require types of financing that are well suited to the certification scheme.

Biodiversity: valuation and economic policy tools

There are significant difficulties associated with applying a sustainable development approach to biodiversity. The heterogeneity of ecosystems and the specific contexts in which they interact with human activity conflict with the unifying method of valuation that is applicable to climate change. Furthermore, the integrity of ecosystems gives rise to extremely rigid points of view that are sterile and hinder debate.

The main conceptual obstacle is the assertion of an intrinsic value of nature that is both absolute and irremediably alien to any measurement, which is encountered in certain attitudes to ecology. Such a value would be beyond human considerations. Could a semantic shift regarding the term "value" be making this an insoluble issue? Because value is a social contract. It has no meaning other than in relation to human activity. How could we conceive of a value that is beyond the considerations of society? What could be the source of this value? If this source were non-human, who then would have the legitimacy to declare and impose it as the principle of a policy regarding nature? Insurmountable philosophical questions are raised. An astonishing illustration of this is found in the recommendation to adopt a policy that re-establishes the "status of nature" that existed prior to its deterioration due to human activities!

If we are to break these deadlocks, we will need to place the question of diversity in the conceptual framework of the theory of intergenerational social well-being and seek valuations within the generalised measurement of wealth.

According to the logic of sustainability, it is the stocks of assets and their long-term evolution that are relevant. Ecosystems must therefore be accounted for as components of natural capital. They produce services that meet essential needs but are not perceived by people until they are in an advanced state of deterioration because they are invisible. That is why these services cannot be included in individual preference functions. This applies to the genetic library, the preservation of soil fertility, the recycling of nutrients, flood control by mangroves, drought moderation by forest cover, waste assimilation and the water cycle. Ecosystems may

have contradictory uses: cultivable land, forestry and urban development. We should remember the remark made by the former Brazilian president Lula, who stated that he was in favour of Amazonian rainforest conservation provided that its residents were not dying of hunger beneath the trees.

The hypothesis of the substitutability of natural capital and capital that is produced, which is supposed to increase when a sufficient level of development is attained, is known as the Kuznets curve. It assumes that there is a normal distribution curve between a pollution concentration index encompassing all forms of pollution and the per capita income of a country. This optimistic hypothesis has been disproved by the facts, as shown by the Stern report. It may only be valid for short-term damage due to local, degradable pollution. It does not apply to waste accumulated by irreversible phenomena or to dispersed pollution (in the atmosphere and oceans), the concentrations of which increase constantly as the income of populations rises.

The intensive use of ecosystems constantly depreciates the natural capital. Their deterioration triggers irreversible processes when they interact with human activities. In this way, rapid population growth in developing countries with fragile soils causes losses of biodiversity which reduce agricultural productivity. Consequently, poverty increases, which exerts an additional pressure on the maintenance of the subsistence level and leads to new losses of biodiversity. When these losses result from the destruction of rain forests, this means that carbon sinks are damaged and climate change is intensified.

Dilemmas thus exist between the protection of biodiversity and economic development, which can only be overcome by global policies. The debate must also be formulated in such a way as to reveal the costs and benefits in order to determine the cases in which public intervention is essential (e.g. to protect endangered species) and the cases in which it is preferable to offer incentives to private stakeholders. This leads to problems of valuation.

The aim of valuation has nothing to do with the discovery of a mythical intrinsic value of nature. Valuation is the result of political debates in which the key issue is to state how much society is prepared to spend on the conservation of the public goods that are particular ecosystems in relation to alternative uses of the revenues generated by economic activity. These debates must also be held because the market does not reveal any preferences, or has no preference at all, for assets that have no individualisable property rights. To determine the values that encapsulate the benefits that can be expected from ecosystems, the costs of their conservation and possibly of their regeneration – if this is possible – must also be calculated.

The alternative to valuation may be required in extreme cases of absolute scarcity such as the extinction of species. This would be a ban on activities that are harmful to biodiversity, imposed by a public authority and accompanied by monitoring carried out by an agency endowed with punitive powers. In this case, decisions are made on a go/no-go basis and very often fail to protect biodiversity. Furthermore, since there are no recognised or approved values, no compensation is paid if the rules are breached.

We thus encounter the problem of the non-substitutability of the components of social wealth. Is it relative or absolute? If it is relative, it must be reflected in the marginal social value of investment in this asset. This price increases at the same rate as substitutability decreases, which makes investing in this asset more socially profitable. It must therefore be considered a priority for public debate. If non-substitutability is absolute, it means that the marginal value of this natural asset increases infinitely, while the availability of the stock beyond the minimum at which it collapses is reduced to zero. In this configuration, economic calculations are pointless because their result is indeterminate. The regeneration of the stock is the result of a public policy involving standards, the prohibition of additional destruction and reinvestment with budgetary funding.

The incentives depend on compensation, i.e. payments for the use of ecosystem services and also environmental credits which allow for investments in the conservation of natural habitats. That is why sustainable development investment projects are those that interact with ecosystems in a reasoned manner. Under the authority of the most appropriate public institutions in relation to the scale of the externalities triggered by the projects, all of the economic and social stakeholders concerned must debate the issues with the support of the most advanced knowledge that independent experts can offer. The aim is to assess the social returns of the planned investments while taking account of the evaluation of the positive and negative externalities.

The economic policy tools are taxes on activities that cause losses of biodiversity and subsidies for those that consolidate ecosystem services. It is always possible to set the quantities of negative externalities that can be tolerated and develop allowance trading markets to set the prices. However, the difference in relation to climate change is clearly revealed. Because the areas of critical importance for biodiversity are localised, the evaluation must concern localised costs and benefits. This would cause the rights markets to be much too restricted to operate correctly, with the worst consequence being mechanisms for arbitration among ecosystems, which must definitely be prohibited. This makes a strong argument for direct public intervention on prices, informed by the social evaluation procedure. Environmental credits may be issued by financial institutions benefiting from public guarantees for financing investments in waste reprocessing for the promotion of the circular economy, converting farms into organic agriculture and renovating private housing.

Conclusion

The quality of growth has become the key issue of this century. The global policies needed for its implementation require a theoretical framework that defines social well-being on the basis of a principle of justice as equity in order to radically reform the social contract of democratic nations. This is because social well-being cannot be inferred from individual preferences. This social contract must encompass the preservation of the ecological foundations of human activity. Sustainable development can only be defined within this framework.

This aim prompts us to re-examine the principle of value far beyond the utilitarian and individualistic basis of the term that applies to market exchanges. Value is the means by which society recognises human activities by agreement within a reasoned public debate. This conception leads to a significant broadening of the representation that is made of the productive base that is available to nations and which they must renew, i.e. the definition of the capital that constitutes the wealth of nations. Therefore, there is a need to adopt principles for the measurement of capital that take account of this productive base in generalised accounting systems. This change has been initiated under the aegis of the United Nations.

However, the history of national accounting reminds us that it was created in response to political urgency. How do you pay for war? What resources are available to the nation? These questions posed by Keynes in 1940 caused intellectual and statistical resources to be dedicated to the creation of the first national accounting system based on GDP.

The political urgency of the global threats posed in this century is not sufficiently apparent to commit States to focus their statistical apparatus on accounting for the generalised intergenerational wealth on which sustainable development policies depend. There is no doubt that this urgency will become apparent. Let's just hope that by then it will not be too late.

Part I: What exactly are we talking about?

Before examining the methodological issues relating to the measurement of nature, the first part considers human-nature-society relationships, the many possible meanings of the very concept of "natural capital" and the economic interpretation of the role of nature in growth. Why do we need to measure natural capital? Does this attempt at measurement even make sense? How relevant is the economic discourse on nature?

Philosophical framework: humanity, society and nature

The Modern Western world view is based on the dichotomy of nature and society. Anthropology shows that the perception of the relationships between humans and non-humans may vary according to different cultures. A detailed observation of these relationships reveals the difficulties in implementing nature protection policies that respect the diverse modes of existence found throughout the world.

The biologist's approach stresses the evidence that nature exists outside human activity. The pre-eminence of biodiversity over the economy leads to the reinvention of economic systems whose prosperity can only be based on the destruction of the "goose that lays the golden eggs".

Finally, philosophical questions arise regarding the meaning of natural capital. Deeply rooted in economics, this metaphor is based on an anthropocentric view of nature whose value is gauged against the services that it renders to humanity. But can we talk about nature having an intrinsic value outside any relationship with humankind?

Conveying, without betraying, the diverse modes of existence throughout the world: an anthropological challenge and/or a political utopia

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Understanding the diverse modes of existence throughout the world has been the aim of anthropology since its origins. Immersed in the daily existence of their subjects, anthropologists learn, over time, to perceive and think about the world in a different manner; in short, they learn to be human in a different way.

This article describes the complexity that characterises the diverse modes of existence throughout the world and the different ways of evaluating the wealth of these worlds. Opting to provide a critical overview of the approaches – anthropological, biological, legal and political – that set out to examine these modes of existence, it reveals the different logical scandals (dualistic human-nature paradigm and its transposition into international environmental law and governance) encountered by these approaches, such as the conflicting misunderstandings that are inevitably generated by their same naturalistic view of humankind's place in a world summed up in terms of its natural capital.

To illustrate this set of "international" misunderstandings, a brief symmetrical comparison of the governance system implemented by the Kasua society in New Guinea, and those governance systems deployed by the different development projects currently in progress on their lands reveals the complexity of the legal-ecological conflicts caused by the conceptual differences governing the destiny of humans.

Understanding the diverse modes of existence throughout the world has been the aim of anthropology since its origins. Its singularity is not limited to its topic of study. It extends to the methodology that it uses to achieve its aim. Anthropology puts experience of life above experience of thinking or, in the words of Tim Ingold, it is "a philosophy *with* the people rather than a philosophy *of* the people" (2013). And ethnologists generally venture far from their usual place of residence, i.e. far from their own people, in pursuit of the promise of a new experience of existing in the world. Immersed in the daily existence of their hosts, both observing and participating in their imaginary and material lives, they learn, over time, to perceive and think about the world in a different manner; in short, they learn to be human in a different way.

This existential experience is, of course, exhilarating. Nevertheless, it remains destabilising. Gaining access to the worlds of other people, who are other people "precisely because they have different 'other people' to us" requires ethnologists to "decolonise their thoughts", and beyond this, to relativise their mode of existence at the most intimate level, along with the values and norms that drive them and determine their interpretation of diverse behaviours that they witness. This openness to other worlds – put to the test of reality and not just of thought – is a prerequisite of the ethnographic experience commonly referred to as "fieldwork". The success of this work quite simply determines the extent of the understanding of other people, such as the approval to convey, without betrayal, how they live and collectively create their world: in other words, their original ways of conceiving of, organising, and activating the properties and relationships that bind them and link them to the existing components of a composite world that has clearly been created in their own image.

This article describes the complexity that characterises the diverse modes of existence throughout the world and the different ways of evaluating the wealth of these worlds. Opting to provide a critical overview of the approaches that set out to examine these modes of existence – anthropological, biological, legal and political – it will reveal the different logical scandals encountered by these approaches, such as the conflicting misunderstandings that are inevitably generated by their same naturalistic vision of humankind's place in a world summed up in terms of natural capital.

The logical scandal of narratives that omit nature

With a distant gaze, ethnologists head home to embark on a new metamorphosis of their being and to report on the relational ecology that they have been privileged to share in another world, with their hosts. This is how anthropological thought – constantly put to the test of other people's worlds – has incessantly revised and adjusted its heuristic proposals that attempt to explain the astonishing diversity of ways of living throughout the world, which have been brought back from all parts of the Earth.

This way of thinking – open by its very essence – has nevertheless been capable of defensiveness. Until the end of the 20th century, this was how it greeted ethnographic facts that reflected environmental perceptions and practices that were clearly different to our own. Indeed, while the societies being studied generally recognised the objective discontinuities encountered in the living world, they did not recognise – in their symbolic, ritual, economic or political interactions – a natural order that is independent of their culture. In short, their relationships with non-humans made no reference to nature and contradicted the universality postulated by the dualistic paradigm on which modern epistemology (and thus anthropology) is based, i.e. the separation of the world and the distribution of its existing components into two separate fields: the field of Nature and of its Objects governed by their own universal laws, and the field of Culture, devoted to the relativism of its only cultural subjects: humans.

Dominated by the "cognitive realism" advocated by Western science, anthropology refused to accept the obvious and did nothing to reconsider its approach to different modes of existence. Rather than accept the plurality of conceptualisations of the world and, beyond that of humankind, it persisted in explaining these challenges to the founding duality by insisting that these apparently hybrid relationships be included in the only two envisaged and conceivable domains: nature and culture. A series of explanations was proposed, "sometimes utilitarian, sometimes symbolic and sometimes functionalist", each in their own way reiterating the society/environment dichotomy[1], and the duality of a universally biological but relatively cultural human being.

The logical scandal of non-human natural history

In fact, and as is often customary in the history of ideas, the question of the epistemological merit of the paradigmatic duality of Nature/Culture increased in relevance following analyses originating not from anthropology and its exotic fields of study but from the sociology of sciences and Western laboratories in which experiments and scientific knowledge are developed. In support of their research in biology laboratories, these analyses brought to light a new logical scandal which on this occasion did not concern a human society divorced from nature but rather a nature divorced from human society. Indeed, the results contradicted this idealistic claim by revealing that science, although "justly steering clear of any context, and any trace of ideological and social contamination", also defied the binary opposition by creating "quasi-objects and quasi-subjects", i.e. hybrids derived from both nature and culture. In other terms and to simplify, scientific societies no longer systematically separated humans from non-humans in their daily practices. Taking place at the very heart of the fabric of modern humanity, this reasoning had a significant impact on the universal claim of the dichotomous paradigm: it relativised "the Great internal sharing between humans and non-humans, science and society" , which justified "the Great sharing that constitutes our modernity, i.e. the Great sharing between us – Westerners – and Them – all of the others – incapable of truly separating what is knowledge from what is society, what is symbolic from what is material and what comes from nature in an unaltered state from what their cultures require (Latour 1991: 135).

This discovery gave rise to a veritable "intellectual cataclysm" in the scientific sphere[2].

On the other hand, it encouraged anthropology finally to adopt a stance in this debate that it had in fact initiated and fuelled. It is true that unlike sociologists or biologists, ethnologists, as I have emphasised, had a long history of recording, understanding and interpreting systems of knowledge and practices from around the world which did not acknowledge a universal nature that is separate from culture. Anthropology was thus no longer capable of relativising this possible Kuhnian revolution. It had also seemingly become mature enough to accept the consequences thereof and accept the need to abandon the traditional dualistic nature-culture paradigm that certainly laid the foundations for its episteme but in which the "nature" category decidedly resembled "an invention and an artifice of Western thought" (Dwyer 1996: 157).

[1] This same dichotomous characterisation had previously prompted numerous theories such as possibilism and determinism, but it also split anthropological research into a materialistic ethno-ecology and a symbolic ethno-ecology.

[2] In the Invention of Modern Science, Isabelle Stengers insists that "a disturbing rumour has been spreading in the world of scientists. It seems that there are some researchers – specialists in the human sciences, no less, who are challenging the ideal of a pure science […]. This field could call into question any separation between sciences and societies" (1995: 11). And, effectively, if we concur with Philippe Descola when he states "remove the idea of nature and the whole philosophical structure of Western achievements will collapse" (1996: 98), then the fear that is expressed is justified.

The final break from the paradigm would be confirmed several years later by the simultaneous publication of two collective works involving around forty specialists from all parts of the world[3]. These powerful pleas in favour of an ontological relativism in fact reached a common conclusion: Western naturalism need to be stripped of its status as a universal benchmark and join the humble ranks of the numerous cosmologies that also set out to organise humankind's place in the world. This "statement" of principle marked a necessary turning point in the history of anthropology. This is because rethinking the interface between nature and society necessarily meant devising a new approach[4] that does not automatically assume the existence of a fixed boundary between humans and non-humans or being confronted with a “completely different intellectual landscape, in which state and substance are replaced by processes and relationships” (Descola & Palsson 1996). Rising to this challenge was, of course, going to be a massive undertaking for the discipline, which was also made more pressing by the state of ecological urgency and globalisation, whose effects were being felt in even the remotest of areas. The key issue was certainly epistemological. It was clearly of a political nature. Overcoming it would offer reasonable hope of the dawning of a new environmental diplomacy[5] that would care more about the true diversity of modes of existence in the world.

The logical scandal of an international environmental neighbourhood law

This crisis of nature far exceeded the solely epistemological framework of the human and biological sciences. It also encompassed the environmental policies which, since the 1992 Rio Convention, made great effort to promote to "others" – i.e. our hosts – a form of sustainable development, that is to say economic development, that is capable of reconciling the interests of the two irreconcilable domains: humans and nature redefined according to its structural definition - biodiversity.

However, all of the ethnographic evidence revealed the inconsistencies and countless misunderstandings that always arose from the implementation of these international policies. Far from promoting a state of harmony between humans and non-humans, local tensions were exacerbated, reflecting the inability of developers (both private and public) to fully integrate the local populations, and symmetrically, the inability of local populations to embrace the eco-environmental values imposed on them by the developers of modernity. The internationalisation of modes of environmental governance ran into a deadlock with damaging consequences. Societies removed from nature were certainly developing into societies of humans with a yearning for nature. The situation was alarming for both humans and non-humans. It attracted the attention of the most eminent specialists who, in their efforts to provide adequate responses to the global environmental problem, endeavoured to understand the inability of policies to effectively associate development and environment and promote a form of ecology other than neighbourhood ecology. Multiple explanations were proposed and converged towards a first point of agreement: the inconsistency of the concept of sustainable development originated not from the "others" but from the philosophy of Western environmental law that permeated the private and public, national and international agreements governing the relationships of populations with their environment in the framework of sustainable development.

For the specialists[6] , there was indeed no doubt that the crisis was "firstly and above all, a crisis of our representation of nature and a crisis of our legal relationship with nature (…), and until this legal relationship has been redefined, our efforts will be in vain, as shown by the very limited effectiveness of international environmental law and the very limited effectiveness of public policies in this field[7] (Ost, 1995: 9). These same specialists also believed that in order to resolve this legal and environmental crisis, we would thus need to rethink our conventional legal approaches based on the traditional nature-object / human-subject dualism,

[3] 1996). Redefining Nature: Ecology, Culture and Domestication (R. Ellen and K. Fukui ed.]), and 1996: Nature and Society. Anthropological Perspectives (Ph. Descola and G. Palsson ed.]).

[4] Most certainly from a sociological point of view, as it is now understood that " the person and the environment espouse an irreducible system" (Descola & Palsson op. cit). But also from a biological standpoint as the cognitive sciences had also acknowledged the same transgression of the nature/culture dualism in the acquisition and development of world knowledge (Maturana and Varela 1987; Lave 1993)

[5] The first diplomatic proposal would thus be made in this way by Ph. Descola in his publication Par-delà Nature-Culture. A powerful manifesto in favour of a monistic anthropology, this work ratifies this major revision. To do so, he hypothesises that the identification modes by which individuals establish resemblances and differences between themselves and other people are not derived from cultural models or habitus, but from a simplified process relating to experience of the world, which structures the way in which each individual attributes the constituent properties of his or her humanity: interiority (intelligence, the soul, reflective thinking, emotions, etc.) and physicality (the body, substances, etc.). The combination of both of these attributes, which are assumed to be universal, would thus allow for limited, but not mutually exclusive, ontological formulas (2005: 322). On the basis of an ethnographic comparison covering all continents, he goes on to isolate four possible permutations defining four major types of ontologies that act as "reference points for contrasting forms of cosmologies, models for social ties and theories of identity and otherness" (2005:176). This relates to animism which establishes a resemblance of interiority but a difference of physicality with the existing elements, totemism which attributes a resemblance of interiority and physicality to them, naturalism which ascribes a resemblance of physicality but a difference of interiority to them, and finally analogism which acknowledges that they have a difference of interiority and physicality (2005:176).

[6] The reader is recommended to consult the following critical studies on environmental law: Imperiali 1998; Kiss 1985, 1998; Hermitte 1990; Jonas 1990; Martin 1992; Ost 1991, 1995; Prieur M. 1984; Remond-Gouilloud 1992.

[7] François Ost, Director of CEDRE (Centre for the analysis of environmental law), and of the European Academy of Legal Theory.

and to implement innovative legal mechanisms that would give an ecological slant to sustainable development law and thus reflect, in Western normative language, a form of nature that is no longer an object but understood in its ecological dimension and in its links with humankind. In short and in tune with scientific anthropologists and sociologists, the theoreticians of environmental law reached a conclusion with similar claims: the legal dichotomy between nature and society was hindering the sustainable development process.

Logical scandals concerning international environmental governance

To illustrate this set of "international" misunderstandings, I would now like to undertake a brief symmetrical comparison of the governance system implemented by the Kasua society in New Guinea, in which I have been working for 20 years, and those governance systems deployed by the different development projects currently in progress on their lands. I consider it useful to make this comparison in order to reveal the complexity of the legal and ecological conflicts caused by the conceptual differences governing the destiny of humankind.

It will show that the crisis thus generated only constitutes an epiphenomenon in what is a much bigger scandal – that of the limits encountered by the naturalistic paradigm in its hegemonic and anthropocentric ways of thinking, acting and evaluating the relationships between humans and non-humans and, beyond that, of its inability to promote in the "others" a state of harmony between people and between people and their nature.

The logical scandal of a sustainable "ungreening"

Because its forested lands harbour a unique, wonderful and still intact diversity, and because the 550 members of this society are acknowledged to be the owners of this biological wealth but also as forming an under-developed and non-civilised culture, the Kasua society has, since the mid-1990s, been battling against several development projects concerning its natural environment: projects regarding the industrial exploitation of its forestry and fossil resources, draft national and international environmental legislations, scientific projects to compile biological inventories and nature conservation projects. The tropical forest of the Kasua people has been besieged by multiple parties. But is this varied forest diversity that is presented and proposed to the Kasua by these foreign stakeholders (industrialists and NGOs, scientists and legal specialists) truly real? In other words, are they really offering the Kasua a way of conceiving of nature – and therefore of their culture – that is just as varied? In view of this symmetrical comparison, the answer would appear to be no. These conceptions – at first sight so diverse – are in fact like the leaves in a forest, dissimilar in their similarity. On the other hand, their "disguised" similarity is structurally and formally very different from the legal and ecological conceptions of the Kasua people. The first and must crucial difference resides in the field of application of law that these conceptions bring into play. For the developers that legitimise their acts on the Kasua's territory in a constitution, treaty, charter, code or contract, the scope of the law is to manage and organise life between people because its role is to "define the meaning of life in society". For the Kasua, life in society is not bound by such limits: the entire forest environment is also socialised because the whole of diversity participates in the same ethical principle that governs the relationships between humans, the reciprocal exchange of life and death. In other terms, nature and its components do not originate from a separate legal reality which is independent from that of people. Humans and non-humans are partners on an equal footing as subjects capable of acting, reacting and therefore interacting with others, with the world that surrounds them that is a single entity. Also, for this people, “the meaning of life in society" means “the meaning of life in a socialised nature” or indeed, “the meaning of life in an ecologised society”.

The second difference, intrinsically linked to the first, resides in the distinctions established by the system in its legal categories and the way in which it instrumentalises the communication between these artificially dissociated elements. While Western law “names, classifies and separates”, it also “establishes the hierarchies between the [categorised] values" (Ost 1995: 20). The categorisation underlying our development projects applies a single boundary to the real world, recognising two sole and identical domains: of people and of others – in this case the forest beings. Moreover, each of these conceptions assigns the same omnipotent powers to this boundary by investing it with the same "active" criteria. The boundary is first of all clear in the sense that it makes it impossible to positively identify the components of the two chosen categories. For these exogenous conceptions, people are the only social beings, the only cultural beings and the only legal and therefore political beings. In short, only people are considered to be the stakeholders and the subjects of actions to be undertaken on nature. And this is precisely in opposition to all of the "others", whose different status is due to the fact that they are deprived of these attributes, because they are only and eternally objects, we might add. The boundary established by these projects is not only clear, it is also fixed and dictates a hierarchy among its categories that cannot be breached. Conversely, and without in any way advocating the blurring of boundaries, the Kasua system does not segment the real world into fixed and opposing categories such as nature/culture or object/subject. Because the role of their law is to manage the

relationships that extend beyond the human sphere to the components of their environment, their system is meant to be more inclusive, assimilating the ecological dimension of non-humans into the legal sphere. *A fortiori*, otherness – interpreted as a category – is gradually but constantly evolving within this relational continuum, according to the participants and the exchanges from which it derives its substance, thus favouring the processuality of the references rather than the stability of criteria established abstractly by the legal categories. This radical contrast does, of course, extend to the legal relationships that are supposed to bind the Kasua to their forest. By relieving the forest beings of their attributes as living beings, i.e. as active and relational beings, all of the projects in question deny the fundamentally reciprocal nature of the relationships that humans maintain with living beings. They only retain a single relational dimension: the unilaterality expressed in a limited manner by the ownership and appropriation of the object by the subject. They only establish a single legal regime, which is essential to the monofunctional regime. Moreover, condemned to exchanging exclusively among human subjects, the Kasua are losing their ecological ties with what used to be their environment. Condemned to being passive and therefore powerless to interact within the confines of the subjects, the forest beings are commodified and turned into assets or objects to be used, legalised, commercialised, quantified, studied or protected by the only subject – humankind – the sole "master and owner" of the legal field of sustainable development. Such reductionism is meaningless within the Kasua's customary law. As I have mentioned, this is a law of relationships with others, an extended relationship with non-humans considered on an equal footing. In other words, it is a law that is enriched by ties and not by objects. Therefore, the relational unilaterality instituted by property is not valued. The Kasua people prefer usufruct to property which promotes relationships between beings by placing the emphasis on their interdependence in order to ensure the reproduction of the whole. In their society, individuals only inherit rights of use for their lands. They hold no actual legal powers over their lands: they cannot dispose of them, transfer or sell them to people that do not belong to their community. Any property that might exist is owned by the community. As the sole custodian, the community is responsible, in partnership with the designated spirits, for a sort of territorial patrimony, inherited from the ancestors and which it is duty bound to pass on to future generations. The lands are thus perceived of as a “trust” according to the Common Law of the English-speaking world, or as a “chose commune” ("common entity"), as defined by art. 714 of the French Code Civil: “There are things that belong to no-one and whose use is common to everyone”. This usufruct status governs all relationships between the people and forest resources that constitute their territory, without exception. Moreover, it is essential, because wild species are never considered to be "things without masters": they are under the authority of spiritual communities. How could the Kasua people claim, on their own initiative, to be exploiting them with impunity, or what is more, to be protecting them and taking the place of the tutelary spirits? For this people, biodiversity must thus be interpreted in its literal sense, i.e. as the diversity of life forms which, be they alive or imaginary, share the characteristic of playing key roles in the world inhabited by the Kasua. In other terms, forest biodiversity is not “for oneself” but “with oneself” (Berque 2000: 101); it participates fully in their definition of existence and of their destiny. The legal regime that arises from it tends logically towards multiplicity and multi-functionality[8], with utilitarianism tending towards the multi-specific rather than the anthropocentric[9]. Associating the combined individual and collective, human and non-human interests, it is a regime of complexity and diversity in which everyone's interests prevail over the interests of the individual, the human collective[10]. This certainly explains why this ecological ethic is rigorously driven home during the initiation rite that promotes the emergence of a new generation of Kasua men and women destined to participate in the joint regeneration of the forest environment.

The logical scandal concerning estimating the inestimable

We have understood. The conception of biodiversity, and beyond it, of humankind's place in the universe that is conveyed by the different development projects, are derived from the same conception: Western naturalism. The differences are thus not of an ontological nature – they only reflect the different uses and implementations of this dualistic cosmology. This explains how these exogenous stakeholders can join forces at just the right moment to estimate a value of the goods and services rendered by nature as an object. This

[8] Unlike a monofunctional regime that would assign one to three types of functions to an area, a single area to the Kasua – irrespective of its extent – is the focus and environment for a multitude of diverse and varied activities (hunting, gathering and shifting cultivation in addition to sexual, artistic, spiritual, contemplative, recreational, pedestrian, ritual and zoological activities, etc.). These activities may be cumulative, practised by different individuals or carried out on a seasonal basis. The use and joint production of wild forest resources advocates a similar multiplicity as opposed to the monospecific industrialisation promoted by our system. As an example, the tribe ascribes over 1,400 different uses to the 600 plants recorded and the variety of their modes of use is just as impressive.

[9] While the Kasua attribute 1,400 uses to the 600 identified trees, they also ascribe 481 other uses that may be derived by the fauna and spirits from these same botanical species. Differing from human uses, this utility contradicts any idea we might have of the Kasua having an anthropomorphic tendency.

[10] Without knowing it, the Kasua people adopt Locke's theory which makes individual "just appropriation" dependent on compliance with a dual condition: “that the use made by a person of his or her property prohibits any form of waste and that there remain sufficient resources of similar quality available to others”, to which is added a third condition that is more decisive with regard to the conservation of the forest environment: that the individual use does not conflict with the reproduction of socialised nature, which is a decisive factor for the conservation of the forest environment.

is the result of the association of legal experts, on the one hand, and scientists on the other, with industrialists and conservationists. Indeed, the first combination teaches us that the exploiters and protectors of nature jointly adhere to the philosophy of Western law and its binary approach that designates property as the universal soul of any legislation governing humanity's relationship with these non-humans. The difference, because there certainly is a difference, relates to the benefits that these exploiters and protectors of the environment respectively derive from this dualistic legal conception. While the former use (abuse?) the category of "objects without masters" in order to legally qualify non-humans of the forest with the mercenary aim of socially and ecologically devaluing their operational value and allowing them to carry out non-selective cutting, the latter, on the other hand, enhance the value of the Kasua land recognised by the Papuan Constitution in order to compensate for the "deficit of appropriation" that afflicts biodiversity; a deficit which, according to environmental economists, could be the cause of the massive destruction of nature (Hardin 1968). The second combination expresses this same ambiguity which seems paradoxical. The involvement of scientists in projects to exploit or conserve biodiversity firstly demonstrates that these stakeholders indisputably share the scientific conception of "a nature separate from social activities and populated by entities subject to universal laws"[11] (Descola 1999: 215). But, for industrialists, while the aim of this involvement of science is to "objectively" qualify and quantify the trees with a view to economically evaluating the stock of resources to be exploited and compensated for, the aim for the scientists is to "objectively" qualify and quantify the natural capital with a view to ecologically evaluating the stock of capital to be protected from human activities. The difference is not always about "nature". None of these stakeholders are challenging the dualistic paradigm or the role that it attributes to humans, i.e. of being the masters and possessors of all natural objects. Here again, the difference relates to the different treatments given to Western naturalism and the different instruments designed to attempt to evaluate this natural capital that is so coveted. Moreover, these differential treatments are neither contradictory nor exclusive. To achieve their conservation objectives, the protectors do not hesitate to reify certain natural beings as commercial value (to be discussed later), and industrialists are willing to fund these same protectors in order to "conserve" a territory that they are exploiting on a massive scale. Furthermore, these financial exchanges will be systematically promoted in their respective public relations campaigns through the placement of their respective logos or the addition of a line of acknowledgements in the final credits of nature documentaries depicting the nature of a forest that remains intact because it has been hardly impacted by the Kasua whose fleeting appearances – always bedecked in their feather-adorned costumes – may deliberately liken them to birds of paradise.

Therefore, from a purely logical and conceptual standpoint, there is no longer any surprise about the associations between developers. The developers have more in common than one might think, including the neo-liberal tendencies voluntarily embraced by the protectors in order to pursue their objectives and simultaneously ensure the renewal of their programmes and of the employees employed thereon[12]. However, although these inter-developer associations are clearly envisageable because they are conceptually comprehensible, they explain, without contradiction but *a contrario*, the blatant inability of these stakeholders to associate the Kasua people, fully and in their practices, with their development project. To remedy this situation, they would need to accept the non-universal scope of their common ontology and thus acknowledge that the Kasua do not share their objectivised vision of living beings and the emancipated and superior position that humankind has claimed in the environment. But are they capable of doing so? The many disagreements over the estimation of the "natural capital" of the Kasua people and the tools for evaluating it will bear witness to the extreme difficulty of jointly managing to formulate a joint and shared estimate of the forest's value. The first disagreement thus naturally arose with regard to the value that would be assigned to the trees exploited by the industrial company[13]. Indeed, the astonishment that followed the massive and noisy felling of the forest was followed by more astonishment with the observation that all of the tree trunks thus cut down or damaged were valued according to a single accounting unit – the m^3 – a measurement that did not differentiate among the species of trees harvested. This indifference, specifically relating to the estimation of the value of the tree being to be compensated for, was absolutely incomprehensible to the Kasua who recognise the uniqueness of each tree populating the forest, as they do for each of the roles that they play within the forest ecosystem: protection of soils, provision of food and habitat for wildlife that is 80% herbivorous, housing the spirits and the many uses and services derived from it by humankind. Although remarkable for being mainly eco-centric, none of these criteria were taken into account in the estimation of the felled trees. Invoking the market forces that oust intrinsic values and use values in favour of the exchange value, the company only paid the amount corresponding to the international price for cut exotic hardwood per m^3, i.e. barely one euro. Another disagreement arose regarding an oil company's visit for prospecting purposes and the issue of compensation for the destruction of forest areas considered sacred by the Kasua people. The contract law did provide for this type of compensation, but under precise terms restricted to

[11] Moreover, the Kasua will never be invited to participate actively in compiling the biological inventories of their forest.
[12] For a critical analysis of the neo-liberalism adopted by the conservation movement and its stakeholders, readers are recommended to consult the summary by: Buscher, Sullivan, Neves, Igoe & Brockington, 2012.
[13] The Malaysian company Rinbujau, which possesses 80% of New Guinea's exported wood and has obtained a renewable 30-year concession from the State that covers the Kasua lands.

"cultural edifices: housing, churches, gardens and cemeteries[14]". However, although the damaged sacred sites were indeed sites that could reasonably be described as cultural sites, in their forms they were "natural edifices": here, a tree inhabited by a bird spirit that provides game for hunters, and there a creek that is home to an ancestral eel that maintains a symbiotic relationship with a certain kingfisher, etc. Wishing to avoid any conflict with the local population, the company granted the request for compensation but categorically refused to pay the amount claimed, which corresponded to the inestimable value[15] that these sites represented for the Kasua. The reasons given were simple: the hybrid composition of these sites – animal + mineral + plant + spiritual but under no circumstances human – as well as their ephemeral and non-intemporal character, made these hybrid edifices incompatible with the compensation for the cultural places provided for by the law.

These conflicts repeatedly arose as the destruction of the forest continued under the relentless march of industry. However they did not exclusively concern the industrialists, whose commercial aims were clearly understood by the Kasua. The values advocated by the protectors would also come into conflict with those of the Kasua. Indeed, emboldened by their constant disagreements with the companies, the Kasua society had taken the initiative to organise a meeting of all its members with a view to evaluating and collectively setting the price for each of the species of their forest that might be damaged by outsiders[16]. The meeting would last two weeks; two long weeks that the Kasua devoted to compiling an exhaustive inventory of all species and all of the uses and services they provided in their daily interactions with the forest. The meeting ended with a great ceremony to which the titulary spirits, the ethnologist and members of conservation NGOs were invited with a view to obtaining their implicit agreements in principle. However, certain valuations were the subject of heated discussions with the protectors, particularly that concerning the southern cassowary, to which the Kasua had attributed a value of $1,000, which was the highest valuation. While this was considered to be a fair price by the Kasua, considering the major role played by this crested member of the ostrich family in the regeneration of the forest universe by facilitating the germination and dissemination of complex forest fruits, the protectors considered this to be much too excessive as the animal is not included on the IUCN red list. They instructed the Kasua to reduce the price. This disagreement was poorly understood by the Kasua. It clearly reflected a paradox, doubtless the same paradox raised by Adam Smith who observed that the value "of the things that have the greatest value in use often have little or value in exchange at all". Indeed, if the cassowary was not worth its use value even though it was considered exceptional by everyone and for all communities, why were certain butterflies – which to all of the Kasua had no use whatsoever – valued at over $500 and included in a sustainable programme with a view to their long-term marketing as collector's items in Japan?

No, decidedly, the logic behind the environmental valuations, as presented by the different developers, was lost on the Kasua. Moreover, when several years later these self-same protectors declared themselves to be the spokespersons of a functionalist ecology and announced to the Kasua the opening of a new financial market for ecosystem services that would allow them to sell the air of their forest at a very high price to the highest bidders, the Kasua smiled incredulously and contemplated their forest universe which, within a single decade, had come to embody a very forlorn and denatured nature.

Lessons to be learned in conclusion

What lessons can we learn from this critical, epistemological and comparative approach to ways of existing together in the world? Certainly, that the uniformisation of the world that is insidiously imposed by the dualistic paradigm is not obligatory and even less inevitable. Surely all that is needed is for the "modernists" that have taken on the roles of developers and/or conservationists, to show greater humility and be willing to enrich their ways of imposing change on the world by adopting ways in which others interact with the world. In many respects, and on close examination, the environmental governance employed by "others" seems to be very innovative. And this is incontestably the case for the principles that govern the "greening" of their legal and ecological regime which is, as a matter of policy, fundamentally: dialectical (addressing the reciprocal relationship between humans and non-humans); global (environment and society are within the same legal sphere); hybrid (to the social identity of the subject of law is added its ecological identity, with the environment becoming an attribute of its legal personality); egalitarian (the human being and the non-human are treated on an equal footing); relational (exclusively managing the relationship, it likens ecological relationships and ecosystem networks to legal relationships and encourages the diversification and intensification of the aspects of a relationship); cross-border (the interdependence of beings that are socially established and ecologically recognised tolerates neither the local elements nor the individual that could jeopardise the reproduction of the whole); progressive and evolutional (it recognises and integrates the ecological reality of

[14] Contract law is thus seen as a poor interpreter of the historical materialism according to which humankind can only make its mark by transforming nature (Godelier 1981).
[15] The Kasua were compensated for the damage caused to their precious trees per m^3 destroyed.
[16] Greatly vexed, the Kasua followed the advice of Pavan Sukdev according to whom "you need to put a price on nature to be able to protect it", *In* Le Monde 20/10/2010.

the environment); complex (combining collective and individual, human and non-human interests, it manages social organisation and ecosystemic organisation); sustainable (establishing usufruct as a legal status, it advocates collective rationality and individual responsibility in the reproduction of everything and everyone); and finally, trans-historical (it takes account of ancestral generations and future generations).

Is being inspired by these innovative values really the product of a single anthropological utopia? And even if this were the case, would this utopia not be coming at just the right time to thwart the progression of environmental policies that "end in failure by (always) forming part of an approach in which nature is considered an object?" (Ost 1995: 11). Is our system running out of steam under the burden of the principles on which it is based with respect to our naturalistic tradition? Why persist in wanting to dictate the workings of the world solely on the basis of this single dichotomous vision? Why persist in wanting to apply the sole principles and relationships that it allows between us – humans and all others – existing entities? Have its very principles – rigidity and constancy, utilitarianism and functionalism, decontextualisation and commodification, neo-liberalism and technocentrism, individualism and anthropocentrism, productivism and consumerism, not revealed their political incapacity to promote a sustainable global development for humanity?

Let us hope that international policies take inspiration and help to spare us any hegemony in ways of existing in the world during the Anthropocene era.

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A "natural capital"? A biologist's view

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Can we and must we attribute a value to biodiversity? This is a genuine question. Ecologists are reluctant to do this due to the obvious risks of monetising and privatising nature, along with the risks of speculation. Furthermore, they are fully aware that legal experts and economists need to intervene and modify the current state of affairs: is biodiversity really a commodity like any other? Clearly no, so how should we proceed? Common sense and human well-being must prevail. We must all acknowledge the indispensable contribution of biodiversity to the survival of humanity: our destiny is inextricably linked to it. Let us collectively implement a very different economic system in which profit can no longer be made from the destruction or overexploitation of nature and its biodiversity. Let us learn to manage this marvellous reproducibility of the living world while refraining from killing the "goose that lays the golden eggs"!

The notion of "natural capital" was proposed by certain ecologists specialising in conservation biology around twenty years ago. And the term crops up regularly in the debates and publications on the major environmental issues and the future of biodiversity. How can we analyse it?

Is life a form of capital?

The age of the Earth has been estimated at 4,600 million years (MY) and life appeared on the planet around 3,900 MY. Nature, which encompasses all of the structures and organisations in the Universe, can thus be traced back to the origins of the Earth. From fragments of a meteorite that fell on Orgueil in the *département* of the Gers in France in May 1864, and which have recently been analysed, we have been able to date its origins to 4,600 MY by chromium isotope measurements. The exceptional value of this chondrite, which is therefore contemporary with the creation of the Sun and the Earth and which never left the solar system during its amazingly long journey, now becomes apparent because it shows that the living world is built on the foundations of a prior geo-diversity. The Earth's dimensions and its distance from the Sun have been decisive factors in the appearance and maintenance of life on our planet. A large proportion of all current living cells, whatever their form and whatever the organisms – from the oldest to the most recent – consist of liquid water. A newborn human baby thus consists of 75% water, our brains contain over 80% and a marine jellyfish contains 98%. And it is precisely because liquid water is so abundant on Earth that life has been able to develop here. Water should not, therefore, be considered separately from our natural capital, as it is our most precious asset.

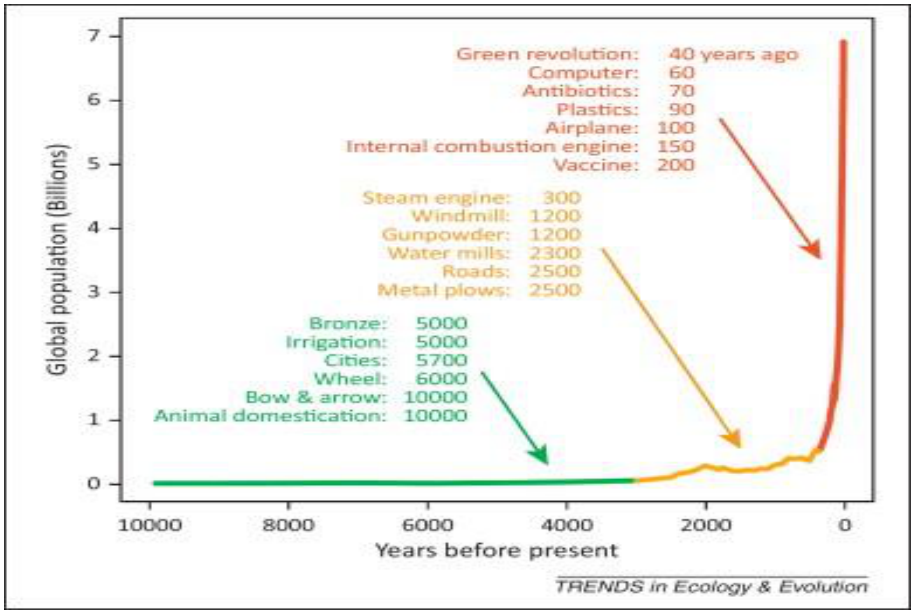
Primitive life appeared in the ancestral oceans, or at least in coastal pools of water. All of the first organisms, since the famous *LUCA* ("*Last Unique Common Ancestor*"), lived in salt water. Life was only able to emerge from this element much later – around 1,000 MY for cyanobacteria and 450 MY for the complex life forms that are animals, arthropods and vertebrates. This marine environment marks the beginnings of life on Earth. All large organisms of the living world have been established in the ocean, from the appearance of the *Eukaryotes* – large, complex cells with a nucleus, around 2,200 MY, to the capture of external bacteria that would become the organelles of the cell, and from pluricellularity (organisms with several cells) to the emergence of sexuality around 1,500 MY, through lateral gene transfer. A sexual organism evolves much more quickly and gives a powerful boost to biodiversity.

The word "biodiversity", a contraction of "biological diversity", was created in 1985. This term is often likened to species diversity, i.e. applying to all living species of bacteria, protists (unicellular), *fungi* ("mushrooms"), plants and animals in an environment. But this diversity of the living world is much more than the mere plurality of species, as it includes both the species and their relative abundance. Biodiversity has been defined as "*any genetic information included in an individual, a species, a population or an ecosystem*" but we also endeavour to describe it as being all interactions between living beings, between them and with their environment. In fact, it concerns the living fraction of nature.

Life, since its origins, has thus been able to develop infinitely varied forms of life that have "joined forces" to create ecosystems in close relationships with their environment. Today, we can easily imagine that over this period of time, the living world has been capable of developing well over a billion species – most of which appeared and then died out – while others remain with us today, in their diverse forms, sizes, and colours, with their varied habits, specificities, lifestyle characteristics, adaptations and their infinitely diverse characteristics...

Countless species have yet to be discovered. For billions and hundreds of millions of years, all evolution occurred under the pressure of abiotic environmental factors – water and air temperature, ocean salinity, acidity of water, light, seasonal rythmicity, etc. – and biotic factors – inter-species relationships and competition, and factors associated with the living world such as food, its composition and availability. After hundreds of millions of years during which these major environmental factors have provided the impetus for the evolution of the living world and its adaptive capacities, a recent era (beginning 10,000 or… 300 years ago?), referred to as the "*Anthropocene*" period, reveals human presence as being the greatest evolutionary force on this planet. Indeed, the decline in biodiversity for "non-natural" human reasons (although we should be careful with this term for fear of dissociating humans from nature, as they are an integral part of it – instead, let's prefer the term "human and non-human reasons") has greatly accelerated due to two variables: human demography and the vast number of associated anthropic activities, with all of these factors linked to technological progress (see figure 1).

Figure 1: Demography of humankind in relation to major inventions.



Source: Adapted from Nekola *et al.* 2013, Trends in Ecology and Evolution, 28 (3), 127-130.

When agriculture was in its infancy some 10-12,000 years ago, there were approximately 5 million humans on Earth, and all of the biomass produced by humans and their domesticated mammals did not exceed 0.1% of the total mass of all mammals (5,000 known species), whereas today it exceeds 90%. In 1750, the total population was estimated to be fewer than 800 million inhabitants**,** rising to 3 billion in 1960, 7 billion in 2012, and a projected 9 billion in 2040. The changes in human population trends over recent periods are clearly edifying.

Living nature is the very essence of the planet Earth. It is based on a prior geo-diversity, based on water and present everywhere, from the Antarctic ice to the sweltering deserts, and from the deep ocean beds to the Himalayan summits. Deep boreholes drilled to depths of hundreds of metres reveal the presence of bacteria. The only lifeless "environment" (if we can call it that?) on Earth, is volcanic lava.
So, today, how should humans consider this living world that surrounds them and of which they are made? Is it a natural capital?

How can we examine this issue?

The FRB (French Foundation for cooperation on research for biodiversity) produced a highly interesting report on the values of biodiversity in 2012 and we shall take inspiration from it.

From the outset, this report stipulates "… *these developments, taking place at the juncture of science, politics and society, regularly promote a utilitarian view of biodiversity and presuppose the existence of a strong link between biodiversity and development. However, this view raises numerous questions relating to the fundamental question of the relationships between mankind and nature, and concern the different representations of biodiversity. That is why it is important to re-examine the recent developments concerning the values of biodiversity in this broader context, as the question of these values cannot be reduced to that of the economic assessment of biodiversity… This new framework is no longer focused on a type of "nature" conceived of as external and opposed to human culture, but on a "biodiversity" from which we derive resources and services and of which we form an integral part…*".

In this regard, in 2010, Jean-Michel Salles (CNRS, and Vice-President of the Working Group for the "*Economic approach to biodiversity and ecosystem-related services – Contribution to public decision-making".* study) emphasised that "…the valuation of biodiversity does not require it to become a commercial commodity and the "values" need not become the price of a licence to destroy…". In 2012, the Caisse des dépôts et consignations (French Consignments and Loans Fund) created a "*Mission on the economics of biodiversity*" to be managed by its subsidiary, the Société forestière, which was allocated a €3 million budget for three years, in support of research, studies and prototypes. Today, it focuses mainly on compensation mechanisms.

With the loss of certain ecosystem services, destruction and massive pollution events, the over-exploitation of fishery resources, the deforestation of tropical forests and mangroves, the destruction of coral reefs, the waste of water, competition from invasive species, soil erosion and salinisation, etc., while taking account of the development of Environmental law (European in particular with, for example, the 2004/35/EC directive relating to environmental liability), and due to the increasingly common obligations to prevent negative impacts or to pay in order to limit them or compensate for them, biodiversity, from being considered *res nullius* is slowly being seen as having different values which are ethical or indeed, which can be converted into monetary equivalents. Our understanding of these services rendered by biodiversity is starting to improve, although it remains far from perfect.

Nevertheless, they remain hard to quantify and monetise, which would be unacceptable to any ecologist (price of nature?). Many economists are seeking to apply the methods that are used to estimate the economic value of a commodity or of a service, to biodiversity. This value is often measured according to criteria of utility and, with greater difficulty, of its contribution to the well-being and general health that it promotes in people.

The economic valuation of biodiversity necessarily involves multiple criteria and the following values can generally be identified (according to the *Millennium Ecosystem Assessment* of 1985):

- *direct use values*: the production of foodstuffs, firewood, raw materials for medication, cosmetic products, research models, landscapes and tourism settings, etc.
- *indirect use values*: by-products of ecological functions, protection of soils from erosion, filtration of water, balanced ecosystems
- *option values*: prices attributed to the conservation of an asset with a view to its future use (e.g. the preservation of a plant known to be of pharmacological interest)
- *quasi-option values*: relating to the conservation of an asset whose benefit has not yet been demonstrated, with a view to its future use (e.g. the conservation of a small area of tropical forest to allow for the future discovery of unknown plants, for as yet unknown uses)
- *non-use values* or *intrinsic values*: relating to the satisfaction of knowing that a desirable asset or fact exists. These values are often associated with notions of justice, the rights of future generations or respect for Nature and help to justify the protection of species or of known sites of natural interest. *Bequest value* is mentioned in relation to the transmission of a heritage to future generations and *existence value* simply relates to the fact of existing.

The FRB document of 2012 covers a very wide range of values: existence, spiritual, ecological, adaptive, evolutionary, scientific, option (potential future use), use (direct and indirect), non-use, instrumental, non-

instrumental, ecosystem service, economic, total economic, heritage, bequest, asset, intrinsic, moral, cultural, recreational, aesthetic and educational values, etc. Target n°. 2 of the Aichi Targets, after the Nagoya conference in 2010, for biological diversity, seeks, *"by 2020, at the latest, to integrate the values of biological diversity into national and local development and poverty reduction strategies and planning processes, and to incorporate them into national accounting, as appropriate, and reporting systems. In paragraph 3 c) of decision X/2, the Conference of the Parties urged the Parties and other governments to examine and, as appropriate, to update and revise their strategies and national action plans for biological diversity, pursuant to the Strategic Plan for Biodiversity 2011-2020"*. A colloquium held at the Fondation des Treilles in September 2014 revisited this discussion "…*should we, must we attribute a value to biodiversity*…". The Proceedings will be published in 2015 (publisher: L. Fonbaustier). Ecologists, although rather hesitant, fully realise that this is a requirement if they would like legal specialists and economists to help them move forward and do everything in their power to prevent the destruction of biodiversity and restore a balance in the relationships between humans and nature. However, the protagonists still disagree on the methodologies to be used. By attributing a monetary value to biodiversity, there is a risk of establishing a system of privatisation of the living world that authorises the richest parties (individuals, companies, States, etc.) to destroy or purchase biodiversity in return for financial consideration, with its increasing scarcity due to its deterioration even helping to encourage a certain form of financial speculation. The FRB's work underlines that certain authors report on *"a risk of pre-emption of the public sphere by the utilitarian view underlying the notion of ecosystem service, which could eventually undermine certain acquired benefits in terms of biodiversity protection, such as the status of protected species and habitats. It warns against a weakening of the argument in favour of biodiversity, which would no longer be based on ethical considerations, especially when "biodiversity is a source of disruptions or "dis-services"* for humans. Another danger may reside in the fact that all of the ecosystem services underlying the flows of services have not been identified, and that there could therefore be a discrepancy between the utilitarian view of the value and the state of scientific knowledge (Doussan, 2009)".

The key issue of considering biodiversity as a commodity will always remain. On 28 January 2015, the French National Assembly definitively adopted the draft law on on modernising and simplifying the Law, including the amendment on the legal status of animals: the Civil Code (Code civil) now states that "… *animals are living beings endowed with sensitivity. Subject to the laws that protect them, animals are governed by the property law (régime des biens)*…". Therefore, this Civil Code now mentions animals in accordance with their nature and not just according to the use that humans make of them as saleable, purchasable, rentable or marketable items. This is a big step forward on the ethical and psychological level without having any practical consequences on the regulatory or criminal levels (Droit animal, éthique et science, April 2015, 85, p.7). Animals are always treated as goods, even if this is not the case, and the same applies to biodiversity.

And in this same volume, I really admired the chapter by Florence Brunois-Prasina in which she compares the behaviours of loggers, ecologists and native Kasua populations in a valley of Papua New Guinea: between the values per cubic metre of timber, without discriminating among tree species for the loggers, and the value of the cassowary – a capital species for these forests with its role governing the functionality of these ecosystems, which is favourably perceived by the Papuans and for the Kasua, the value of the green birdwing butterfly included on the IUCN lists… the discussion is extremely sensitive and fascinating for ethnologists and ecologists alike.

Therefore, is biodiversity a type of capital? Yes, certainly from the ecologist's standpoint, this is the case for the entire living fraction of nature that plays such a decisive role in the evolution of terrestrial systems and is essential to humanity, which cannot survive without it. Today, there are even attempts by economists to base currencies on "ecosystem capitals", which means that there is a genuine interest in preventing damage to them (cf. Liétaert, 2012). However, there are major – and sometimes radical – differences of opinion in the assessments of the methodologies to be employed in order to make progress. Monetisation does not appear to be desirable and, in any case, takes us back to the differences in estimations of values, as we have clearly seen among the protagonists in that Papuan valley studied by our colleague in previous chapter of this publication.

So are we collectively capable of implementing a system that, in the future, will prohibit making (an often quick) profit from the destruction of nature and biodiversity, or from its over-exploitation? How can we restore some balance between humankind and biodiversity, with which it is inextricably linked and without which it cannot survive?

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Natural capital – a narrow view of the values of nature and environmental policies

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The notion of natural capital is a metaphor derived from works carried out at the interface between economics and ecology, and has quickly spread to the political sphere. However, this metaphor fails to account for the complexity of the values of nature and the political challenges arising from their valuation. On the one hand, it only encapsulates a small proportion of the values of biodiversity and ecosystems and neglects to take account of essential values such as cultural values and non-anthropocentric values. On the other hand, it potentially gives a very poor view of public decision-making in which the specifically political issues relating to debate and power struggles give way to management based on expertise. Far from definitively discrediting the relevance of this metaphor, highlighting its limitations and the simplifications that it makes should allow it to be usefully employed when restricted to its field of legitimacy, but also and above all, it should encourage the adoption of other messages and other rationalities than an approach that is strictly inspired by standard economics in response to the major environmental challenges of our time.

The power of a metaphor

Metaphors are widely used in scientific fields. We are happy to talk about the tree of life, selfish genes and struggles for existence, etc., although the roles of these stylistic devices may vary. Metaphors are sometimes used for didactic or illustrative purposes, helping the uninitiated to acquire new knowledge by associating it with more familiar things. On other occasions, they are employed as heuristic devices, using an analogy with an already known phenomenon to facilitate the comprehension and explanation of the phenomenon being studied, as when talking about "adaptive strategy" in the evolution of the living world to highlight *fitness* optimisation phenomena which are analogous rational utility maximisation strategies. Metaphors thus have a key role to play, both in the constitution of scientific knowledge and in their dissemination to the public. In practice, these linguistic transfers from the common level to the scientific level frequently lose their metaphorical dimension, becoming, according to the neologism employed by Maasen and Weingart (1995), "demetaphorised", and end up being fully absorbed into the scientific discourse, changing status from an analogy between a scientific fact and a common fact to the status of a description or definition of the scientific fact itself. Beyond the strict search for knowledge, the selection of metaphors by the scientific community and their dissemination to the public reflect power struggles and moves to legitimise certain messages to the detriment of other modes of representation and description of the world. Indeed, metaphors convey a whole series of extra-scientific preconceptions and norms and, after their adoption and dissemination, contribute to the reconfiguration not just of knowledge but also of perceptions of reality and possible horizons in terms of the formulation of hypotheses and priorities for investigation.

In this article, we shall be devoting our attention to the notion of "natural capital". This metaphor, seeking to designate the natural processes and elements that are beneficial to human beings, is less strictly scientific than the above-mentioned examples. Indeed, although it first appears in the field of environmental science – particularly in the quite explicit attempts to hybridise the natural sciences and economic sciences – it rapidly permeates the field of public action, as is clearly shown by this publication. And the prospect of it being appropriated by decision-makers in such a manner can be seen as a form of justification for the choice of the metaphor. Many ecologists have considered the metaphor of natural capital to be a way of "speaking the same language" as the decision-makers, which will help make their messages more audible and more convincing (Pearce & Atkinson 1993).

We can now mention two levels of interpretation of the metaphor of natural capital. In the first place, this is a mechanistic metaphor based on an analogy or on drawing parallels between nature and manufactured capital – a river producing fish like a factory would produce cars. This mechanistic view of nature is not new. It echoes another metaphor that was coined in the 17th century by Descartes in his animal-machine theory. In the fifth part of the "Discourse on the method" (Discours de la méthode), the purely metaphorical content of the expression is clear. Referring to animals, Descartes mentions "this body like a machine which, having been made by the hands of God, is incomparably better structured and more admirable in its movements than any that may have been invented by men". Animals are not therefore likened to automata, but they are deemed to be similar in one aspect only.

However, if the notion of natural capital is considered in the wider metaphorical context within which it is placed, it appears that beyond this mechanistic view, it also reveals an economically oriented view of nature. A river produces fish not really like a factory produces cars but more like a factory produces profits. Here, the metaphor is extended far beyond the simple notion of natural capital. The operation of ecosystems and their interactions with human activities are compared to the capitalist system: natural capital generates flows of goods and ecosystem services (in return for work via human capital and institutions via social capital) in the same way that physical capital generates goods and commercial services. In both cases, the productivity of capital (natural and physical) is mediatised by work (human capital) and institutions (social capital). In this case, it is all of the interactions between individuals and their environment that are analogised with an economic system in which the maintenance and accumulation of capital may be not only a source of enrichment, but also the specific outcome of the system in question.

In this article, we shall be analysing the limitations and risks of such an analogy, not in order to discredit it but in the hope that a useful and reasonable use of the notion of natural capital is possible, provided that certain precautions are taken to define the scope of its legitimacy and leave room for other messages and other rationalities when the metaphor is ineffective. We shall firstly describe the emergence of the notion of natural capital, which fits into two divergent fields of discourse, according to whether they are based on strong or weak views of sustainability. We shall then underline the simplifications that this notion makes, firstly in the conception of the values of nature and then in the underlying perspectives of the politician and of public decision-making. We shall aporetically conclude by mentioning the grave dilemma now confronting environmentalists, who must often choose between the risk of seeing the protection of nature marginalised due to the lack of audible arguments in a society of growth, and the adoption of a rational approach that would apply even to aspects that endanger biodiversity, thus losing, in advance, the battle that would consist of challenging this rationality.

The notion of natural capital

The notion of natural capital intervenes in a context of the mainstreaming of environmental concerns in the economy (see ten Brink in this volume). The key issue is to report on the limitations that the depletion of natural resources and the general degradation of ecosystems impose, or should impose, on the economic operation of societies. This metaphor, strongly associated with the messages about sustainable development, is used at two separate levels that need to be defined.

While both of the approaches to natural capital share the aim of creating harmony between ecology and economics, they go about doing so from opposite directions, so to speak. The first approach is adopted by economists who use the metaphor of natural capital to internalise certain environmental considerations within the general framework of standard economics (Pearce 1988), proposing a sort of economic basis for ecology and giving birth to environmental economics. This involves amending the economics of natural resources in order to adapt them to ecological considerations and to the problems posed by the decline of biodiversity. The second approach is more commonly adopted by ecologists who use the notion of natural capital to place the economy within a broader ecological framework and, to the contrary, defending a "greening" of the economy (Costanza 1992, Daly 1996, Folke et al. 1994). This is referred to as ecological economics. These two approaches differ in their respective ways of perceiving sustainability, nature and the valuations of its values.

The second dividing line is that separating "weak" sustainability from "strong" sustainability. In its economically oriented version, the notion of natural capital allows for the theorisation of the idea of sustainability by removing the constraint imposed on the current generations by the needs of future generations, provided that the different forms of capital can be substituted for one another. Indeed, if we consider that a type of development is sustainable provided that the total capital transmitted by one generation to the next is at least equal in amount to the capital it has inherited, then the degradation of the natural capital is acceptable so long as it is offset by at least an equivalent increase in another form of capital. This is described as weak sustainability. This compensation may be made possible by savings, for example (Pearce and Atkinson, 1993). Provided that a society saves (in currency) as much as it spends (in natural resources), the goal of weak sustainability is attained. However, the idea that heterogeneous forms of capital can be substituted for one another has been heavily criticised. Pelenc and Ballet (2015) sum up the main obstacles to the substitution of natural capital with manufactured and human capital and vice-versa in the following manner: The degradation of natural capital is, in many cases, irreversible (e.g. the extinction of species) or is subject to threshold effects (e.g. the eutrophication of natural environments). Manufactured capital requires natural capital in order to be produced, if only in terms of energy supplies and raw materials and in this way, it cannot be indefinitely substituted for natural capital. Natural capital is usually multifunctional whereas manufactured capital is generally monofunctional and, when it satisfies several functions, the latter are quite easily identifiable. Finally, because the relationships between the operation of ecosystems and human well-being are still poorly understood, it is hard to envisage what type of natural capital could adequately compensate for the loss of a given proportion of the natural capital.

Hence the idea of identifying a critical natural capital within the overall natural capital (Etkins et al. 2003, De Groot et al. 2003). The criteria for identifying this critical portion of the natural capital vary from author to author. Three criteria are generally applied: 1. The essential role for life and human well-being. 2. The impossibility of replacing the services rendered with artificial alternatives. 3. The risk of the irreversibility of losses of services. The definition of critical natural capital varies from one author to another, with their positions situated along a continuum ranging from weak to strong sustainability according to the confidence they have in capacities to innovate in terms of technological substitution and the importance they attach to uncertainty.

A second dividing line within the different meanings of the notion of natural capital concerns its valuation. This question is directly related to the question of substitutability as the latter depends on the commensurability of the values of the different forms of capital. Indeed, one of the ways of proving that a loss of capital can be adequately offset by the gaining of another type of capital is to show that the value of the gains is at least higher than the losses. Such proof must consequently be based on a monetary valuation of the losses and gains in order to ensure the commensurability of the heterogeneous values by expressing them in a common (monetary) unit. Monetary quantification thus plays a decisive role insofar as it helps to attenuate the specificities of environmental goods and services and makes them comparable to (and therefore perhaps replaceable with) other types of goods and services. Whereas the advocates of ecological economics will, in principle, be favourable to the monetary valuation of natural capital, the advocates of a stronger approach to sustainability are more generally inclined to produce non-monetary measurements of natural capital, particularly based on biophysical indicators such as productivity and ecosystem load capacities. It should however be noted that the boundary between environmental economics and ecological economics has gradually become blurred and that monetary valuations have become widespread, with some of the most famous examples produced by teams generally associated with ecological economics (Costanza et al. 1997).

A simplified view of values

The notion of natural capital, defined as a "stock of materials and information generating a flow of goods and services that promote human well-being" (see ten Brick in this volume), only designates the portion of the natural world that is useful to human beings. It therefore only encapsulates the anthropocentric values of nature, i.e. values strictly focused on human interests. It is important, in certain contexts, to focus on these values and on the capital they represent for human societies, such as when there is a need to compare a series of regional development options that have different impacts on the environment and on human well-being. In particular, the notion of natural capital may cast light on certain indirect and distant costs of economic options that, on first sight, seem to maximise the satisfaction of human interests. When a cost-benefit analysis of a development project that is likely to create jobs but will require the drainage of wetlands is produced, it is often easier to perceive the benefits relating to the creation of jobs – if only because these are elements that are already deployed in the economic field – than to estimate the costs potentially incurred by the destruction of the wetlands, in terms of water quality, for example. This creates a bias in favour of commercial activities, which may partially explain certain contemporary environmental disasters, such as the weakening of coastal areas due to urban development, or soil erosion linked to the intensification of agricultural practices, since the immediate commercial benefits are more predictable and more easily quantifiable than the indirect environmental costs. Developing effective tools for understanding and possibly quantifying natural capital may therefore be a way to partially correct this bias.

It should nevertheless be acknowledged that the values of nature or of certain natural entities are not all necessarily linked to the satisfaction of human interests. Indeed, it is possible to consider that nature or natural entities may have a value in themselves, which is independent of any utility. Such values are referred to as non-anthropocentric. Different moral theories have been developed around this shift in focus since the 1970s and form the core of environmental ethics. These theories strive to justify the attribution of an intrinsic value to non-human beings: because any sensitive being has at least a minimal interest in not suffering (Singer, 1997); because any living being can benefit or suffer from our actions, depending on whether or not they hinder its ability to stay alive and flourish according to its own nature (Taylor, 1986); because certain supra-individual entities such as species and ecosystems have their own specific property, be it their continuity over time or the maintenance of their identity, their stability or their integrity (Callicott, 1989); because life as a whole is driven by a principle that transcends us – the principle of evolution – and because we form a community with the rest of the living world of which we are neither the masters nor owners but simply, as Aldo Leopold put it, "fellow passengers with other species in this great Odyssey of evolution" (Leopold, 2000).

Conceiving of the values of biodiversity without taking account of the possibility of integrating what it is worth in itself or the ways in which it benefits from entities other than just human beings would be unjustifiably chauvinistic (Routley, 1973). It would also mean failing to take account of the strong intuitions that have given birth to many environmentalist and conservation biology movements. In the article that acts as the "birth certificate" of this discipline, Michael Soulé (1985) did indeed state that the normative core of this new field of

research resides in the recognition of the intrinsic value of biodiversity, with the expression "intrinsic value" in this context being taken to mean the non-instrumental value – the value attributed to something in itself – disregarding its utility for anything other than itself. However, the notion of natural capital does not, in any manner, allow us to take account of this important aspect of the values of nature and of the reasons that we might have to protect it.

Independently of non-anthropocentric values, the notion of natural capital – if only because it relates metaphorically to the economic field – may skew the perception of natural values in favour of the most easily conceivable manifestations of these values in economic terms. To put it more simply, even if, as we have noted, the notion of natural capital does not necessarily imply that this capital will be quantified monetarily, the main justification for this metaphor comes precisely from the fact that it opens up practical possibilities to integrate costs and ecological benefits at the accounting level in return for their expression in monetary terms. However, certain values are not quantifiable – especially the intangible values that are often referred to as cultural ecosystem services.

The Millennium Ecosystem Assessment (2005) provides a list of purportedly "cultural services": Cultural identity or diversity, spiritual and religious values, knowledge systems, educational values, inspiration, aesthetic values, social relations, sense of place, cultural heritage values, leisure activities and eco-tourism. Although leisure services can, to a certain extent, be justifiably considered as services, most of the components of this list are not, strictly speaking, benefits. Indeed, just because something produces benefits does not mean that it can be reduced to the notion of benefit. It is not because friendship may seem useful to us in many respects – precisely because our friends render services to us – that its value can be reduced to the sum of the services that it represents. On the contrary, someone that only seeks to make friends in order to benefit from them would in fact be incapable of forming true bonds of friendship, which are, in their very essence, relationships with no ulterior motives, in which the other party is important to us for what he or she **is** rather than what he or she can offer us. Likewise, while the link with nature may have a positive impact on our well-being because it enriches our spiritual life or exalts our aesthetic emotions, this link in itself cannot be reduced to a mere service (Maris, 2014). The cultural values in action in our relationship with nature are, to a much greater extent, the intricate network on which the identities and preferences of human beings are mapped out in their relationships with themselves and the natural world. These are irreducible values, which are very poorly conveyed by notions such as ecosystem services and natural capital. They cannot be quantified and are probably incommensurable with other types of goods and services. They are the fruit of a dynamic joint production between ecosystems and societies, and it is usually impossible to determine which ecological entities represent the natural capital from which they are derived.

For these cultural values, as for non-anthropocentric values, the notion of natural capital is not in itself problematical as it quite simply refers to something else altogether. However, it is important to emphasise the existence of these blind spots and stress that natural capital only amounts to a part of what is important to us in our desire to protect nature, and that an environmental policy approach based exclusively on the conservation of natural capital could never, under any circumstances, succeed in encapsulating the fundamental values of our relationship with the living world – values that are as firmly based on respect for the living world itself (non-anthropocentric values) as on our own identity (cultural values).

A very narrow view held by politicians

Although the notion of natural capital has triggered numerous debates between environmental economics and ecological economics, these two families of use converge in their desire to highlight the fact that economics can and must take care of environmental problems. In the economic field, the metaphor of natural capital, within the rationality and vocabulary specific to this discipline, thus allows for the internalisation of the concern for the ecological conditions of human development.

But the people that use and defend the notion of natural capital have much more ambitious claims than the development of a technical concept that is limited to the field of economics. They are generally much more concerned with providing a public decision-making tool, and the very fact that this publication has been produced reflects the decision-makers' interest in this notion. In the wake of its appearance in the scientific literature, the reference to natural capital has spread well beyond the field of economics, and particularly into the spheres of international governance, via the Brundtland Report, for example, which formalised the idea of sustainable development (CMED 1987), and then after the Rio Earth Summit in 1992 in a wide range of national biodiversity strategies, in NGOs (e.g. in Carley & Spapens 1997), and within the World Bank.

Such a tool is not only descriptive, however. It has a strong, and often implicit, normative capacity, concerning the values of nature and the aims of harmonious coexistence. Indeed, talking about natural capital and stressing the need for public policies to adopt this notion – through indicators such as green GDP, for example – does not just imply offering a neutral but colourful view of nature or of the operation of ecosystems. It also involves capturing, through this utilitarian and economic view of nature, the essence of the relationships

between citizens and nature (a strictly instrumental valuation) and the aims of public action (economic optimisation or maximisation).

Demanding that nature protection policies be deployed in line with an approach that seeks to maintain the natural capital (Daly, 1995), means encouraging decision-makers to focus exclusively on the instrumental values of nature – in other words, to protect natural environments only to the extent of the benefits we can derive from them, even assuming the adoption of a broad conception of these benefits that includes the indirect benefits relating to the operation of ecosystems and the potential long-term benefits. As we have seen in the previous section, such a view of the values is very narrow and fails to take account of certain essential values such as non-anthropocentric values and cultural values. Furthermore, the idea that public action should aim to maximise capital, regardless of whether we accept substitutions of different forms of capital, in some respects boils down to extending rational choice theories to public action (Neimun & Stambough 1998). In the same way that a perfectly rational person would tend to maximise the utility of these choices, collective action could take the form of a maximisation exercise in which the environmental costs and benefits would be taken into account better than they are now, precisely because they could be expressed at the same level as economic costs and benefits. The policy would thus be reduced to an optimisation algorithm in which the required ingredients would essentially be those of the joint expertise of ecologists and economists. The knowledge of critical natural capital (defined in biophysical terms by ecologists), in addition to the variations of surplus natural capital and of the supply of ecosystem services, would guarantee the best public decisions. This is an extremely poor view of political action which disregards its specifically political dimension. It is bereft of public, debate, conflict and the collective construction of a common world of shared values – all that remains is a cold and "objective" governance that seeks to maximise the sum of the individual utilities, conceived of in an atomic and static manner.

Such a view of the possible use of the notion of natural capital in public policies is obviously exaggerated but it nevertheless remains representative of a sort of ideal to which several advocates of the ecosystem services and natural capital-led approaches aspire (Costanza et al. 1997). It is also interesting to discover in which circles and with which audience this metaphor is the most successful. The major international texts on the protection of nature (Convention on Biological Diversity, Aïchi Targets, The Future We Want (Rio+20)) do not mention it. Certain declarations even clearly distance themselves from this metaphor (People's Summit Declaration[17]). At the same time, the business world has shown great enthusiasm for the notion of natural capital (Natural Capital Declaration (NCD)) and the European Union has made it the main aim of its environmental strategy (To protect, conserve and enhance the Union's natural capital (Article 2)).

Less than a political tool, the metaphor of natural capital sometimes seems like an invocation. It relates to an apolitical level at which experts and bureaucrats would be in charge of decision-making for society. But values of nature – and consequently the value of natural capital – are a field of creativity, struggles and transformation. Defining natural capital, even in its technical sense and limited to just the instrumental values of nature, means deciding what is important to us and what is worth bequeathing to future generations, knowing whether peat bogs are more important than suburban housing estates, and whether we can live decent lives in a world without sand lilies, ocellated lizards and ancient forests. The valuation of ecosystems and biodiversity is without doubt a key political issue and it is reassuring that decision-makers are showing an interest in it. However, given the heterogeneity of the values concerned, their dynamics and their underlying power and legal issues, this valuation cannot be reduced to an accounting task that would seek to record the benefits that we derive from ecosystems in a purportedly objective manner and then reduce them to a common monetary value.

According to Akerman (2003), the success of the metaphor of natural capital beyond the academic sphere has had a dual impact: 1) Extending computational (and especially monetary) approaches to environmental questions – in some respects forcing them to be absorbed into the economic sphere and 2) Marginalising the other forms of comprehension of these questions and more broadly of the relationships between societies and their environment. If these observations are confirmed, then the notion of natural capital, which as we have seen may be useful provided that we are aware of its limited scope for shaping the values of nature and political relations, could pose more risks than the benefits it might offer in the quest to seek ways forward.

Indeed, while integrating environmental problems into the economic sphere is most probably a lesser evil than maintaining the status quo, which allows the environmental cost of many economic activities to be completely ignored, it is important to guard against the second impact at all costs. More than ever, we must take account of the importance, diversity and heterogeneity of the values of nature. To this end, it is important to find ways to understand these values that circumvent the existing power relationships and injustices in order to avoid favouring the values (and interests) of the parties that are already the most economically and politically powerful. Multicriteria and participative approaches (Munda, 2004) (Hisschemöller 2001) are still at an

[17] http://rio20.net/en/propuestas/final-declaration-of-the-people%e2%80%99s-summit-in-rio-20

embryonic stage but are nevertheless highly promising ways of enriching public policies with a more complex conception of the values of nature than that given by the valuation of natural capital.

Conclusion

The gamble of environmental economics, which has been explicitly endorsed by certain environmental economists (Pearce & Atkinson 1993), is that economics, subject to several reforms and the integration of values of nature into its prevailing rationality, can help to resolve the environmental crisis facing us. Conversely, for the founders of ecological economics such as Daly (1995), the key issue is not to reform the standard economy but rather to revolutionise it by placing ecosystem thinking at its heart. Although these two movements are seemingly opposed, they actually converge in their way of seeking solutions to environmental problems within the dominant framework of anthropocentrism and a capitalist economy.

Such an aim is obviously praiseworthy. Considering the influence of economic exchanges on the lives of individuals and on the natural world today, it is urgent to reassess the rules of the game in order to ensure that the markets and finance are unable to pose such frequent threats to the well-being of individuals and the operation of ecosystems. In particular, the new knowledge of ecosystem services that we have acquired should help us to reconsider the notions of costs and benefits when we are assessing a project or a public policy in such a way that the immediate and monetary benefits do not always gain the upper hand over the indirect, long-term benefits. To this end, it would be a pity not to take advantage of the precious tool that is the notion of natural capital.

However, by gambling on the possible integration of environmental constraints into the prevailing model, we are denying ourselves the opportunity to challenge this model at a more fundamental level. It is always assumed that the political and economic frameworks could integrate environmental constraints without a radical upheaval. However, there is some justification in thinking that these prevailing frameworks are actually the cause of the current crisis. The radical instrumentalisation of nature, this divide inherited from modernism which imagined human beings to be the "masters and owners of nature" and likened progress to a complete liberation from natural constraints, is now revealing its limitations. We are aware of humankind's links with the entire living world and have a better understanding of the multiple dependencies that bind us to ecosystems. Similarly, the damaging effects of the race to accumulate and ensure economic growth on human societies and nature have been revealed: increased productivity impoverishes the soils, the over-consumption of fossil fuels disrupts the climate, mass-consumption generates more waste than can possibly be recycled and the globalisation of trade generates hitherto unseen inequalities.

Nature is not a form of capital. It is neither fixed nor at our disposal. The notion of natural capital is above all metaphorical. But at a time when it is becoming apparent that the current economic crisis has to a great extent been triggered by a society of (over-) consumption, accumulation and individualism – all consequences of the neo-liberal ideology that can trace its roots back to the founders of capitalism – it may be wise to question the relevance of adopting the vocabulary, the world view and rationality of the very movement that has caused the problem, so that we can attempt to resolve it. This observation puts environmentalists in a joint dilemma: should they adopt a language and tools specific to the model they want to transform on the pretext that they will be more efficient but with the risk of contributing to the perpetuation of this very system? Or should they distance themselves more radically from the prevailing approaches in order to open up new fields of discourse and action? Far from being able to answer this question, we hope that by defining the framework of legitimacy of the notion of natural capital as we have endeavoured to do so, and by casting light on the values that it ignores and the political issues that it could eliminate, we will be helping to limit the notion of natural capital to the appropriate contexts and encouraging researchers and decision-makers not to settle for a lesser evil but rather to pursue more ambitious aims associated with the valuation and conservation of the multiple values of biodiversity and ecosystems.

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Ten Brink, in this book.

Theoretical economic framework: from "growth" to "green growth"

At the heart of the integration of nature into theoretical models of growth, the concept of "natural capital" has been a source of misunderstandings regarding the intentions of its promoters. In its theoretical sense, it is interpreted alternatively as a new factor in the production function F(K, Knat, L), a new component of social well-being U(C, Knat) or as a new price via instruments used for the valuation of externalities. But this economic formatting of natural capital, which is necessarily a very narrow approach, has been perceived as an attempt to commodify nature. As monetary metrics may also imply that the substitution of different types of capital (manufactured, human and natural) is possible with no regard for the critical thresholds specific to natural dynamics.

Taking account of the polysemy of the concept will allow us to clearly define the nature of this capital. It is not a type of capital that can be appropriated and exchanged on a market. It is the product of a social and regional but non-market dialogue concerning the definition of missing values whose meaning is fundamentally political.

The clarification of the concept of natural capital will facilitate a debate on the quality of growth. How does the consumption of nature contribute to growth? How much impact does the destruction of nature have on growth, or to put it in another way, what is "true" growth?

Natural Capital – an old concept with a new life

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"Natural Capital" (NC) is a term proposed by David Pearce (Pearce et al., 1989), as a metaphor to shed light on the role of nature in supporting the economy and human welfare. The concept builds on the idea of manufactured capital as one of the factors of production (together with land and labour), which was introduced by Adam Smith and David Ricardo in the eighteenth century.

The term "capital" refers to a stock of materials or information, which can generate a flow of goods and services that improve human wellbeing. Paul Ekins (1992) defines four kinds of capital, i. e. manufactured, human, social and natural capital (see also Ekins, 2008 and Box 1), where the latter is constituted of the stock of natural assets that provide society with renewable and non-renewable resources (e.g. timber, water, fossil fuels, minerals) and a flow of ecosystem services.

The analogy with other forms of capital, such as manufactured and financial capital, has helped to highlight the role of nature in the economy. It has also been useful for underlining the loss of natural capital and in exploring the underlying causes of its unsustainable use and management (ten Brink et al., 2012).

The term natural capital is often used synonymously with biotic natural capital (i. e. biodiversity as an asset). It is, however, a broader concept and one that includes both biotic and abiotic elements. It has also been used as shorthand for the value of the flow of services, and also as a measure of the stock. Furthermore, in economics and finance, the sum of the flow of value into the future can be seen as the value of the capital stock, its "capitalisation" or "capital value" [18]. It is therefore important to be clear as to what can be considered as natural capital, how the stock of natural assets differs from, but links to, the flow of goods and services, and what is meant when capital stock and its values are discussed.

Figure 1 below presents an illustration of natural capital and its relation to the flow of goods and services that builds on the analytical framework developed in the context of the EU 'Mapping and Assessment of Ecosystem and their Services' initiative (European Commission, 2013). Part of natural capital focuses on biotic elements and includes ecosystems as assets (i. e. ecosystem capital) as well as biodiversity as assets. These lead to flows of ecosystem services they provide to society (see Figure 2). Natural capital also includes sub-soil assets (e.g. geological resources), and other purely abiotic assets such as the ozone layer and climate system. These assets in turn lead to a flow of broader environmental goods and services. Flows of goods include the flow of minerals and fertilisers, solar and wind energy.

[18] The value "today" of all future value flows can be presented as a "net present value (NPV). This in practice is an economic exercise, developing a projection of values into the future and applying a "discount rate" (broadly a measure of the opportunity cost of capital) to the future values and summing them up into a single value today – the NPV.

Box 1 : The different types of capital

Manufactured or "man-made" capital includes produced assets that are used to produce other goods and services, such as machines, tools, buildings and infrastructure – i. e. fixed assets. Manufactured capital can also include money and other financial assets, sometimes called "financial capital". Financial capital is seen by some as a distinct category of capital (Aronson et al., 2007 and Van Andel & Aronson, 2012).

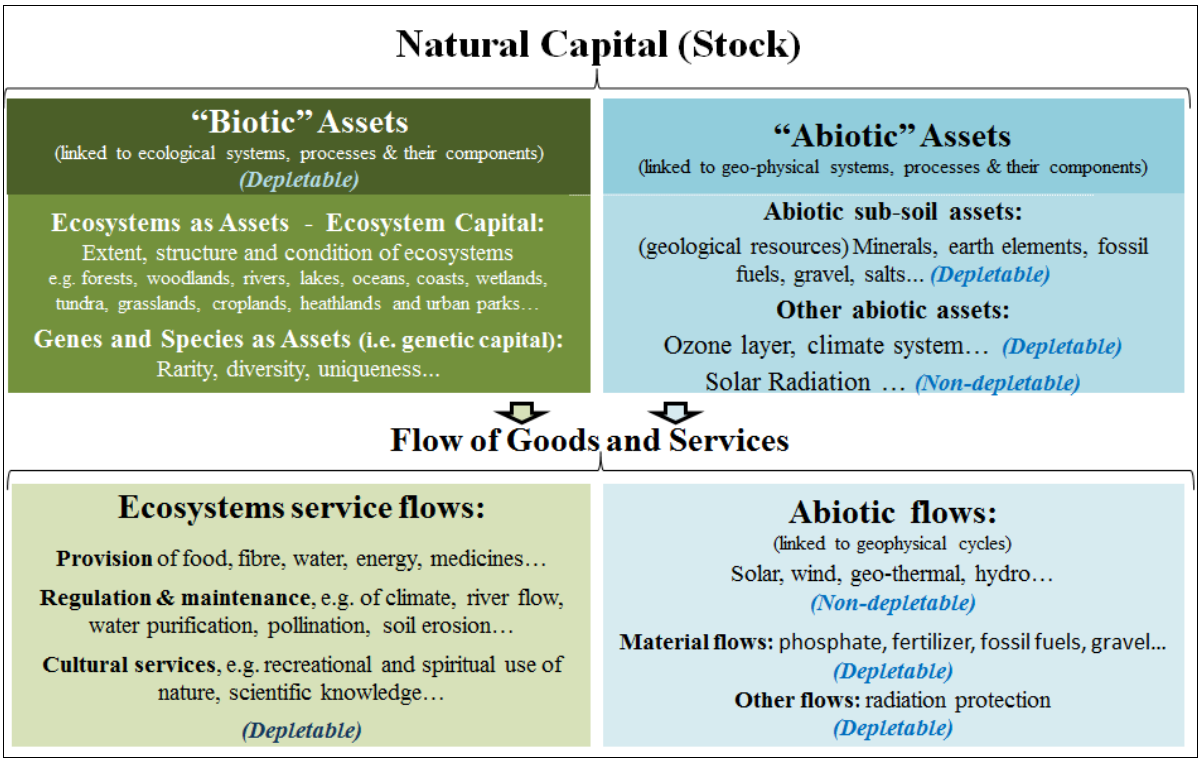
Human capital: This generally refers to the health, well-being and productive potential of individual people and includes mental and physical health, education, motivation, and work skills. These elements contribute to a happy and healthy society and also improve opportunities for economic development through a productive workforce.

Social capital: Like human capital, this is related to human well-being but on a societal rather than individual level. It consists of the social networks that support an efficient, cohesive society and facilitate social and intellectual interactions among its members. Social capital refers to those stocks of social trust ; norms and networks that people can draw upon to solve common problems and create social cohesion, e.g. neighbourhood associations, civic organizations and cooperatives. The political and legal structures that promote political stability, democracy, government efficiency, and social justice (all of which are good for productivity as well as being desirable in themselves) are also part of social capital.

Natural capital: In addition to natural resources like timber, water, and energy, and mineral reserves, that are generally priced, natural capital also includes natural assets that are not easy to value monetarily (e.g. species diversity, ecosystems that perform ecological services like climate regulation and water provision) and can be considered as the components of nature linked directly or indirectly to human welfare. Forests, agricultural land and soil, grasslands, wetlands, rivers, and coral reefs are examples of natural capital.

Source : ten Brink et al., 2014, building on TEEB (2011), Pearce et al., (1989) and Ekins (1992)

Figure 1: The Components of Natural Capital



Source: Adapted by authors from MAES analytical framework, European Commission (2013)

Examples of biotic natural capital include forest ecosystems, grasslands and croplands, rivers, lakes, coastal areas and oceans, as well as urban parks. The more biodiverse rich of these are often designated as protected areas for biodiversity (e.g. EU Natura 2000 network), while others have land use permits for activities that focus on a particular ecosystem service – i. e. croplands and forests for food and timber. In between these can be land designated (i. e. via zoning within spatial plans) for particular services (e.g. water forests, dune area for water filtration, coastal protection areas, or urban parks for recreation), much of which is increasingly recognised as green infrastructure that offers both eco-system services and biodiversity co-benefits. The genes and species component of biodiversity can also be important assets for health, society and the economy, as illustrated by genetic materials that can prove valuable for pharmaceuticals and medicines, and gene diversity that can support crop resilience to pest, or species resilience to outside pressures.

The importance of these ecosystems (and hence the value of ecosystems as assets, or capital) relates to their extent, structure and condition, as well as the interaction between the ecosystem and the social and economic systems that manifest themselves through the supply of ecosystem services. In addition, natural capital includes species and genes. Here the rarity, diversity and uniqueness are key factors contributing to its importance to society and the economy. The importance of this natural capital has historically been under-estimated or overlooked, with the exception of ecosystems' abilities to provide provisioning services such as of food, fibre, and fuel.

On the abiotic side, natural capital includes assets such as geological resources (minerals, fuels) and other abiotic assets such as the ozone layer, climate system and solar radiation. These assets lead to a flow of goods and services in the form of materials (fuels, fertilisers), solar radiation and wind, as well as radiation protection. The geological resources have long been valued, and the abiotic assets of the ozone layer, climate system and solar radiation are increasingly understood and valued, though still less integrated into policies, economies and accounting systems than sub-soil assets.

Some of the natural assets and services, biotic and abiotic alike, are renewable (i. e. flow of services continuously renews if the asset is not depleted or degraded), such as clean water provision and fish provision. Others are not renewable – such as phosphates and minerals. Some assets and services are depletable – e.g. ecosystems and fish provision – and others are arguably not – e.g. solar radiation and solar insolation. The management and sustainable use of natural capital needs to take into account whether the assets, goods and services are depletable, degradable and renewable. This in turn requires an appreciation of the interactions of the stock of the asset (the capital), the flow of the good and services, implications of demands for services on the assets itself (e.g. over extraction of fish on the fish stock and hence future ability to produce fish) and implications of the degradation of the asset due to other pressures (e.g. soil degradation and agricultural outputs).

Historically, where (policy and statistical) emphasis has been on natural capital, it has been on certain abiotic assets and their flows. The current emphasis on biotic natural assets and the associated flows of goods and services is seeking to help develop a fuller picture of natural assets, of the natural capital that forms a basis for economies and societal wellbeing (see Figure 2).

However, it should be noted that the distinction between biotic and abiotic elements is not so clear-cut, as an ecosystem is "a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit" (Convention on Biological Diversity, art.2). For example, water is an abiotic element in itself, but ecosystems play a key role in its cycle, and also water is essential for nutrition and plays a key role in all ecosystems (Haines-Young and Potsschin, 2013). As another example, fossil fuels (an abiotic resource) were derived from the biological degradation of organic matter.

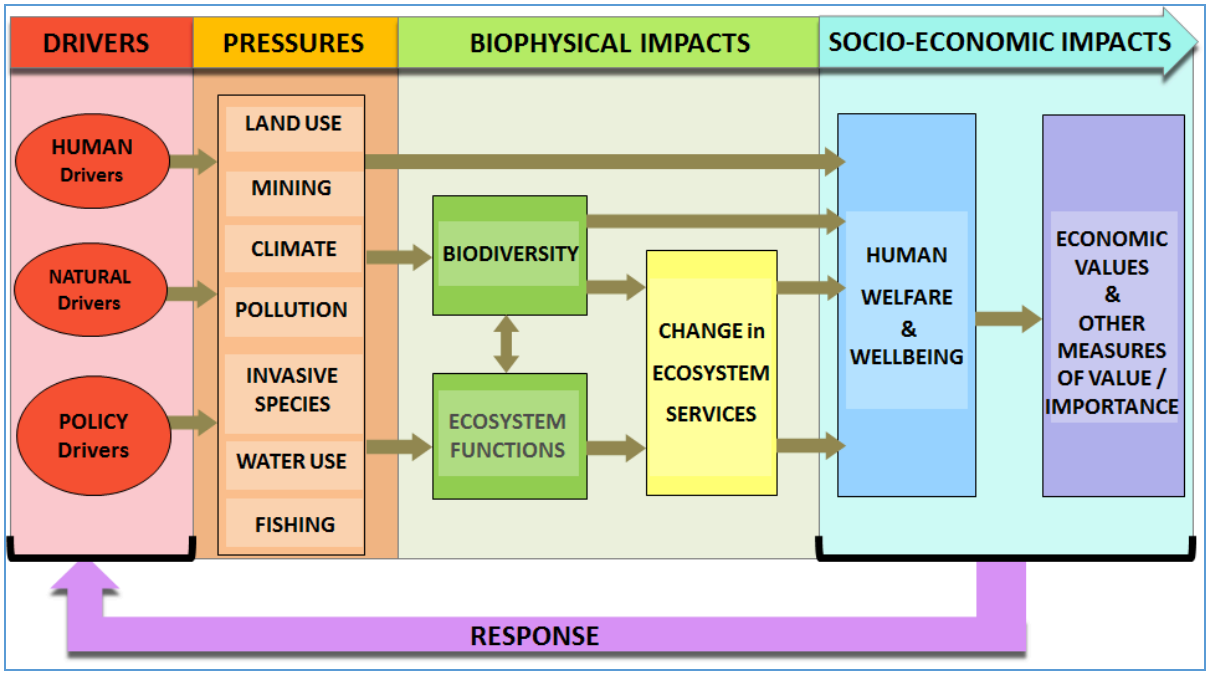
All four types of capital are needed to support human welfare. However, an important share of natural capital is non-substitutable with manufactured or other kinds of capital, and the manufactured, human and social capital would not be built without natural capital (Costanza et al., 1997). For example, minerals, metals and energy are needed to build the components of manufactured capital ; human and social capitals are heavily dependent on the physical health of individuals, who in turn are dependent upon ecosystem services to maintain good health, including food, freshwater, timber and fibre and a wide range of regulating ecosystem services (e.g. water purification, nutrient cycling, protection from floods and other extreme events). Thus, natural capital is arguably the most important of the four types of capital as it is embedded in and underpins other forms of capital.

Natural capital is a driver of wellbeing, livelihoods and the economy

Nature consists of ecosystems, landscapes, habitats, species, and genetic materials. It provides a number of ecosystem goods such as food, raw materials, medicine, and water, as well as a range of services such as regulating the climate, contributing to air and water quantity and quality, and mitigating natural hazards (see Chapter x). Nature also offers a wide range of cultural benefits related to human health, recreation, tourism, scientific knowledge, spiritual/cultural identity, and social inclusion. These benefits depend on the functions of ecosystems and the interactions of the ecosystems with society and economic activity. The ecosystem functions reflect the quantity, quality and diversity of species, genes and ecosystems and the interactions between the different components of nature (including living and non-living elements). The interaction between nature's multiple functions and activities of our societies and economies, drive the value of the flow of ecosystem services. À range of natural and man-made drivers create pressures that can affect the ecosystem state and functions, which in turn can affect the nature and level of services, and subsequently its value.

The schematics below present a simplified illustration of these interactions. Figure 2 depicts pathways from drivers to value of impacts, illustrating how changes in biodiversity can occur from a range of pressures, and lead to changes of ecosystem functions, which in turn lead to changes in the provision of ecosystem services, that affect human welfare and wellbeing, and that can be measured using a range of metrics.

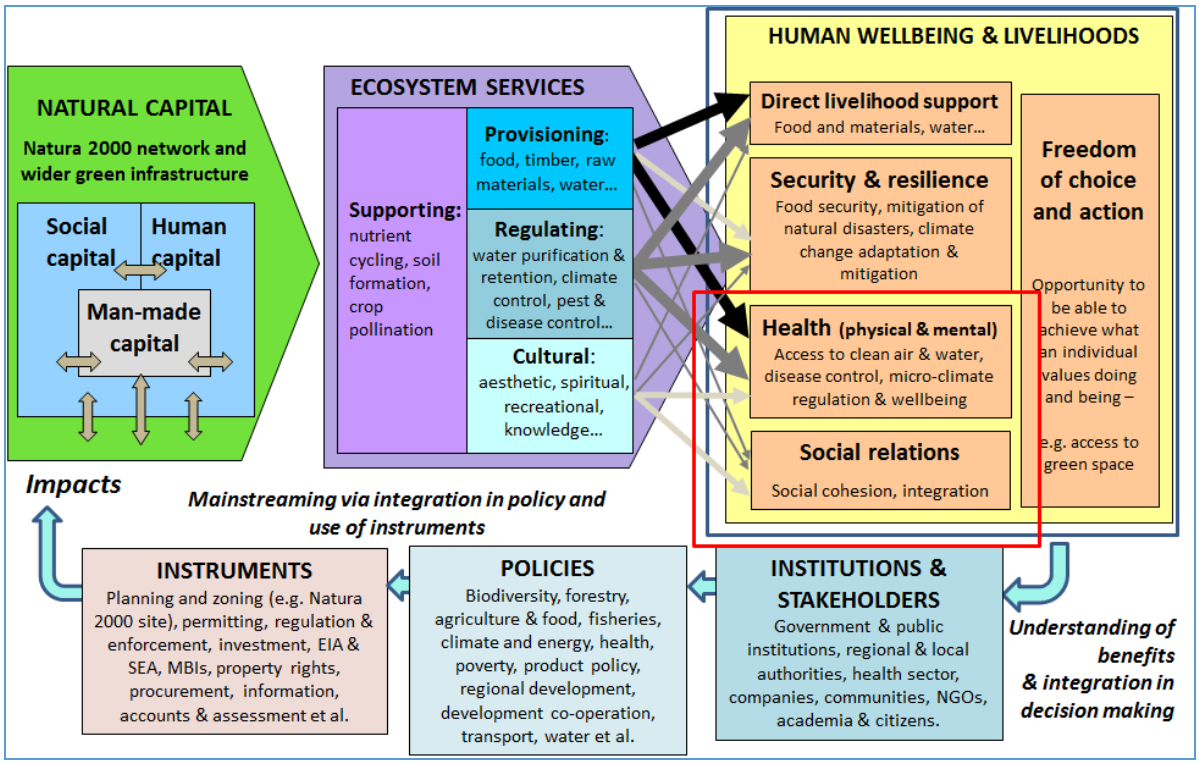
Figure 2: The Pathway from Drivers to Impacts



Source : Adapted by authors from TEEB, 2011 and Braat et al., 2008

Figure 3 shows the interactions of the four forms of capital, their role as a driver for ecosystem services, which in turn support (the many dimensions of) human wellbeing and livelihoods – direct livelihood support (e.g. provision of food), security and resilience (e.g. mitigation of natural disasters), health benefits (e.g. micro climate regulation which can reduce the heat island effect in cities), social relations (e.g. social cohesion through access to nature) and freedom of choice and action (e.g. freedom to do what one wishes to do). Furthermore demonstrating the multiple values of nature can lead to an appreciation of the importance of nature by institutions and stakeholders. This can lead to them integrating the role and values of natural capital into their decision making processes, governance, instruments choice and implementation, that in turn have impacts on nature and hence natural capital (and the three other forms of capital) – see section 5.

Figure 3: Natural Capital, Ecosystem Services, Wellbeing & Livelihoods and integration into decision making, policies and instruments



Source: Own Representation building on MA (2005) and TEEB (2011a)

Nature is more than natural capital

The concept of Natural Capital is anthropocentric, as it focuses on those aspects of nature that benefit humans, and do not directly reflect the intrinsic value of nature and the benefits to other species [for ethical discussions see chapters 1 and 3]. However, in certain contexts it can play an important political role, as it can help to shed light on the benefits that nature provides to human society ; and consequently on the need for nature protection not only for moral reasons but also as a way to enhance human wellbeing and economy. As such, it can contribute to influence policy-making towards an improved environmental protection, besides acting as an environmental education tool for awareness building. In summary, while nature is understood to be more than "natural capital", it is nonetheless a useful metaphor to communicate the value or benefits of nature to people and the wider economy (MA, 2005).

The concept, however, also has risks and controversy, as focusing only on benefits to society can overlook the intrinsic values of nature and the moral issue that nature is not only there for humanity's benefit. The concept could also be seen as encouraging commoditisation of nature as expressed in Rio at the People's Summit that ran parallel to the Rio+20 Summit in 2012 (see People's Summit Declaration[19]; and also Levidow 2014, McCauley, 2006 ; Kosoy and Corbera, 2010). Furthermore the use of payments, while useful in certain contexts, creates risks in others, notably where there are collective responsibilities sustaining resources through the commons and/or a culture of stewardship based on responsibility, culture and social norms. Furthermore, the use of the natural capital concept may lead to the prioritisation of the protection of areas that are more directly used by humans over others with higher biodiversity value. This may be useful for service provision, but may lead to lesser support for biodiversity conservation for its intrinsic value.

For this reason, it is important to understand such risks and the natural capital concept needs to be seen in conjunction with biodiversity objectives. And accounting needs to be used as a complementary tool to wider biodiversity and social indicators and insights.

[19] http://rio20.net/en/propuestas/final-declaration-of-the-people%e2%80%99s-summit-in-rio-20

Furthermore, it is important to understand to what extent different tools (such as natural capital accounts, see chapter 18), cost-benefit analysis, environmental impact assessment (EIA) and strategic environmental assessments (SEA) do (or could potentially) take into account different types of natural capital, changes in the quantity and state of the natural assets, and the flow of associated ecosystem services. This will help understand what importance such tools give to nature and natural capital – i. e. how much of the complexity of nature and interactions with society and the economy can be captured by such instruments, how this might affect the meaning of the results and hence how best to use these tools.

Commitments to integrate the Natural Capital concept are increasing

The TEEB initiative (The Economics of Ecosystems and Biodiversity, launched by the European Commission and German Ministry of Environment and now under UNEP management) underlined and promoted the concept of natural capital, noting that "*The world's natural capital is not a luxury for the rich but a necessity for all. The value of nature has long been overlooked in economic signals, policy instruments, public investments and national accounts. This has contributed to unprecedented erosion of natural capital, causing economic loss and social hardship and undermining prospects for long-term prosperity and quality of life. Now, however, awareness of these many values is growing and policy makers are beginning to change their approach to natural capital.*" (Page 453, ten Brink et al., 2011 in TEEB 2011)

This understanding is increasingly reflected either explicitly or implicitly in a number of high-level policy commitments that integrate the natural capital concept.

The global Strategic Plan for Biodiversity 2011-2020 under the UN Convention for Biological Diversity (CBD), to which over 190 parties committed at the CBD COP 10 in Nagoya,[20] Japan in 2010 (CBD, 2010), does not explicitly use the term natural capital, but arguably implicitly recognises the importance of natural capital. The 20 global biodiversity targets for 2020 (so called Aichi targets) do not mention the term "Natural capital" explicitly, but the targets do mention the values of nature and several are dedicated to the conservation and restoration of ecosystem services. In particular, Aichi Target 14 addresses 'essential ecosystem services'[21] and Target 15[22] is focused on carbon sequestration and natural hazards management[23]. Aichi Targets 1 and 2[24] focus on the values of biodiversity, with ecosystem services values implicitly integrated. Similarly, the Rio+20 outcome document – *The Future We Want* – does not use the term "natural capital", but rather uses the term, "natural resources and ecosystems", though again recognises the multiple values of nature to society and the economy as well a the intrinsic values – "*We reaffirm the intrinsic value of biological diversity, as well as the ecological, genetic, social, economic, scientific, educational, cultural, recreational and aesthetic values of biological diversity and its critical role in maintaining ecosystems that provide essential services, which are critical foundations for sustainable development and human well-being"* (para 197, The Future We Want - Outcome document[25]).

The EU's 7th Environment Action Programme, on the other hand, explicitly recognises the importance of natural capital. It has as its first priority objective - *To protect, conserve and enhance the Union's natural capital (Article 2).* It also states that (point 17) *The Union's economic prosperity and well-being is underpinned by its natural capital, i. e. its biodiversity, including ecosystems that provide essential goods and services, from fertile soil and multi-functional forests to productive land and seas, from good quality fresh water and clean air to pollination and climate regulation and protection against natural disasters.*

In addition to these two high-level examples, a range of countries have integrated the concept of natural capital into their policies and decision-making processes. As illustrated by the development of the "Natural Capital Committee" in England and the DE Natural Capital Germany initiative. The former is an independent advisory body, set up in 2012, that provides advice to the government on the state of England's natural capital (…forests, rivers, land, minerals and oceans) and produces a regular set of State of Natural Capital reports that include recommendations for, inter alia, investment in natural capital[26]. The latter, German, initiative engages a wide range of stakeholders to focus on natural capital values and synergies with business, climate,

[20] Tenth Conference of the Parties (COP10) of the Convention of Biological Diversity (CBD)

[21] Target 14 states that "By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable".

[22] Both within Strategic Goal D: Enhance the benefits to all from biodiversity and ecosystem services

[23] Target 15 states that "By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification."

[24] under Strategic Goal A:Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society

[25] https://sustainabledevelopment.un.org/futurewewant.html

[26] https://www.naturalcapitalcommittee.org/

rural areas and cities, as well as aiming to develop a common vision for *Natural Capital Germany: New Policy options* (to be concluded 2017).

At the level of the private sector, businesses have adopted the Natural Capital Declaration (NCD) which includes a commitment to account for natural capital in their balance sheets (NCC, 2012). The NCD commits companies that sign the declaration to integrate natural capital considerations in loans, equity, and insurance products, as well as in accounting, disclosure and reporting frameworks[27]. The expectation is that this approach will 'help businesses understand the risks and opportunities that arise from accounting for natural capital in their decision-making processes[28].

The above examples are a subset of commitments that have been adopted at different levels that integrate the concept of natural capital explicitly or implicitly. For the moment the promise of benefits from the use of the natural capital concept is stronger than the arguments warning of the risks, at least in the European context. The overall benefit of the use of the natural capital concept will importantly depend on how the term is operationalised.

Tools for operationalising the Natural Capital concept

There is a wide potential to operationalise the natural capital concept in policy. This is known as mainstreaming or integration and makes use of assessment tools to target, and policy instruments to help implement, the concept in practice. The 7EAP recognises the wider contributions of policies to nature, noting that - *A substantial body of Union legislation seeks to protect, conserve and enhance natural capital, including the Water Framework Directive, the Marine Strategy Framework Directive, the Urban Wastewater Directive, the Nitrates Directive, the Floods Directive, the Priority Substances Directive, the Air Quality Directive and related directives, and the Habitats and Birds Directives*[29]. Kettunen et al. (2014) present an assessment of the current integration of natural capital and ecosystem services into policies (at the EU level) - looking at the conceptual and operational integration[30]. This assessment showed that within the EU there has been a range of policy developments and reforms that have provided opportunities for taking up the ecosystem service concept across different sector policies, potentially directly affecting the EU's 28 Member States.

However, while there is good conceptual integration of natural capital in a range of EU policy areas, operational integration is generally weaker. Consequently, the existing EU policy framework for natural capital and ecosystem services remains far from optimal. This is particularly true when considering the integration of natural capital and ecosystem services into different sectoral policy instruments. The majority of the existing policy instruments are still primarily focused on regulating ecosystems from the point of view of specific natural resources - in other words addressing single ecosystem services such as provisioning of food, fish and timber - rather than addressing the full range of services ecosystems provide and linkages therein.

There is a wide toolkit of measures and instruments that can help to address the above identified gap and fully operationalise the natural capital concept (see Figure 3 ; see also TEEB 2011). These include information tools such as the System of Environmental-Economic accounts (SEEA), assessment tools (such as valuation, extended cost-benefit analysis, multi-criteria assessment, SEA, EIA, and mapping), economic instruments (e.g. payments for ecosystem services, and subsidies and their reform), regulation (designation of protected areas, and other zoning options to reflect biodiversity and wider natural capital ; as well as property rights).

On SEEA there are a range of global and national commitments to improved environmental accounting – in practice committing to the use of the SEEA, with some focusing on natural capital accounts under the central framework (i. e. economic accounts for sub-soil assets, timber, fish), others focusing on SEEA-Experimental ecosystem accounts, which take account of stocks (e.g. biophysical asset accounts) and/or flows (ecosystem services flow accounts) - see Weber 2014 and chapter 18 of this book.

Payments for Ecosystem Services (PES) tools are ways of creating a value for services from natural capital with beneficiaries of the service rewarding providers of the service. There is a lot of interest in this tool, though it too, is not without risks and costs (upfront investment costs, issues of property rights, questions of suitability

[27] http://www.naturalcapitaldeclaration.org/wp-content/uploads/2013/10/NCD-booklet-English.pdf

[28] https://iucn.org/news_homepage/all_news_by_theme/economics_news/?17183/IUCN-leads-the-way-towards-valuing-nature-in-business

[29] Directives 2000/60/EC, 2008/56/EC, 2008/56/EC, 91/271/EEC, 91/676/EEC, 2007/60/EC, 2008/105/EC, 2008/50/EC, 2004/107/EC, 2009/147/EC and 92/43/EEC respectively.

[30] Conceptual integration: Conceptual integration refers to the integration of ecosystem services and natural capital into the overall premises and objectives of different policy areas. Conceptual integration is assessed based on the key strategic policy documents setting out the scope and objectives for sectoral policies.

Operational integration: Operational integration refers to the uptake of ecosystem services and natural capital in practical policy implementation. Operational integration is assessed based on the availability of concrete policy tools and instruments that take up and implement the concepts.

of using economic incentives and availability of funding) – see ten Brink et al 2011 and chapter 17 in this book.

Protected areas, such as the EU's Natura 2000 network, are arguably the core of natural capital, covering the EU's rich ecological heritage, rare and endangered species, and providing a wider range of ecosystem service benefits. Such areas underline that it is both biodiversity of intrinsic value and natural capital that supports our society and the economy – see ten Brink et al., 2012 and Kettunen and ten Brink 2013 and chapter 14 in this book.

Investment in restoration (e.g. forest, wetlands, agricultural lands grasslands) is similarly an important instrument to respond to an appreciation of multiple values of nature. For example such investments can be made to improve ecosystem service delivery of forests and agricultural land, to improve coastal protection from storm surges and sea level rise by restoring multi-functional salt marshes to help with climate adaptation, to peatland restoration to secure the carbon stored and increase the carbon sequestered while also supporting biodiversity. It is often better - from both a biodiversity and economic perspective - to avoid the need for restoration, but when land (or marine areas) are degraded the economic and biodiversity arguments often clearly suggest that restoration is in society's best interest, leading to an appreciation of natural capital and its value.

To understand the benefits of action and the costs of inaction, it is important to understand the wider set of trade-offs of any land use decision, permit, management practice, policy commitment or instrument implementation. For this, an extended CBA can be a useful tool as could wider multi-criteria assessments. Berghöfer, A. and Röder, N. (2014) present an interesting recent analysis of the relative merits of different land use options for peatland in Germany, taking into account the wide set of ecosystem services to compare investment in peat land restoration (e.g. by rewetting), to different potential agricultural uses of the land (see also TEEB 2011). Ultimately, there is a need for assessments to take account of the multiple pros and cons of options, understand the biophysical aspects of any decision, the economic arguments and the social winners and losers.

The EU's MAES initiative is one major effort to support the understanding of the biophysical aspects of natural capital. This initiative, with bottom up engagement by Member States, aims at mapping and assessing Europe's ecosystems and the services they deliver. This ambitious commitment will support improved governance through better evidence provision, inputting into the science policy interface (SPI) and over time helping to integrate natural capital and ecosystem services in policymaking and implementation.

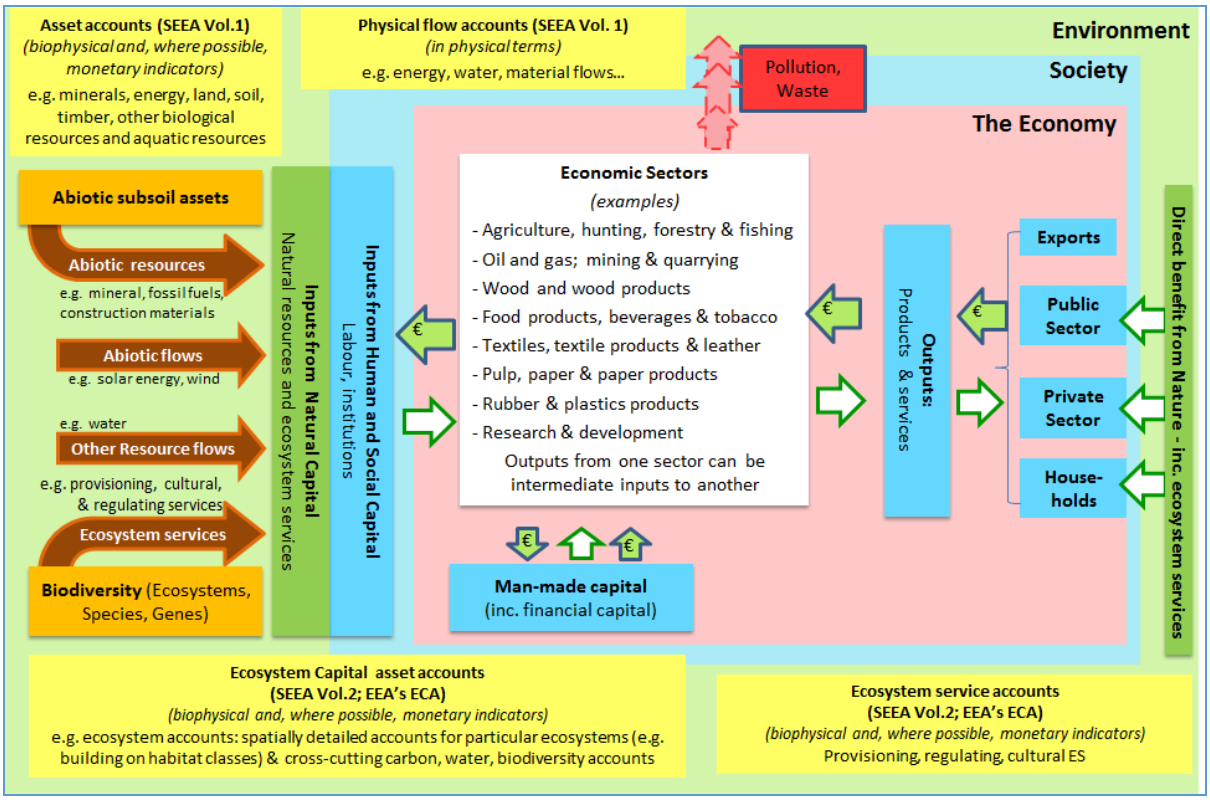
For a wider discussion of tools, see TEEB 2011 and http://www.operas-project.eu/.

Next steps for natural capital

There is an ongoing need for further mainstreaming of natural capital (and wider nature) into policies – to ensure that the social and economic values as well as the intrinsic values are duly taken into account (Kettunen et al., 2014 and 2015).

There is a need for further development of natural capital accounting (MAES and SEEA) to ensure not only that commitments are met, but that policy makers have additional evidence for decision making – see Figure 4 below that show the different SEEA accounts in the context of the economy, society and the environment and the associated natural capital stocks and flows of goods and services (see also and chapter 8 and 18 in this book).

Figure 4: Natural Capital, Ecosystem Services, Wellbeing & Livelihoods and integration into decision making, policies and instruments



Source : Adapted by authors from TEEB, 2011 and Braat et al., 2008

Similarly, the integration of multiple benefits of natural capital can usefully be integrated into assessments (IA, EIA, SEA) as well as extended CBA, and can drive commitments to reform harmful incentives and subsidies - as evidence of ecosystem service losses should help provide additional arguments for reform (see Oosterhuis and ten Brink 2014).

Overall, the objective should be to understand the planet's natural capital stock, how society and economy benefit from it, how changes to the natural capital stock can either create or destroy wealth and wellbeing. This should be done at the scale of the planet (to understand our "safe operating space", country and down to the project and local decision levels). This requires an understanding of how we interact with nature through the flow of services, and how our decisions drive changes in nature that can be positive (e.g. restoration and investment in natural capital stock) and negative (e.g. degradation or ecosystem loss). This will, in practice, require a plurality of tools and metrics (monetary and non-monetary) to cover the range of insights needed for a better understanding of the full implications of our actions.

Finally, for good governance it is critical that any assessment tries to identify what we do not yet know (i. e. some of the functions of ecosystems and risks of tipping points as ecosystem's degrade) and the implications of what we are measuring. As nature is more than natural capital, and there are intrinsic values of biodiversity complementing economic and societal values obtained from nature, it is important that the metaphor of nature being natural capital is not over-stretched or over-used, and that the rarity, uniqueness and richness of biodiversity are fully integrated in decisions and practices.

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Nature in economics – a conceptual history

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I describe the changing and contingent role of Nature in economics. To the Physiocrats, Nature was the source of wealth as well as an order which the economy is a part of. This also applies to the classical economists, for whom nature sets the distribution of revenues and limits the accumulation of capital. Nature is then gradually ignored by economics, especially among neo-classical economists, who are more interested in understanding the conditions of economic equilibrium than production costs. The economy, having become self-referential, is disembedded from physical processes. Economics encompasses Nature, which can therefore be analysed and regulated with the same instruments as the rest of the economy, I.e. prices: environmental economics is simply a field of application of general neo-classical principles. From the 1960s onward, some research works restore Nature's status as an interdependent system, in which the economy is just one transformational force operating within Nature's frames. Ecological economics, because it insists on the physical measurements of phenomena, renews the economic analysis of Nature, but fails to strongly modify the neo-classical approach.

This overview of the relationships between economic analysis and nature is not intended to retrace the history of the concepts used today by economists in their analysis of the environment. Such an approach quickly becomes a search for the precursors of contemporary thought; it often legitimises the current concepts which are portrayed as the necessary outcome of a process of analytical clarification.

Our intention is rather to investigate the changing and contingent role of nature in economic analysis: what view of nature is given by theories and tools of economic analysis? This view, far from being stable, branches out in different directions; it is subject to tensions and even oppositions. Placing the theories in their historical contexts, comparing approaches in different eras and examining the variations of nature's role in intellectual constructs inform us about the presuppositions behind the concepts. We can thus understand what they include and what they exclude, instead of being complacent about their relevance for solving environmental problems.

In a short piece like this one, we can only focus on the most abstract economic analysis. Indeed, its theoretical component reveals most clearly the relationships between the concepts. Through the purity of paradigms, it allows us to understand how economic analysis considers nature. A more in-depth investigation should study the practical knowledge forged in contact with the real management of some resources (particularly the economics of forestry or fisheries), and how these have been incorporated into general economic knowledge.

The source of wealth for the Physiocrats

The first economists were haunted by the origin and substance of value. Nature enters into their analyses through this founding question. In the mainly agricultural economic system of the 17th century, the Englishman William Petty (1623–1687) drew parallels between labour and lands in the creation of wealth: labour is the father of wealth and lands are its mother.

Physiocracy can be seen as a convenient *starting point* for systematic economic analysis. Around the leading figure François Quesnay (1694–1774), the Physiocrats insist on the role of the land as the sole source of wealth. Nature is the only force able to multiply wealth. The net product – the difference between what nature gives and what it receives – is harvested by farmers. Through economic exchanges, this net product is distributed to the unproductive classes, which consume as much as they produce. Rooting value in nature goes hand-in-hand with the general project of physiocracy: to establish a government by nature that replaces politics. The laws that must be enforced by the monarch are those dictated by the natural order. If they are followed, they bring prosperity to all. The importance of land to the Physiocrats bears witness to the link between power and property wealth in traditional societies. It reflects the still holistic framework of their thinking. This theory formulated by the Physiocrats also reveals a specific conception of value, i.e. the primacy of food over other goods. For them, nature is thus the organising frame of society and the source from which it originates.

The framework of accumulation for Classical economists

Running counter to the path taken by the Physiocrats, economists gradually came to prefer the second source of value according to Petty. Only labour adds value to production, as reflected by the labour value theory. However, the land does not disappear from economic thinking. In the classical political economy, the land still appears as a factor of production, alongside labour and capital. It is a major determinant in the analysis of distribution carried out by David Ricardo (1772-1823). Ricardo distinguishes among the revenues of three classes: workers, capitalists and landlords. Landlords receive a rent that corresponds to the difference in yield between their lands and marginal land, the least productive one. The profit is the difference between the yield of the marginal land and wages paid to workers that cultivate it.

The land thus plays a decisive role in the distribution of the revenues. Because of its decreasing yields, the land also limits the accumulation of capital. Indeed, Ricardo places his analysis of distribution within a capital accumulation dynamic. Capitalists invest their profit in capital, which leads to an increase in production. The resulting increase in the population leads to a search for new lands, with lower yields. The yield of the marginal land declines, the rent increases and cuts the capitalists' profit. When the marginal land can no longer cover the subsistence needs of the labourer that cultivates it, the profits are nil and the accumulation stops. The economy reaches its stationary state.

In classical economic theory, land is thus the frame in which the economic process operates, from both a static perspective – with the determination of the distribution of the revenues – and a dynamic perspective – with the end of accumulation. The land – i.e. nature – contains the economy. The notion of land is, however, idealised and devoid of its tangible reality. For the Physiocrats, the land had a life – it was capable of being improved or deteriorated – hence their interest in agronomic works which promised to improve agricultural production. For Ricardo, the land is reduced to a characteristic – a yield for a given surface area. It becomes a geometric notion and loses its biological characteristics; it becomes a mere *space*.

Marx's metabolic rift

Ricardo influenced the political economy throughout the 19th century, and in particular two figures we shall now be studying: Marx and Jevons, the originators of two antagonistic intellectual traditions.

Ricardo's lasting legacy can firstly be found in the work of Karl Marx (1818–1883). Marx transforms Ricardo's labour theory of value into a theory of exploitation. By applying the labour value to labour itself, Marx reveals the surplus value – the difference between the value produced by one hour of labour and the value needed to (re)produce one hour of labour. This surplus value is captured by the capitalist and its dynamics are for Marx at the heart of the evolution of capitalism: concentration of private means of production, which favours their socialisation; impoverishment of the working class, which prevents the realisation of the growing surplus value; the need for major investments to cope with competition, which impacts the rate of profit, etc. For Marx, this triple contradiction of capitalism must lead to a workers' revolution and the replacement of this economic regime.

Marx's vision of capitalism is not restricted to the relations between workers and capitalists. On the basis of his extensive historical knowledge, Marx also turns his attention to the peasantry and the opposition between town and country. Marx was very impressed with the theories of the chemist Liebig on the impoverishment of soils and was aware that the end of an organic, circular form of agriculture would jeopardise their fertility. As the rural flight separates the places of food production from the places of consumption, organic waste no longer returns nutrients to the soils, which eventually become impoverished and no longer suitable for farming. On the one hand, capitalism creates a shortage of nutrients in the countryside, and on the other, it creates an excessive concentration of waste in the cities, which is transformed into pollution. Marx refers to this as the metabolic “rift” generated by capitalism.

Marx and Engels were thus aware of the damage that could be caused by economic development. Their vast knowledge of history had made them familiar with the unexpected ecological consequences of human activities. Their materialistic view of the economy gives a role to nature. For Ricardo, this role was very limited, but for Marx, nature has again its own life, one that is endangered by the imbalances of the industrial world. Capitalism creates a rift in its metabolism and saps its nourishing powers.

The economic power of coal for Jevons

Ricardo's legacy extends to William Stanley Jevons (1835-1882), who would become his brilliant successor but also an ardent critic.

During the course of the 19th century, the British economy underwent radical changes. With industrialisation, the previously organic economy – i.e. dependent on living resources produced by the biosphere – becomes a mineral economy, depending on resources extracted from the earth, especially coal. In the 1860s, the British start to fear that their commercial and industrial power could be weakened if their coal supplies started to run out. Jevons contributed to this debate by publishing a book that would become popular and make him famous: *The Coal Question* (1865).

While this book has fallen out of favour with economists, it remains remarkable. Jevons examines all of the issues (technical, economic and geological) relating to coal. He describes the changes in coal production costs and prices and estimates the amounts of coal available underground in different countries by consulting geological reports. Rudimentary statistics reveal the paramount importance of coal for all production activities. Jevons produces a truly multidisciplinary work, combining several different methods in his examination of a single problem. By going back over the history of the British economy during the previous century, he shows that the use of coal leads both to the expansion of production and technical progress (invention of the steam engine and railways). He considers coal to be a driving force of the industrial revolution.

On the basis of this analysis, Jevons postulates that the cost of mining increasing amounts of coal will constantly rise, which will eventually jeopardise the competitiveness of British products. Jevons wavers between insisting on the absolute limits of production due to the limited amounts of coal available and fearing stagnation, especially in relation to other countries, which would result from a rise in the costs of mining coal. In fact, Jevons transposes the classical theory of capital accumulation – with coal replacing land – in line with the economic changes of the era. Indeed, he formulates an underground version of the stationary state.

What image of nature is produced by this adaptation of the classical theory? Even though coal is an inert substance – in contrast to Marx's soils – mineral resources are a key agent in the economic history told by Jevons. Resources set the economic process in motion: directly, by supplying the energy required for production, and indirectly, as the difficulties associated with their mining and transportation trigger the invention of new machines. As in the classical theory, resources establish limits that control the economic process, but Jevons' coal also causes structural changes to the economy.

The omission of nature by neo-classical economists

Whereas *The Coal Question* is of classical inspiration, Jevons is known for his reformulation of economics on several principles (particularly that of marginal utility), a paradigm referred to as neo-classical. Where the classical theory placed the emphasis on production costs, and thus triggered an investigation of the physical determinants of production and the relationships among social classes, the neo-classical theory places the emphasis on the utility obtained from production. Research shifts towards the subjective psychological conditions for the valuation of goods. Furthermore, whereas the classical theory focused on the dynamics of accumulation, and therefore on the modifications of production over historical time, the central notion of the neo-classical theory is equilibrium – the equilibrium established by market forces. The method shifts from empiricism and historical observation towards theoretical speculation. With the rise of neo-classical economics, nature all but totally disappears from the discipline until the Second World War: it has no place in the new conceptual framework and is not a priority research focus.

However, this does not mean there were no concerns over resources. In the United States, the beginning of the conservation movement coincided with the end of the conquest of the West (1890-1920). Led by Pinchot, it seeks to promote the reasoned use and scientific management of the immense resources of the American West. The aim is to attain the maximum sustainable level of production. In 1931, the American economist Harold Hotelling (1895-1973) wondered whether the claims of the movement are vindicated from an economic viewpoint: is the rate at which resources are exploited by private producers too high compared to a social optimum? Hotelling is aware of the limitations of the standard static framework. But he has access to a technique that remains little used by economists: the calculus of variations, which can be used to find optimal dynamic paths.

Extractors of resources in a competitive situation, that seeks to maximise its discounted intertemporal revenue, produce the same price path as the optimisation of the social value of the resource. The conservation movement finds no economic justification in the waste that might be generated by competition. In the real world, comments Hotelling incidentally, competition phenomena for access to resources do occur, which leads to cyclical price movements that generate significant amounts of waste. But these phenomena are

difficult to model using the calculus of variations and Hotelling soon moves away from his initial question. He is less interested in the conservation movement and the rate of extraction of resources but more in the resources of the calculus of variations. It allows for the analysis of more complex cases, such as when a producer is in a monopoly situation, or when the price depends on the amount of resources already extracted. Hotelling's fascination with this tool leads him to indulge in a succession of tedious calculations. He has found a playground and is determined to explore every aspect of it.

Hotelling's article is characteristic of the neo-classical approach. With regard to the method, he builds an ideal world based on preconceptions, with competitive markets, maximising producers and an infinite time horizon. He then logically explores this world and describes the mechanics of these abstractions. With regard to the content, what clearly emerges is the regress since the first economic considerations concerning the conservation movement by the institutionalist economist Lewis Cecil Gray, who had noticed the conflicting approaches at work in the maximisation of profit and in the conservation of resources and questioned the validity of some forms of consumption. Hotelling, however, does not distance himself in any way from the aim of maximising profit. The social value of the resource is measured in light of its demand, irrespective of the reasons that fueled that demand.

Hotelling thus integrates nature into a pre-existing system which it can no longer influence. Nature can no longer change the economic dynamics, it is merely a latent value that must be harnessed to the maximum extent. Just as a speculator buys and sells according to the market prices, a mining producer mines resources according to their prices. The mine is a reserve of value that is just as malleable and fungible as stocks and shares: it is governed by the same laws, the laws of the markets.

The dematerialisation of economic analysis

The neo-classical methodology, its insistence on the conditions of equilibrium and its psychological theory of value thus obfuscate the specificities of nature. The economic process is seen as an autonomous system that only relates to itself and does not need a physical basis. Other factors exacerbate this disappearance of nature from economics.

Despite the lucidity of its founding fathers, Marxism drifts gradually towards a conception of nature that is given away for free, and that must be exploited to the maximum technically feasible. For example, Trotsky hoped to redesign the mountains and re-route the rivers. The internal evolution of Marxism thus led to the neglect of ecological issues, and this was strengthened by the "really existing" socialism. The external impacts of Marxism were similar. By exacerbating the conflict between the working and capitalist classes, the class struggle shifted the economic debate towards the distribution of revenues between two classes. Economists formulate this problem in the form of two production factors, and only two – capital and labour. The Earth and resources are removed from this scheme.

The Keynesian thinking of the 1930s add the final touch to the dematerialisation of economics. Even though Keynes himself is sensitive to extra-economic benefits, from the arts of life and the value – particularly aesthetic – of nature, his influence consolidates an aggregated view of the economy, summed up in terms of monetary flows. The effective demand is a monetary aggregate that can be supported and strengthened by the issuance of public debt. The economy is perceived as a network of monetary flows and the materiality of these flows is of little importance. Instead of being a flow of manufactured products, the economy becomes a monetary circuit. The invention of national accounting strengthens this perception of a closed world. The economy, considered from a monetary perspective and represented by a balance sheet, resembles a closed circuit in which consumption and investment are compared to the produced value added. The physical content of the productions is no longer important. The resources that support the production process are not accounted for and disappear from the view of the observer.

Environmental economics – an application of the neo-classical paradigm

A dematerialised economics is thus established. We might say that it has been "disembedded" from physical processes, by applying to economics the language that Karl Polanyi used to describe how the economic system broke free from social structures throughout the 19th century. The economy is "landless", having no ties with nature and no need for resources or land to develop. It is an autonomous, self-referential system. Nature has no place in it, it quite simply no longer exists – it is invisible. In the post-war period, however, it comes back into economics in two ways.

The first concerns the growing awareness of pollution. Economic thinking revolves around the concept of externality – a legacy of the work of Arthur Pigou (1857-1959). An externality occurs when the action of one agent affects another agent who does not choose to incur its consequences. Building on some of Marshall's

ideas, Pigou was the first to mention the concept of externality in his treatise *The Economics of Welfare* (1932), in which he reviewed the mechanisms that create externalities, which we now refer to as market imperfections. In particular, he gave a brief description of an "environmental externality" relating to a factory owner who is not incentivized to reduce the smoke emitted from his factory because the reduction in pollution would mainly benefit the owners of the surrounding land. Pigou considered this to be a minor matter.

In the two decades following the war, the concept of externality, which had previously gone unnoticed, was discussed at length and gradually refined. In response to the proliferation of externalities (industrial pollution, urban congestion and wastage of land), the recommended solution according to Pigou's approach is to introduce a tax corresponding to the difference between the private cost and the social cost actually incurred by the collectivity. Such a tax for each externality must allow the price system to provide the right incentives to the agents: this means internalising the externalities.

The principle of the Pigovian tax is rejected in 1960, in an article by Ronald Coase (1910-2013), which stirs up a hot debate until today. Take the example of a chemical factory and a laundry using water from the same river. The effluent discharged into the river by the chemical factory prevents the laundry, situated downstream, from cleaning their linen. This causes a conflict and an externality because the rights of use for the river – the vector of the externality – are poorly defined. If they were clearly defined, the companies could engage in a negotiation by mutual agreement. This would lead to the definition of a price for these rights of use and a de facto internalisation of the externality. The chemical factory, for example, could buy the rights for the river water held by the laundry if its net profit from the use were higher than the price of these rights. Alongside the importance of property rights, Coase's analysis also highlights the transaction costs that prevent such arrangements in practice.

There have been many squabbles about the differences between the Pigovian and Coasian traditions, especially with regard to the role of the State, the confidence in markets and the leeway given to private stakeholders. But less has been said of what these two approaches have in common. In spite of all their contradictions, they both share a common goal: to bring nature into the economic system. Whether through taxes or defined property rights, the aim is always to give nature an economic dimension, i.e. to integrate it into the price signal automatically created by the markets.

This trend is also perceived in nature's second return in economic analysis. It is the consequence of fears over the availability of resources followed by fears over their absolute scarcity – concerns that increase in the immediate post-war period and peak in the 1970s with the Club of Rome Report (1972) and the oil crises that follow. This is when the economic theory of natural resources is consolidated, following in Hotelling's footsteps (we shall return to this later). Natural resources are considered to be a production factor, but their behaviour is exactly analogous to that of the other factors. They are reserves of value that need to be depleted at the optimal rate. Nature becomes a form of capital like any other: "natural capital". Nature has now been transformed into an economic commodity, both conceptually and practically.

Like a flight of falcons, economists have colonised the spaces that remained outside the economic system and have subjected them to close scrutiny with their tools. Environmental economics is just the application of general economic theory to a new field. Previously invisible, nature is now engulfed in economic analysis. The self-referential system is extending its range, encompassing more and more fields. The new incorporation of nature does not lead to a dialectical synthesis. On the contrary, it is the climax of the extension of the neo-classical thinking. In classical economic theory, nature was the framework that shaped the evolution of the economic process. But henceforth, nature is only worth as a component of the economic system, as a part of the exchange and creation of value.

Ostrom's commons

Alongside this prevailing view emerges a debate on the common ownership of resources, led by Elinor Ostrom (1933-2012). Starting from analyses of fisheries, the standard approach places the emphasis on the definition of individual property rights in order to prevent the over-exploitation and degradation of common pool resources. Running counter to this theoretical approach, Ostrom shows, for example, that some communities invent institutional mechanisms that allow for the sustainable management of common pool resources. Resources are no longer property rights, sources of externality or forms of capital, they have, in Ostrom's view, an ability to influence the social mode of their management, which adapts to their characteristics. They are the foundation stone underpinning the stakeholders' negotiations. Institutions and resources are involved in a dynamic relationship of joint construction: changes in the resource generate new rules, while the implemented rules shape the future of the resource.

Nature thus regains its role as a driving force. Moreover, the perspective of economic valuation no longer applies. The question is not to find out whether the institutions are capable of deriving the maximum value

from the resource, but whether the exploitation is conserving the resource and guaranteeing its sustainability. While the means are still political and social, the status of the resource acts as a yardstick for the success of the institution. There is clearly a reversal of the perspective, whose aim is now the sustainability of the resource.

Ecological economics or the metabolism of the economy

By placing nature at the heart of the socio-economic processes, Ostrom and her school come close to the field of ecological economics. Ecological economics was meant to be an alternative to the prevailing neo-classical conceptualisation. The repercussions of economic activity on extra-economic elements – particularly nature – and feedback effects are not exceptions located outside the economic system, or peripheral curiosities of the theory. The key concepts of ecological economics take account of these ubiquitous phenomena. Economic activity is integrated into a network of material extraction, processing and discharge operations. Monetary flows, which move from hand to hand, conceal material flows, which anchor the economy in the lithosphere – the source of mineral products – and the biosphere, which encompasses all ecosystems. From this macroscopic standpoint, the economy is included in bio-geochemical cycles which ensure the regulation of planet Earth. Economic activity, if its economic consequences are "externalities", disrupts the operation of these regulations and causes local and global imbalances.

Nature is not conceived of with the concepts of economics, but rather the other way round: the economy is analysed through the lenses of nature. Instead of being the subject, along with other factors, of an economic valuation, nature becomes both the confluence of economic flows and the yardstick by which they can be measured. Ecological economics thus prefers physical measures to monetary measures. The method leans towards multi-criteria analyses of environmental projects and is not limited to cost-benefit analyses. The use of several criteria means that attention must be paid to the conflicting values that arise in project evaluations. Nature reveals the tensions existing throughout the society.

A marginalised attempt at renewal

Of course, there are precursors to this school of thought, which were isolated and are only retrospectively noticeable: Lewis Mumford (1895-1990), Patrick Geddes (1854-1932) and Serge Podolinski (1850-1891). The Ukrainian socialist Podolinski shows that, for one calorie spent into agricultural production, the modern agricultural system produces fewer calories than the traditional peasant-farming system. In the modern system, the energy used in the production of fertilisers must in fact be deducted from the calories added due to photosynthesis. In the most mechanised systems, which also use fossil energy for farm machinery, the agricultural system consumes more calories than it produces. Podolinski's work clearly illustrates the methodology and concerns of ecological economics.

During the post-war period, some economists challenged the neo-classical framework. For William Kapp (1910-1976), externalities are inherent to capitalism: the quest for profit by cutting costs encourages producers to get society to pay the costs they used to pay themselves. Producers externalise the costs of their activities in order to remain competitive. The very process of cost-based competition, which is supposed to regulate economic activity and guide it towards the common good, continually creates externalities. Boulding, Georgescu-Roegen and Daly "re-embed" the economy in its physical infrastructure: pollution is merely the negative consequence of the consumption of resources. The linear economy, which extracts and discards with no concern for the consequences, is the main reason for ecological disorders; only a circular economy could prevent the proliferation of pollution and externalities. Kneese and Ayres draw visionary conclusions from this conception of the economic process in their article "Production, consumption, and externalities", published in 1969: the increased combustion of fossil energy sources results in the emission of significant quantities of greenhouse gases into the atmosphere, with the attendant risk of global warming.

This research is conducted at the very center of economics, published in the leading journals and held in high regard by orthodox economists. Nicholas Georgescu-Roegen (1906-1994), who presents an entropic view of the economic process, is a renowned representative of mathematical economics. The physical "disembedding" of economic analysis described previously in this article was therefore not inevitable. In the late 1960s, increasingly profound questions about the aims of economic development, the consequences of the commodification of the world and the resulting ecological degradations, start to be posed. However, this entire research programme is soon marginalised. Why?

The abrupt change was only possible in a social and political context of setting aside intellectual and social protests. In particular, the economic crisis that follows the oil crises makes growth, which had previously

attracted much criticism, now essential. In this context, a key event in the shift in the economic analysis is the Club of Rome Report and economists' reactions to it.

The Club of Rome Report on The Limits to Growth (1972) produces an intellectual upheaval at the time. With calculation techniques and a framework integrating resources and pollution similar to those used in the most advanced economic analysis, the team, led by the Meadows couple and inspired by Jay Forrester, reach spectacular conclusions. They believe that the rising population and the growth of industrial production are leading towards an eventual collapse of the economic system, i.e. towards an enforced reduction in the population and standard of living. This collapse will either occur due to the depletion of natural resources or, if there proves to be a sufficient availability of the latter, due to the repercussions of pollution.

The economists' response to this challenge that directly and spectacularly called into question the pursuit of growth, which had been the key aim of economic policy since the end of the war, is to create mathematical models revealing the possibility of perpetual growth. Where the Club of Rome's "World model" is based on empirical data and propose quantitative estimates of the trends described qualitatively above, the economists' models are based on theoretical arguments concerning the substitutability of natural resources with manufactured capital and the existence of infinite technical progress. Taken seriously, they mean that production is possible, even with a minute amount of resources.

The conflict between two approaches to production and nature becomes apparent. For neo-classical economists, production is pure value – flows of utility without content: nature only represents a value flow that is commensurable with production and interchangeable with other forms of capital. For the Club of Rome, and the ecological economists at a later date, production is a set of items and services which necessarily have a material basis. Nature provides the raw materials for this production. Under these conditions, technical progress, without being non-existent, is necessarily limited. Conversely, for the neo-Classical economists, infinite technical progress is only conceivable because production is completely immaterial, devoid of any physicality.

The debate about the limits to growth thus informs us about the contradictory ways of considering production and the economic process, and how it integrates into the natural world. Following the Club of Rome Report, neo-classical economists once again turn away from studying the material processes that underlie the economy. What was, in the late 1960s, at the cutting edge of economic thinking about the environment, is relegated to its periphery.

It is thus with a heterodox status that ecological economics becomes established around the *Ecological Economics* journal in the late 1980s. This organisational structure allows for the dissemination of concepts such as:

– life-support functions of ecosystems: these functions go beyond amenities and supplies of resources and services

– critical threshold: exceeding this limit may lead to the collapse of an ecosystem and economic calculation is only possible below these thresholds

– resilience: this allows a system to recover from damage and originates from diversity and redundancy (but not from efficiency)

– and sustainability: the ability to perpetuate something.

These concepts enjoy great success and are taken up, in its own manner, by environmental economics, whereas at the same time, ecological economics is less impermeable to the valuation of nature, with a branch of this school of thought actively engaging therein. The relevance of these corpuses remains to be proven in response to the ecological problems of our time.

The proposals developed by Michel Aglietta in the introduction to this volume take the middle ground between these two major schools of thought. While some of them concern the economic valuation of nature, the value of nature is not what is revealed by the market. If the decentralised exchanges are no longer automatically beneficial, the prices resulting from the market interactions are not sufficient to direct the action. Some exchanges must be carried out under the conditions laid down by the public authorities or negotiated by the social partners. These proposals thus lie within the scope of a tradition that emphasises political prices, alongside the economic prices (with the paradigmatic example of the political price being wages, especially under the Fordist regime). They thus involve a democratic management of nature. This indicates that the whole fabric of social structures is required to support the reproduction of nature, which has been permanently damaged by the extent of our extractions and pollutions.

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From growth to green growth

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"Grow now and clean up later", meaning concentrate on economic growth and deal with the environment later, no longer appears to be a viable option as it is sometimes costly to delay taking action. This is especially the case when the modes of development create irreversible effects relating to the choice of technologies, economic structure or infrastructures and urban forms. This is important for developing countries that will be constructing the majority of their infrastructures in the decades to come.

Growth must therefore be reconciled with poverty reduction in poor countries, with the need to avoid irreversible environmental impacts. This may be carried out through "*green growth*", i.e. growth that is *efficient* in its use of natural resources, which is *clean* by limiting pollution and environmental impacts, and which is *resilient* to disasters and crises.

Although many observers fear that green policies have high costs for benefits that will only become apparent in the long term, the reality is that many short and medium-term benefits are possible. And action needs to be taken right now on issues that involve a high risk of irreversibility in order to minimise future regrets.

Many observers have highlighted the dangers of economic growth for the environment, and have suggested challenging the idea of growth as a political objective (Victor 2008). This argument – made primarily in rich countries with annual per capita income of over $30,000 – appears to be clearly less relevant in developing countries, in which the average annual per capita income is $3,500. A redistribution of the current global production would in fact only lead to a worldwide annual per capita income of $8,000. Furthermore, even after a decade of rapid growth, 1.3 billion people have no access to electricity, 900 million people have no access to drinking water, 2.6 billion have no sanitation and 800 million have no access to roads during the rainy season. Even presuming continued growth, nearly one billion people are living on $1.25 per day in 2015. In light of these figures, the pursuit of economic growth could be seen as a legitimate aim in poor countries.

Certain commentators have suggested that environmental problems resolve themselves with economic development and that poor countries cannot concern themselves with the environment (Grossman and Krueger, 1995). But here too, the argument does not stand up. During the last 250 years, growth has largely been achieved at the expense of the environment, and today, this tendency seems to be unsustainable, with regard to the climate but also to the impoverishment of soils, the use of fresh water and biodiversity. Furthermore, a distinction must be made between environmental problems that affect well-being through amenities (i.e. the pleasure of benefiting from natural areas), and those that affect revenues and security. Poor households that struggle to feed and house themselves properly may not attach the same value to parks and gardens as richer households. But they are extremely vulnerable to soil degradation – and its impact on agricultural yields – or to the lack of waste collections – which leads to epidemics of dengue fever and impairs drainage, which leads to flooding in the event of heavy rain. In these cases, immediate attention to environmental problems is required.

In addition, "grow now and clean up later", meaning concentrate on economic growth and deal with the environment later, no longer appears to be a viable option as it is sometimes costly to delay taking action. This is especially the case when the modes of development create irreversible effects relating to the choice of technologies, economic structure or infrastructures and urban forms. This is important in developing countries that will be constructing the majority of their infrastructures in the decades to come. For example, a recent study concerning Brazil shows that it is preferable to implement relatively costly actions such as the establishment of public transport without delay, because such measures take a long time to deploy and are required in order to attain the long-term greenhouse gas reduction targets (Vogt-Schilb et al., 2014).

And what is worse, certain choices are completely irreversible, such as the destruction of certain ecosystems. Kenya's traditional forests are thus in the process of being destroyed. And while their role as a reservoir of water or carbon could be restored in the future, the losses of biodiversity are probably irreversible (Chapin et al. 2000). What is more, in the case of climate change, the window of opportunity to attain the goal set by the international community is closing fast.

So what should be done? In Hallegatte et al. we suggest that growth must be reconciled with poverty reduction in poor countries, with the need to avoid irreversible environmental impacts. Therefore, the efforts must focus on actions that will be indispensable over the next five to 10 years in order to prevent economies from being locked into unsustainable development modes and to limit irreversible environmental losses and consequently the future regrets. This can be carried out through "*green growth*", i.e. growth that is *efficient* in its use of natural resources, *clean* as it limits pollution and environmental impacts, and *resilient* to disasters and crises.

Is green growth possible?

In 1956, Robert Solow presented a model in which the growth of gross domestic product (GDP) originates from the increase in the quantity of physical capital, the amount of labour (or human capital), and productivity. In this model, physical capital increases through investment. The amount of labour increases because of demographic growth, the increase in the rate of participation in the labour market, education and the improved health of workers. Productivity also increases due to technological developments which may originate from investments in education and research and development (R&D), economies of scale and practical experience – learning by doing.

What this model lacks is the idea that economic production depends on the stocks of natural resources and the quality of the environment, i.e. that the environment is a factor in the production function. This idea has been regularly put forward, at least since it was proposed by Malthus (1798), but it was only in the 1970s that the classical theory of growth was amended to take account of "natural capital" as a production factor (Dasgupta and Heal 1974; Nordhaus, 1974; Solow, 1974; Bovenberg and Smulders, 1996). If the environment is considered to be productive capital, it is logical to invest in it, and environmental policies can be considered to be investments.

In this new framework, environmental policies can directly increase economic production by improving the environmental conditions. But green policies can also indirectly contribute to economic growth, because current economies are very inefficient in their use of resources. Indeed, numerous market failures affect both the environment and the economy. The correction of these failures could increase productivity and produce benefits beyond the environmental sphere. Environmental policies may theoretically increase GDP which is traditionally measured via four channels:

- Production factors. Environmental policies may raise GDP by increasing the amount of natural capital, labour and physical capital. Individual, transferable fishing quotas, for example, may help to maintain and even increase fish stocks and consequently the economic activity that depends on them. The ecological remediation of the Loess plateau in China has allowed farmers to almost double the income of farmers and led to a significant reduction in flooding. Environmental policies may also increase the quantity and productivity of labour by improving the health of the population, in addition to increasing physical capital through the improved management of natural risks. Protecting mangroves, for example, not only protects biodiversity but can also improve the resilience of coastal areas in response to hurricanes and flooding.

- Efficiency. Environmental policies can increase the productivity of the economy by correcting the market failures that adversely affect the efficient use of natural resources. Energy efficiency is a traditional example of this. Many companies and households do make sufficient investments to reduce their energy consumption to zero or even negative levels. This is due to market failures and behavioural biases. Environmental policies that aim to reduce energy consumption can correct these market failures and influence behaviours, leading to less environmental damage and a more efficient economy, with a higher potential for growth.

- Boosting the economy. During an economic recession, i.e. when the use of production capacities is low and unemployment is high, increasing demand through green investments may boost business and employment (Zenghelis, 2011). However, under-employment is not always linked to demand and it may also be of a structural nature, especially in developing countries. In this case, boosting the economy may be costly and ineffective in creating jobs.

- Innovation. It has been observed that environmental policies (e.g. taxes on fuels in Europe or negotiable SO_2 emission permits in the United States) may stimulate innovation and increase the potential production of the economy. As investments in knowledge and innovation tend to be lower than what would be desirable (due to externalities), policies that encourage green technologies may make a useful contribution to boosting these investments (Porter and van de Linde 1995). The effect of environmental policies on innovation is illustrated by investments in R&D for photovoltaic energy. Initially motivated by the desire to limit greenhouse gas emissions, their success could make photovoltaic energy competitive in relation to fossil fuels and thus increase the electrical energy supply while reducing the cost of the distribution of electrical energy (particularly in areas not served by electricity grids).

Environmental policies may also impact well-being through **redistributive effects.** For example, subsidies that encourage energy consumption (especially subsidies on fuels) are harmful to the environment and mainly

benefit the richest people. According to a study carried out by Arze del Granado et al. (2010) in 20 developing countries, 20% of the richest households monopolise 43% of these subsidies. Replacing them with targeted monetary transfers (or subsidies for connection to water systems and electricity grids rather than consumption) can thus free up resources for public investment (in schools or infrastructures) and be beneficial both to poorer people and the environment.

Environmental policies can also reduce the risks that threaten growth by increasing the **resilience** to environmental impacts, such as natural disasters and economic crises, such as oil crises and the volatility of raw material prices. In this way, they can stabilise production and consumption which leads to greater well-being.

The compromises and synergies between green policies and growth

Environmental efforts may also, of course, reduce productivity and growth, by forcing companies to use more costly or less productive technologies, by reducing R&D in non-environmental fields, or by requiring the replacement of productive capital based on polluting technologies. Political decision-makers must therefore assess the costs and benefits of environmental policies.

The balance between costs and benefits depends on how they are defined. In a strictly economic framework, a policy designed to protect a mangrove swamp has an economic cost (because it prevents shrimp farming, for example) and does not create any direct economic benefits. But in a framework that includes the evaluation of ecosystem services, this policy also has direct and enhanced economic benefits, e.g. due to the protection provided against coastal storms. Urban policies may also be designed in such a way as to produce joint benefits in terms of air pollution and health as well as with regard to access to housing (Viguie and Hallegatte, 2012).

All in all, although many observers fear that green policies have high costs for benefits that will only become apparent in the long term, the reality is that many short and medium-term benefits are possible. And action needs to be taken right now on issues that involve a high risk of irreversibility in order to minimise future regrets.

A starting point is to classify potential green growth policies according to the benefits they generate in the short term and the urgency of their implementation, as shown in Table 1. Developing countries (especially low-income countries) should concentrate on: environmental policies that have a negative or no environmental cost and which create synergies with development (such as urban planning); those that have a positive economic cost, but have significant and direct effects on well-being (i.e. when they target local environmental assets such as local air pollution or natural risks); and environmental policies whose cost can be offset by external resources (such as international aid).

This framework (and its political implications) is developed in the World Bank reports entitled "Inclusive Green Growth: the pathway to a sustainable development", published in 2012, and "Decarbonizing Development – three steps toward a low-carbon future", published in May 2015.

Table 1. Identifying the priorities for the creation of a green growth strategy

Local and immediate benefits \ Inertia and/or risk of irreversibility	**MINOR (compromises are required between the short and long term, or between the local and global benefits)**	**MAJOR (the policies produce immediate local benefits)**
LOW (the action is not urgent)	– Production of low-carbon energy at high cost – Stricter regulation of waste water – Reduction of the use of fertiliser	– Drinking water, sanitation, waste collection – Production of low-carbon energy at low cost (e.g. hydroelectricity) – Reduction of losses from water systems and electricity grids – Reduction of demand for water and energy – Small, multi-use reservoirs
HIGH (the action is urgent)	– Reduction of deforestation – Protection of natural areas and coastal zones – Creation and reduction of fishing quotas	– Urban planning and land use – Urban public transport – Family planning – Sustainable intensification of agriculture – Large dams and multi-use reservoirs

Comment: the examples provided in this table are for information only insofar as the joint benefits and risks of irreversibility are highly dependent on the context.

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Part II: Measurement attempts

The measurement of natural capital presents an image of the status of nature. Indicators and metrics, although certainly simplistic, give us an understanding of the wealth and frailty of the relationship between humankind and nature.

Attempts to measure natural capital revolve around the three following approaches:

- a biophysical approach consisting of compiling an inventory of all components of natural capital;
- the physical accounting and monetary evaluation of natural capital when damage is observed;
- the valuation of the unpaid ecological costs that reflect the monetary value of the degradation of natural capital.

The aim of this second section is to develop a dialogue among the different methodological proposals in order to reveal the innovations, deficiencies and knowledge requirements.

The key methodological issues of the "new wealth indicators"

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This article focuses on the criticisms of Gross Domestic Product (GDP), especially since the 1990s, by the "school of new wealth indicators", and on the different attempts made to define and implement additional and/or alternative indicators to it. After setting out the reasons for the criticisms and the principles underlying the definition of the new indicators – especially with regard to citizens' involvement in choosing them – the article goes back over the contributions and limitations of the work undertaken by the Commission for the measurement of economic performance and social progress under the aegis of Joseph Stiglitz and Amartya Sen, which was published in the eponymous report in 2009. It examines two indicators in greater detail, one proposed by the World Bank: adjusted net savings (ANS), and the other by the United Nations Development Programme: inclusive wealth index (IWI), in which monetisation plays a prominent role, in order to reveal the limitations.

We are involved in a multidisciplinary school of thought (sometimes referred to as the "French school of new wealth", cf. reference [1]), consisting of about ten authors whose first works appeared around the turn of the millennium. We share several concerns: being critical of the traditional and prevailing indicators and gross domestic product (GDP) in particular, sharing an interest in alternative indicators capable of revealing the collective aspects of well-being, and believing that the choice of these new indicators needs to be the product of a democratic process and not of the private work of a closed circle of experts. From this point of view, the Commission for the measurement of economic performance and social progress established in 2008 (known as the Stiglitz Commission) constituted a confirmation – and indeed a legitimisation – of the work carried out previously, but also and in other regards, an obstacle.

In the first part, we set out each of the three common elements to this school of thought and reveal the way in which the Commission's Report has redefined the way of asking these questions. In the second part, we turn our attention to the presuppositions required for the adoption of widely publicised indicators such as Adjusted Net Savings (ANS), in which the Stiglitz Commission has taken an interest, and more recently the Inclusive Wealth Index (IWI).

New conception of wealth and a new process for determining new wealth indicators

1990s: renewed criticism of GDP and realisation that France is lagging behind

Although signs of the insufficiency of GDP have been around for as long as GDP itself, the most highly publicised challenges were firstly made in the Meadows report and by the Club of Rome in 1972. Although pessimistic regarding the consequences of the prospects for growth in the economy and demographics, the results were largely forgotten in the 1970s and 1980s and set aside, especially in reaction to the major economic crises confronting the developed economies. In the late 1980s, the Brundtland Report of the World Commission on Environment and Development put forward arguments asserting the strong and urgent requirement for ecological sustainability for current and future generations.

The renewed vigour of the challenge to GDP as the unequivocal indicator of wealth since the 1990s is of a different nature for two reasons: firstly because it is not dying down and secondly because it is following a different path to that of mere alerts. It is more associated with the idea that the quest for economic growth (i.e. the expansion of GDP in volume) is the origin of some of the excesses that have taken hold in economies. These excesses are having counter-productive effects, either in ecological terms (climate change is linked to growth, as are losses of biodiversity and the depletion of non-renewable natural resources, etc.), or in social terms (we are witnessing a rise in inequalities at the global level, especially within nations).

In this context, two projects emerge simultaneously in the early 1990s. Both of them give a powerful impetus to the creation of new indicators. Firstly, the United Nations Development Programme (UNDP) presents its first human development index (HDI) in 1990. Benefiting from substantial support from Amartya Sen, it runs counter to the structural adjustment policies orchestrated by the International Monetary Fund and the World Bank by considering that, in order to be on a sustainable human trajectory, nations must have access to education, health and economic resources. This is an opportunity to shake up the economic hierarchy of countries because, according to the United Nations Development Programme, there is no correlation between per capita GDP and the composite HDI indicator, at least for countries with a very high level of income.

At the same time, researchers are developing a physical indicator of environmental sustainability which gives birth to the "ecological footprint" concept widely disseminated by civil society networks, and especially by the Footprint Network and the World Wildlife Fund (WWF) non-governmental organisation. In a very educational manner, this indicator helps to emphasise the ecological non-sustainability of the global growth model, the role played by rich countries in it and the idea that northern countries have an ecological debt towards southern countries.

The systematic review of alternative wealth indicators, carried out by Jean Gadrey and Florence Jany-Catrice in 2002 at the request of Dominique Méda (DARES research coordination mission which had launched a programme to investigate these issues [2]), revealed the profusion of initiatives throughout the world and noted the already diverse range of indicators proposed. These researchers also insisted on the fact that what they were witnessing was not a movement of opposition to national account systems, but a movement of relativisation and integration of current national accounts into multi-dimensional issues. "The majority of the innovative indicators devised since 1990 are quite broadly based on national accounting data", but "their originality is that they are not solely based on the latter" [3].

This work also expressed astonishment at how France was lagging behind other countries – particularly those of the English-speaking world – on these issues, with the exception of a few pioneering projects that addressed the issue by re-examining the very notion of wealth, including those by Dominique Méda in 1999 in Qu'est-ce que la richesse*? (What is wealth) [4]*, Patrick Viveret in 2002 in Reconsidérer la richesse (*Reconsidering wealth*) [5] and Bernard Perret in his report entitled Indicateurs sociaux, état des lieux et perspectives (*Social indicators, a review of the current situation and outlook*) [6].

At the end of the 2000s, France embarks on a multitude of deliberations on how to measure sustainable development and sustainability. The French Ministry for the Environment thus publishes several studies on sustainable development indicators. Following the "Grenelle" Environment Forum in 2009, it establishes a consultation committee in partnership with the Economic, social and environmental council and the National statistical information council (see box 1).

Similarly, the Stiglitz Commission orders a series of projects carried out by the National institute of statistics and economic studies (INSEE) (on the carbon footprint, the water footprint, satisfaction indicators based on the 2010 time budget, etc.[31]).

[31] Read the special section on the INSEE website:
http://www.insee.fr/fr/publications-et- services/default.asp?page=dossiers_web/stiglitz/performance_eco.htm

Box 1:

Sustainable development indicators (SDI) derived from a French national consultation (2012)

1. Total greenhouse gas emissions (challenge 1)
2. Carbon footprint (challenge 1)
3. Share of renewables in final energy consumption (challenge 1)
4. Energy consumption on transport per inhabitant and intensity in relation to GDP (challenge 2)
5. Productivity of resources and consumption of materials per inhabitant (challenge 3)
6. Abundance index of common bird populations (challenge 4)
7. Land take (challenge 4)
8. Life expectancy and life expectancy in good health at birth (challenge 5)
9. Monetary poverty rate after social transfers (challenge 6)
10. Employment rate of people aged 55 to 64 (challenge 6)
11. Integration of young people (aged 16-25) excluding employment and excluding training (challenge 6)
12. Public development aid (challenge 7)
13. Drop-out rate of 18-24 year-olds (without qualifications from upper secondary education) (challenge 8)
14. Share of domestic expenditure on R&D in GDP (challenge 8)
15. Proportion of women in decision-making bodies (challenge 9)

(The underlined indicators are the key SDIs adopted by the European Union, amounting to nearly two-thirds of the indicators; the other six originated from the consultation).

Source: "Les indicateurs nationaux du développement durable" Cécile Dormoy, Louis de Gimel, *in* "Les indicateurs de développement durable", La Revue du CGDD, January 2010.

http://www.developpement-durable.gouv.fr/IMG/pdf/RevueCGDD_idd_1_.pdf

How can we classify the existing indicators? A reasoned typology

Throughout its entire history, i.e. since the 1930s and the preliminary work by Simon Kuznets [7], the criticism of GDP has always been accompanied by the promotion of alternative or complementary indicators to GDP. The methodological choices adopted are not neutral: they are an expression of the multiple interpretations of the concept of well-being and of the sustainability to be promoted.

A rational way to classify these multiple indicators consists of firstly identifying them according to the values they promote, which may be supported by a more sustainable human development project and/or by environmental considerations. Secondly, these indicators are elaborated by different methods: some favour summaries or dashboards of several key indicators (as for the French SDIs), while others combine a wide range of variables in a single indicator (composite or global). The indicators of the United Nations Development Programme have composite formats, meaning that they weight heterogeneous variables without using a common accounting unit. On the other hand, other indicators favour the use of a single accounting unit – often monetary. This produces environmental or "green" GDP, in the sense that "to the national accounting figures are added monetary estimates of values linked to gains or losses of environmental quality, and of certain social qualities" (Gadrey, Jany-Catrice, 2012, p. 69). This also applies to the World Bank (ANS) and UNEP (IWI) initiatives to which we shall return later in this article.

Alongside these diverse initiatives, other approaches are based on subjective measurements, with the supposition that individuals are responsible for amalgamating the values (social, environmental etc.). Richard Layard has thus defended the idea that not only is it possible to measure happiness and its evolutions, it is also necessary to base public policies on the maximisation of happiness, from a Benthamian perspective, and on the rigorous analysis of the evolution of the data that allow for its measurement [9].

Summary of sustainable development indicator initiatives

\	*Heterogeneous weighted indices (not systematically monetised)*	*Adjusted GDPs, by addition or subtraction of monetised values*	*Consistent assessments, which are followed up and have no composite indices*	*Subjective indicators:* leave individuals the freedom to choose
Predominantly social or *socio-economic, human development, etc.*	E.g. UNDP indicators (HDI, Human Poverty Index (HPI) etc.); Social Health Index (SHI), BIP40 ("barometer of inequalities and poverty"), etc.	E.g. Nordhaus-Tobin Index of Sustainable Economic Welfare (ISEW)	Social or socio-economic assessments	
Predominantly environmental, with a variable number of social criteria	E.g. Dashboard	E.g. Green GDP, Economic well-being indicators, Adjusted Net Savings (ANS), Inclusive Wealth index (IWI)	Environmental or socio-environmental assessments	E.g. life satisfaction indicators Happiness indicators

Source: the authors, inspired by Gadrey, Jany-Catrice, 2012.

Involving citizens in the choice of indicators – a necessity

Separating the thinking on social condition indicators from their development and the ensuing social uses is problematical. This can indeed lead to solutions that may appear attractive from a theoretical standpoint, but which are ineffective, misleading or illegitimate from an operational perspective.

Redefining the types of wealth or shared assets of organisations, regions or even nations, can only be the product of shared conventions. This requires an analysis of the arrangements for the participation of the stakeholders and social forces associated with this construction [10] and knowledge of how to (re-)establish a democracy of collective choices. In this same vein of questions, the French Forum for other indicators of wealth (Forum pour d'autres indicateurs de richesse – FAIR[32]) has promoted the concept of collective well-being that cannot be reduced to the sum of the well-being of individuals, and asserts the need to acknowledge the existence of a common heritage (natural and social) that falls due to each generation, which needs to be catalogued and whose changes need to be monitored[33].

The question of an appropriate scale inevitably arises. On the one hand, the legitimacy of certain indicators has increased due to their universal nature (good examples of this being GDP and the HDI). At the same time, they overshadow the local specificities and reflect a prevailing view of human development or sustainability. However, indicators developed through deliberative democratic processes run the risk of being non-comparable.

In such contexts, the preferred way of making collective and social choice decisions is through hybrid forums[34], i.e. open debating and discussion bodies that bring together experts and civil society, in which social forces can state their case, deliberative processes are respected, and in which the collective intelligence is greater than the sum of individual points of view. Together, these stakeholders make reasoned decisions after discussions about what constitutes the "wealth of an area or of a community", and "well-being for all". This is

[32] A network created in 2008 when the Stiglitz Commission was established, with a view to stressing the need for a democratic process in the choice of indicators of wealth and progress.
[33] See D. Méda [4] and [11], C. Barrère et al., in particular. (12).
[34] M. Callon, P. Lascoumes, Y. Barthe [13].

exactly what numerous local initiatives are seeking to do[35], in France and elsewhere. These experiments suggest breaking away from technical expertise on indicators, re-appropriating the key issues that they implicitly embody, and renewing the democratic thinking on the basis of the question of the identification and preservation of fundamental rights, shared assets and the general interest. In their own way, these initiatives thus transform the perception of wealth and justify the democratic legitimacy of their plurality.

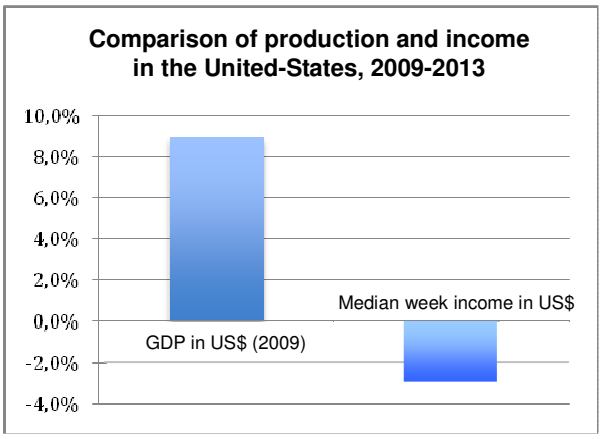
Contributions and limitations of the Stiglitz Commission

The Stiglitz Commission legitimises the insufficiency of GDP, adopts an individual perspective on the quality of life (versus social health) and is hesitant about ANS

The mid-2000s was a propitious period for international deliberations regarding the reconsideration of wealth. After an initial experiment in 2001 that was not followed up, with a report entitled "The Well-being of Nations", whose tone contrasted sharply with the organisation's traditional publications, the OECD assumes the leadership of institutions seeking to rethink the measurement of progress, under the impetus of its head statistician Enrico Giovannini in particular. In 2007, the European Parliament organises a major symposium entitled "Beyond GDP", subsequently renamed "GDP and Beyond". Similarly, international organisations produce works that seek to provide monetised sustainability indicators (firstly ANS by the World Bank and more recently the IWI by the UNEP).

But the initiative that legitimises the need for new progress and sustainable development indicators is the work of the commission consisting mainly of economists – including several Nobel prize-winners – and chaired by one of them, Joseph Stiglitz. This commission scientifically validates the criticism of the irrational use of GDP: its Report sets out the traditional limitations of GDP and proposes more precise ways to evaluate the production of services whose measurement methods are limited by the dogma of "volume". The Report also contains a number of proposals on how to account for voluntary and domestic work, on the basis of the observation that as they are not included in the accounts, they are underestimated in public and political projects[36]. More generally, the Stiglitz Commission promotes the idea that consumption accounts rather than production accounts should be used as the basis for developing a more accurate understanding of well-being and that it is important to take better account of the inequalities in this domain.

Consequently, as reflected by the graph below, the change in GDP in the United States after the financial crisis of 2009 (+9% in volume) was very different to the change in the median weekly income of full-time and part-time employees (-3% in constant dollars).



BEA and BLS data.

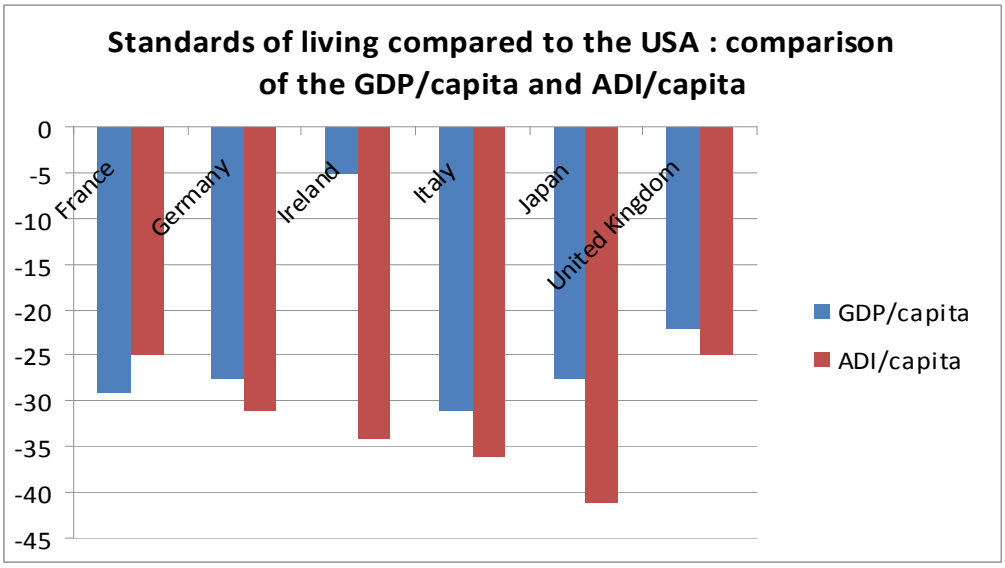
[35] And whose variety is described in a Special Edition of Alternative Économiques: "La richesse autrement", FAIR [14].
[36] The question of failing to take account of domestic work and leisure in GDP and of their possible integration into the latter is controversial cf. Jany-Catrice Florence, Méda Dominique, "Women and wealth : Beyond GDP" " [8].

The post-Stiglitz Commission works carried out, especially in France, have given INSEE the opportunity to explore the degrees of inequalities reflected by different indicators to a greater extent than in the past. This is the case for the distribution of "adjusted disposable income". According to per capita GDP, the main European countries and Japan are positioned around 25% below the level of wealth of the United States (see the following graph).

But the results are very different when the measurement of adjusted disposable incomes, i.e. the incomes that households actually receive with the addition of the estimated public health and education expenditure that directly benefits them: France then has a better standard of living, whereas Japan and Ireland have considerably lower standards of living (INSEE, 2010).

These are substantial progress. On other points, however, the work carried out by the Stiglitz Commission is much more questionable.

Annual national accounts of the OECD



Source: Insee Références, L'économie Française, June 2010.

Regarding the possibility of taking the idea of social health – promoted by the French Forum for other indicators of wealth (FAIR) – into consideration in order to account for changes in social cohesion or disunity based on indicators of changes in inequalities and therefore of risks of balkanisation or social disintegration, the Stiglitz Commission decides to include an entry on "quality of life", combining individual and social dimensions. Two avenues are explored in detail. One of them takes account of quality of life on the basis of the subjective declarations of individuals and the analysis of their satisfaction, feelings and affects. It is based on theories of hedonic psychology and follows directly in the footsteps of utilitarian economic studies that analyse what makes the experience of life (for each person) pleasant or unpleasant. The report shows a real interest in the U-index proposed by D. Kahneman and A. Krueger which "measures the proportion of time during which the prevailing feeling of an individual is negative" (p. 236). The other, relating to a more objectivised view of the quality of life is established on the basis of an overview confined to its members' areas of expertise. It takes account of the different variables likely to provide information about the different dimensions of the quality of life, such as health, work (paid and domestic), commuting, recreational activities, housing, governance, social ties and different aspects of insecurity.

With regard to the question of sustainability, the Stiglitz Commission suggests that stocks of wealth, which are required to ensure the maintenance of annual economic growth and are feared to be gradually running out, should finally be estimated. This is another step in the right direction. However, the Report immediately declares its intention to limit its scope to the economic aspects of sustainability, suggesting that a clear distinction must be made between the data for present and future well-being, and questioning the validity of initiatives that aim to merge them together into a single combined concept. The Report does defend the idea of

dashboards that record physical resources but hesitates to include a monetised indicator albeit the aggregative property of this accounting unit which allows the economic, social and environmental dimensions to be simultaneously taken into account. This hesitation is particularly apparent in the promotion of ANS in its interim report of April 2009, followed by its omission from the final report submitted in September 2009. In the meantime, in July 2009, the Forum for other indicators of wealth published a critical analysis that drew attention to the advances made by the Stiglitz Report but also to the risks attached to monetisation in general and to ANS in particular,[37] which must have had some bearing on the greater reserve shown in the final version of the report.

ANS: birth of an indicator fraught with danger

Through its first willingness to include Adjusted Net Savings – the monetised global indicator developed and disseminated by the World Bank [16], the Stiglitz Commission implies that sustainability requires a constant stock of capital over time, capital measured in this context from the perspective of economic capital (gross adjusted savings of households), natural capital (monetary estimation of damage to natural assets), and human capital (education expenditures). This corresponds to the idea that society must be capable of giving future generations a set of "economic" opportunities that are at least commensurate with those given to the current generations. This indicator does not avoid a certain number of pitfalls, which are critical to the analysis of "progress"[38] and sustainable human development.

The most important of these pitfalls is the type of language favoured: that of recourse to money. This is not a new idea. Many initiatives have been developed in order to give a monetary value to components of human activity or assets that are not "visible" in this light. This was the case for the monetary measurements of the social and environmental costs of productive human actions, carried out by Nordhaus and Tobin in 1973, the monetisation of services rendered by biodiversity[39], and even the monetisation of social impacts. with no doubt, the monetisation of non-market and non-monetary wealth can, on a one-off basis, attract considerable attention, as with the shock wave caused by the publication of the Stern Report on the economic cost of failing to take action vis-à-vis the environmental and societal impacts of global warming. The idea that doing nothing could be much more costly in the long term than taking action today is an effective way to persuade people that are especially receptive to this type of argumentation. Moreover, we must be careful to differentiate between giving a "price" that is supposed to reflect a value, giving a "political" price that bears no relation to this value, and the actual cost of an action or a failure to act. Nevertheless, monetisation faces numerous criticisms that are difficult to refute[40].

Firstly, it requires the creation of prices in domains that do not use them. These imaginary or implicit prices are created on the basis of questionable representations, in a utilitarian framework and using sometimes controversial methods. Among them, the willingness to pay – or to receive – method is often prefered. This method defines a price based on questionnaires sent to individuals who state their preferences in monetary terms. For different scenarios, questions of the "how much would you be willing to receive in compensation for damage to such-and-such a component of biodiversity?" type are submitted to representative agents. Different studies show that there may be strong resistance to such surveys, whether this is due to a cognitive inability to attribute a monetary amount to a situation that lacks one, or to a political or ethical desire to resist this form of valuation. This leads to respondents giving a "protest mark" of zero to the valuation exercise or simply refusing to participate in it[41]. The market-based approach to the valuation of assets is in fact incapable of recognising certain values and is even opposed to their expression according to Clive Spash [22]. Finally, the extension of monetisation to domains that were hitherto excluded from this approach is also the reflection of a collective inability to obtain recognition for values other than monetary value[42]. This type of economic valuation is indeed based on the idea that the values are always pre-formed and excludes the very notion of deliberation from the process of judgement formation.

Monetisation then puts all of the measured dimensions on an equal footing, regardless of their heterogeneity,

[37] The “Stiglitz report”: A well-argued assessment, a questionable method, and proposals that are not up to current challenges. A response by the FAIR forum to the draft sumary report issued by the Stiglitz Commission http://www.idies.org/public/FAIR/r_action_FAIR_longue_Eng.pdf. Also see Florence Jany-Catrice, Dominique Méda, 2011, “Le rapport Stiglitz et les limites de l’expertise”, note de travail de l’IDIES, no. 14

[38] Méda D., 2009, "Quel progrès faut-il mesurer?" [17]

[39] Chevassus-au-Louis et al. "Approche économique de la biodiversité et des services liés aux écosystèmes - Contribution à la décision publique" [18].

[40] The drafting of this article coincided with the publication of a book that clearly assesses the benefits of monetisation as well as the criticisms that can be levelled at it, cf. Jean Gadrey, Aurore Lalucq, "Faut-il donner un prix à la nature ?" [15].

[41] J. Milanesi, “La nature est elle soluble dans l’utilité ?” [19]; F. Jany-Catrice, "Quand mesurer devient maladif" [20].

[42] J. Gadrey, F. Jany-Catrice, “The New Indicators of Well-Being and Development” [3].

suggesting that components can always be substituted for one another and that damage to one of them can always be offset (repaired) by another[43]. This way of accounting for aspects of deterioration disregards the irreversible nature of certain types of damage or of exceeding certain critical thresholds[44] (nuclear damage, extinction of living species, destruction of an ecosystem, climate change or total breakdown), which cannot be remedied by any economic investment.

Finally, and even if the majority of their promoters refrain from doing so, these monetary evaluation processes seem to be one of the premises for identifying sources of activities and their commodification. In this respect, the language of monetisation can get people used to the idea of the marketing of such assets[45]. In promoting the idea of "green growth", the Rio+20 debates broadly confirm this suspicion. The green growth term, in practice, covers two approaches in an ambiguous manner: firstly, the identification of new activities that are intended to replace polluting industrial activities (e.g. the electric car, which is sometimes presented as the paradigm for green growth), and secondly, the identification of new sources of economic growth in hitherto non marketed domains. New technologies consequently appear to constitute a possible reservoir of growth and the key way – epitomising human ingenuity – to refute the idea that the rate of growth should henceforth be limited[46].

IWI: the omission of the environment

Highly publicised at the time of Rio+20, the IWI was developed by economists, including Partha Dasgupta, in the framework of the United Nations Development Programme (UNDP). The aim of this indicator is twofold: to break away from the UNDP's human development index (HDI) whose main failing is that it does not take account of the environmental dimension, and to rival ANS, which remains an indicator of flows (the sum of capital flows) whereas the IWI seeks to summarise the stocks of capital that constitute well-being.

In the IWI, three types of capital (economic, human and natural) are summarised and estimated on a monetised basis. In a way, this involves making a monetised inventory of the stocks (or annuities) of this capital. In the IWI, the multiple values of sustainability are expressed in the form of prices. Be they market prices or the product of contingent valuations, these prices thus reveal individual preferences regarding what must be conserved, as revealed by Géraldine Thiry and Philippe Roman [25].

Subject to the same criticisms as are levelled at ANS, we believe the IWI to be even more blameworthy. Indeed, such essential "natural capital" as climate and flood regulation, fertile soils, biodiversity and drinking water has not been included in this measurement of wealth. The reasons given are that their estimation defies measurement and that including them would assume the validation of the substitution of capital hypothesis, which their promoters refuse to do. However, by excluding these essential elements from this measurement of sustainability, some of the results obtained raise very difficult questions, which FAIR has been observing since 2012. For example, according to the IWI, the country whose overall sustainability has the highest growth rate is… China. And all rich countries are steadily moving towards global sustainability, including the United States. However, we know that for these countries and many others, indicators of ecological pressure and social health are well and truly in the red and reflect substantial deteriorations.

Conclusion

The Commission for the measurement of economic performance and social development, established in order to draw conclusions from the limitations of GDP, opted to carry out its expert appraisals in closed committee, prompting two major criticisms from scientific and associative movements formed in the past few years or especially on this occasion regarding the development of new indicators. The first criticism concerns the mono-disciplinary nature of the composition of the commission, with the vast majority of the committee members being economists and most of the reasoning proposed being of an economic nature, whereas multi-

[43] D. Méda, F. Jany-Catrice [9] ; I. Cassiers, G. Thiry [22].
[44] See Rockström et al in particular. 2009 [23] and Anthony D. Barnosky et al. (24).
[45] In box 7 of the Summary for decision-makers of the UNEP report, The Green Economy, 2011, recourse to the inclusive wealth theory is recommended. This method is presented by the World Bank in its 2006 report, "Where is the Wealth of the Nations? Measuring Capital for the 21st Century". In this same report, the UNEP considers that the trade negotiations conducted in Doha under the aegis of the WTO could make a significant contribution to the promotion of the green economy, with a particular emphasis on the removal of tariff and non-tariff barriers on environmental goods and services and the liberalisation of the trading of agricultural products.
[46] See D. Méda, "La Mystique de la croissance. Comment s'en libérer" [11] and Attac, "La Nature n'a pas de prix. Les méprises de l'économie verte", Les Liens qui libèrent, 2012

disciplinarity is required[47]. The other relates to the discarding of procedures that could have allowed for a broader appraisal and the resolution of controversies, for example, which is a common practice in democracies for such fundamental issues and had already been carried out by the French Economic, Social and Environmental Council on the same issue, or for even more radical democratic procedures that could have allowed those primarily concerned – the citizens – to answer the question of "what really counts" in ensuring the long-term future of the society to which they belong. The results of these consultations could then have been compared to those held in other countries in order to allow for the definition of complementary or alternative indicators to GDP, focusing on the changes to critical assets and usable by the entire international community in the same way as the 2008 national accounting system.

In this way, the Commission did not carry out an in-depth analysis of the legitimacy of its proposals for new indicators, and instead asserted the "arbitrary" nature of the choices (in terms of the dimensions adopted, the variables and – for global or composite indicators – the weightings).

Moving away from this arbitrariness on questions of general interest assumes experimentation with ways of elaborating collective preferences. This requires the enhancement of the dialogue among different stakeholders, by comparing their requirements and not being restricted to the criteria of specialised experts, which may be a source of legitimacy and a way of strengthening it. It is only on this condition that new indicators could be considered to be shared conventions. With the recent adoption of the law on new wealth indicators (Eva Sas law adopted in April 2015), France has now started a period of learning how to combine democratic consultation and expertise: At the time of the Finance Act, this law made the publication of quality of life and sustainable development indicators a mandatory requirement, and left their choice open to public debate. The Economic, Social and Environmental Council and France Stratégie, which were asked to conduct this exercise, proposed and then finalised a list of ten additional indicators after a limited consultation process. The disparate evolution of these indicators will not be easy to interpret but it is nevertheless a first step towards challenging the domination of GDP which has prevailed since the late 1990s[48].

[47] Regarding the need for a multi-disciplinary approach, see the report by the philosopher Tom Dedeurwaerdere, entitled "Sustainability Science for Strong Sustainability", which proposes measures such as an institutional reform programme for sustainability science. http://biogov.uclouvain.be/staff/dedeurwaerdere/2013-01-11-rapport%20science%20pour%20DD_FR.pdf; on the need to take account of natural science, e.g. see the last report for the Club de Rome, Ugo Bardi, Le Grand Pillage, Institut Veblen/Les petits matins, 2015, which develops a chemistry-based approach.

[48] See http://www.alterecoplus.fr/economie/nouveaux-indicateurs-de-richesse-rien-nest-joue-201504090600-00001167.html

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National accounting and consideration of the natural heritage

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The first part presents a brief overview of the conceptual model of inclusive wealth developed by economists. It examines its implications for attempts to extend the scope of national accounting to the national heritage and to ecosystems in particular. The main requirements resulting from such an aim relate to completeness, valuation, integration and sustainability. For reasons of both a conceptual and practical nature, the desire to merge national economic accounting with a hypothetical system that could be used to account for ecosystem assets and services in monetary terms at "full scale" is considered to be unrealistic.

The second part proposes an approach that is limited to integrating the measurement of the deterioration of ecosystems. The concepts of unpaid ecological costs, ecological debt and final demand at total costs have been proposed for this purpose. Economy and Nature are conceived of as two separate entities. Any unpaid ecological costs give rise to transfers in capital from Nature to Economy and represent a variation in the ecological debt of the latter.

The conceptual model of inclusive wealth and its requirements

The sustainable development approach is generally presented in a theoretical conceptual framework that extends wealth (the assets) beyond the physical or intangible economic assets produced, in such a way as to incorporate the other components of inclusive wealth that are human capital, social capital and natural assets (in reality, cultivated natural resources are already included in the national accounts in the form of the economic assets produced). From this perspective, the notion of inclusive wealth aims to cover all sources of well-being. The latter is sustainable (its variation is positive or nil) if the variation in inclusive wealth per capita, while accepting the substitutability of the different types of wealth, is non-negative. The existence of limitations to substitutability implies that both the variation in inclusive wealth per capita and the variation of critical natural assets per capita (those for which other types of assets cannot be substituted) are non-negative. The value of the stocks of the different components of inclusive wealth is supposed to be measured by the present value of the flow of services they generate.

In this context, references are often made to an article by Martin L. Weitzman published in 1976, in which, by making strong assumptions, he endeavours to justify an interpretation of net national product or income, in a framework of inclusive wealth, in terms of both well-being and sustainability [7].

National accounting is often asked, quite insistently, to place itself in this type of conceptual framework so that its estimates can take account of the stocks of assets extended in this way and of the resulting goods and services.

The case of human capital, envisaged to its full extent, i.e. covering both physical human assets (human beings from their birth) and intangible human assets, mainly in the form of education assets, has long been discussed by economists and statisticians. The major difficulties raised by the possible inclusion of human capital, thus extended, in the national accounting system have been revealed[49]. National accountants have reached a consensus in considering that the estimation of human capital should be carried out in a satellite account of the national accounting system rather than being integrated, with difficulty, into the integrated central framework of this system. These types of works have generally been limited to educational capital. In addition to analysing the relationships between investment in education, its stock and the level and changes in

[49] For a brief summary, focusing on John Kendrick's works in the 1970s, see A. Vanoli "Une histoire de la comptabilité nationale (p.385-387)/A History of National Accounting (p.306-307)" (see reference [5] of the bibliography at the end of the article).

people's incomes, the main aim of works on human capital is to contribute to the estimations of total factor productivity for an entire economy or the branches of economic activity. It is clearly seen that, except at the global level at which an economy may possibly be conceived of as a single, representative economic agent, there needs to be a distinction between the assets used by production units and the assets owned by production units. In fact, the problems raised by the question of the representation of human capital, in both the micro and macro accounts, call for an overall analysis of human resources in an additional accounting framework that would include numerous variants.

Regarding the notion of social capital, in spite of its actual and symbolic importance, it remains very vague and clearly needs to be understood by other means than valuations in terms of monetary value as defined by national accounting.

It should be added that the concept of sustainable development, as devised at the global level in the 1990s, includes a dimension of intergenerational and intragenerational equity that clearly raises ethical questions. The statistical information system in its entirety is rightly required to insist on the observation and measurement of distributions, be they in relation to flows of income, consumption, etc., or wealth . The aim is to obtain elements that are crucial to the assessment of the state and evolution of societies. But the responsibility for making the ethical choices themselves – explicit or implicit – that allow for the judgement of this aspect of the sustainability of development, and for which the notion of "critical level" is not easy to envisage, falls to individual societies and the human community as a whole.

Finally, the actual social demand that is made of national accounting in terms of the measurement of the sustainability of development primarily concerns the inclusion of natural heritage. This article is thus dedicated to the relationships between the economy and nature.

A distinction must be made between nature as a source of extractable natural resources (goods) whose availability decreases with their removal, on the one hand, and nature as a source of ecosystem services whose quality and quantity may decline through damage to natural assets, on the other.

Taking account of both of these roles of nature in national accounting and both types of relationships between the economy and nature that need to be represented poses very different problems and difficulties of highly variable proportions.

Natural resources

In fact, the question of the depletion of natural resources due to their extraction should have been resolved long ago in a more satisfactory manner, directly within the framework of the traditional national accounting system. Under certain conditions, non-cultivated natural resources are considered to be economic assets in the system'sense as non-produced assets (i.e. not produced by the economy), but until now, the total value of the resources extracted, including their value prior to extraction measured by the rent derived from them, has been included in the measurement of both gross domestic product and net domestic product – a solution that has long been criticised.

Since its first version in 1993, the United Nations' Integrated Environmental and Economic Accounting' [SEEA 1993] – proposed the deduction of depletion costs, corresponding to the quantitative depletion of non-produced natural resources, from the domestic product of the national accounts, as one step for calculating a "net domestic product environmentally adjusted" or "Eco domestio product" . The SEEA 2012 set out this solution in greater detail by proposing a modified sequence of economic accounts. The latter calculates a "depletion-adjusted net value added" by deducting the estimated amount of the depletion of natural resources from the net value added (obtained by deducting the consumption of fixed capital from the gross value added). This method is similar to that used for the consumption of fixed capital, but is carried out in an additional stage of the accounting process. One consequence of this solution is that GDP, which is essentially the total of the gross values added by the branches of production, is not modified. Only the net domestic product (NDP) is reduced.

A preferable solution would be to consider the value of the depletion of a non-renewable resource (the extraction of non-cultivated renewable natural resources is a more complex case, as only the resources extracted beyond the renewal capacity of nature come into play; this point shall not be considered here, as I have developed it elsewhere, cf. [4]) as the value of the disposal (by the owner to the extractor, both of which may constitute the same economic unit) of a fraction of the stock of the resource in question. A significant consequence of this disposal of assets to be entered in the capital account of the economy would be to reduce the value of GDP and not just of NDP[50].

[50] Further information can be found in part IV (Depletion/extraction of natural resources (renewable or non-renewable) and adjustment of

Be that as it may, the next version of the SNA/ESA will in all probability include a better solution than the current one. However, we need to be aware of the fact that the problems to be resolved concerning natural resources are simplified because we are generally dealing with market resources. This means we have lots of information about the quantities and prices of the extracted resources and often – even though it is more uncertain – about the physical quantities of the proven or potential stocks (the main shortages of information concern non-cultivated renewable aquatic resources which cannot be directly observed). The main problems to be resolved are of a conceptual or information-processing nature.

Ecosystems

Representing and measuring the stocks and services of non-cultivated ecosystems in national accounting (flows and stocks of crops are already included in the traditional national accounting system) is a completely different matter, because most of what needs to be accounted for is situated outside the field of economic transactions that is observed, analysed, measured and synthetised by the national accounting system (via the statistical system). The fraction of flows relating to non-cultivated ecosystems, which peripherally already give rise to economic transactions, is taken into account in the latter; it is "internalised" (and in general soon becomes very difficult to observe *ex post*). It has thus been left out of the following explanations.

Extending the scope of patrimony (wealth) in national accounting to allow for the "full-scale" inclusion of ecosystems ("natural ecosystems" maybe to be more accurate, given the use of the ecosystem concept in numerous fields of human activity in recent years), involves requirements that tend to be mutually self-reinforcing.

The first requirement is for **completeness.** This may be a surprising term since complete coverage at the national level is, by definition, inherent to the very idea of national accounting. But its implications must be considered within the theoretical conceptual framework briefly described at the start of this article. Natural heritage (all natural assets) must be represented in their entirety. Similarly, the services (goods, as we have seen, can be left aside) must also be represented in their entirety. Within this theoretical context, ecosystem assets and ecosystem services must be represented and measured in a consistent manner. This means that, in compliance with the theoretical measurement of the value of economic assets by the current value of the services that will be derived from them, the value of an ecosystem asset would be measured by the current value of the ecosystem services that originate from it.

Therefore, if the recommendation is to create accounts for ecosystem services in physical terms, accounts for ecosystem assets in physical terms, accounts for ecosystem services in monetary terms and accounts for ecosystem assets in monetary terms – as recommended on an experimental basis by the SEEA 2012 Experimental Ecosystem Accounting – we are left with an aim that, in addition to being very substantial, also raises doubts as to whether, in its full extent, it is conceptually valid as the basis for a system of *ex post* observation, like national accounting, which must remain grounded " in the real", even if the idea that a certain amount of imputations and modelling is inevitable can be accepted in order to take account (but to what extent?) of phenomena that are quite remote from directly observable economic phenomena. The question of the representation and measurement of the vital ecological functions carried out by ecosystems is particularly complex.

The **second requirement** is for **a homogeneous and coherent valuation, at both micro and macro levels, using the current valuation method of the SNA/ESA national accounting system** (to be more precise, this is the method of the central conceptual framework of the SNA/ESA that produces the standard aggregations of GDP, Gross National Income, Gross National Expenditure and net worth of economic wealth). To allow for the integration of stocks or flows estimated "in monetary terms" into the central framework of the SNA/ESA, it must be possible to interpret their valuation as having been carried out in "equivalent transaction values".[51] Transaction values are the valuation mode used for the central framework of the SNA/ESA.

However, the methods used to estimate ecosystem services that have been proposed and implemented by economists provide values that do not generally constitute "equivalent transaction values". They are, in fact, usually based on estimates of people's willingness to pay for ecosystem services, obtained by means of contingent evaluation surveys that integrate modifications to the fringes of the availability of ecosystem services under specific conditions, particularly concerning location[52]. This willingness to pay includes

GDP and NDP) of my paper submitted to the 2012 IARIW Conference: Towards the Estimation of Final Demand at Total Costs (paid economic costs plus unpaid ecological costs) in an Extended National Accounting Central Framework (French version available on request).

[51] Otherwise, could we imagine that a central framework that has been redesigned according to the inclusive wealth hypothesis should be subject to a valuation method that is no longer in terms of transaction values, as defined by economic transactions?

[52] These methods, above all, seem to be implemented in the case of ecosystem services that directly benefit final consumers and for which the latter can clearly comprehend the key issues and, perhaps, the trade-offs in question. The measurement of the willingness to

consumer surpluses that the transaction values of the national accounts do not include. In the traditional terminology, these are referred to as estimates of "use values" (and possibly "non-use values") but not of "exchange values"[53].

This requirement regarding the valuation mode is particularly strong when viewed from the perspective of the **complete accounting integration (third requirement)** of ecosystem services and assets and economic products and assets – the initial hypothesis examined in the first part of this article.

Because there are *ecosystem services* which are *rendered directly to final consumers*, we need to be able to evaluate them in terms of equivalent transaction values if we want to be able to add them to the final consumption of economic goods and services in the current national accounts in order to obtain an extended measurement of consumption. We seem to be incapable of doing this at present. We could think about getting around this difficulty by trying, in a conventional manner, to combine the changes in two sub-aggregates rather than add them together. However, it should be borne in mind that the estimation of a total value for all final, direct ecosystem services continues to pose problems, especially when values estimated for specific points or small areas of observation and analysis are applied to much larger areas (an issue referred to as the "value transfer problem").

But the integration requirement poses even more complex problems for the *ecosystem services rendered to producers as defined by national accounting*. The economists that carried out extended estimates of the value of ecosystem services – in some cases at the global level (see Costanza 1997 and 2014 [1] and [2], for example) – usually according to types of services and categories of ecosystem assets, all emphasise that a proportion (which they do not identify as such) of the services they have evaluated is already "included in GDP" ([1] p.157) as it is incorporated into the contribution of natural capital to the goods and services that constitute it. While there is no doubt about the existence of such contributions in physical terms stating that they are "included in GDP", which is an aggregation of transaction values, is an ambiguous statement.

Therefore, the need to disentangle the respective contributions of nature and the economy (labour and capital produced) is frequently mentioned. But this question, which is not at all simple when viewed from the perspective of values, does not appear to have been investigated any further. It can be interpreted in several ways. An initial – and probably the most common – way could be to consider that it requires a redistribution of the total transaction values, as they are measured by the national accounting system, among their current components, *plus* one more. However, it is clearly seen that this would assume that the current prices of the different products represent their "true" absolute values, and therefore that their current relative prices are their "true" relative prices, whereas the current price system does not assign value to the contributions of nature in question. A second way could be to state that the value of the ecosystem services assigned to the productive process of each product is added to the current price of this product to give its "true" price, and hence its "true" relative price thus revealed. Although more satisfactory, such an approach is poorly suited to an integrated system of "*ex post*" statistical accounting adjustments, as it would be unrealistic to presume that the system of quantities would remain unchanged. This leads to the conclusion that the "full-scale" integration of ecosystems and their services into national accounting is inconceivable outside large-scale modelling operations.

Other problems are raised by the integration requirement. For example, in many cases, diverse ecological functions correspond to given categories of ecosystem assets. On the other hand, there are no clearly identifiable types of services for certain ecological functions. And many (or most?) ecosystem services/functions cannot be counted using physical units. It is important to stress the particular complexity of the vital ecological functions mentioned above. As a consequence it is sometimes concluded that the only way to aggregate them, and even to "count" certain types of ecosystem services so to speak, is money t means, in the case of services that are primarily non-monetary and quite remote from the scope of the measurement power of money as defined by Pigou.

At this point, I will not refer to the more elaborate works which do not seek to integrate, in the general sense of the term, economic and natural accounting, but rather to analyse in depth the contribution of specific ecosystem services to certain economic productions. The emblematic case relates to the pollination role of bees. This is an edifying example because, as in several other cases, (e.g. coral reefs and mangrove swamps), it is the existence of the actual or potential degradation of nature that has provided the incentive to assess the value of the services of these natural assets and laid the foundations for attempting to do so. The actual or potential degradation of ecosystems is, in fact, the key issue.

In all, an in-depth analysis of all of the problems that could be posed by complete integration does not appear to have been carried out, neither by environmental economists, nor – which is perhaps more surprising – by

pay for ecosystem services that are rendered to economic producers poses trickier problems.

[53] The ambiguity of expressions such as "measurement in monetary units" and "in monetary terms", which are used in this context, should be noted at this point. They are not equivalent to measurements "in units of monetary value". Indeed, a given unit of monetary value constitutes a general equivalent of exchange values but not of use values.

national accountants[54]. In this regard, it should be noted that the SEEA 2012 does not propose a complete integration of this type, but its position is ambiguous.

Furthermore, the aim of the integration that is recommended by the conceptual framework used here as a reference, **is to measure the durability/sustainability of development** by focusing on a single indicator of the variation in the extended patrimony (wealth). Can meeting such an objective be really **required of the current national ex post accounting system of the future?**

A positive answer to this question often seems to be so self-evident that the question is not even asked. It was, however, explicitly examined bythe Commission for the measurement of economic performance and social progress, known as the Stiglitz Commission, in its 2009 report. The Commission did indeed distinguish between the two notions/dimensions (current/sustainable). In this way, it clearly showed that the question of sustainability was not a matter of observation (*ex post accounting*), as might be carried out by national accounting (which does not exclude certain forms of modelling), but of long-term future modelling and a particularly ambitious form of modelling based on strong hypotheses. The Commission clearly did not adopt the idea that the correct current measurement (of product or income) should be the sustainable measure itself.

It may be recalled that the Commission strongly emphasised the distinction between the means (the goods and services covered by GDP and other resources) and the results of their use in terms of "well-being/quality of life". This means that the correct current measurement (of product or income) cannot, on its own, constitute an aggregate measurement capable of gauging the "well-being/quality of life" of the population of an economy[55].

At this stage, it might be considered more realistic to seek a possible integrated accounting measure in national accounting for just certain relationships between the economy and nature, rather than seek to achieve a form of total amalgamation between economic accounting and a hypothetical "full-scale" system of accounting for ecosystem assets and services in monetary value terms. To avoid any misunderstanding, it is important to emphasise that the conclusion proposed here applies to the *ex post* central national accounting system, in view of its role and necessarily limited aims. It does not invalidate the relevance of the inclusive wealth approach in an attempt to model the sustainability of long-term growth – this is left to analysts and model builders.

An approach limited to integrating the measurement of the degradation of ecosystems.

This is the type of more modest, although still ambitious, approach that is used to convey the proposal that I have been making for the past few years, concerning a conceptual framework for the integrated central national accounting system, that would be extended to cover the damage caused to natural assets by economic activities.

The Economy and Nature as two separate entities

The starting point is to conceive of the Economy and Nature as two separate entities (encompassed by the super-entity of the Planet), as opposed to the habitual practices of environmental accounting in which Nature is represented, in different ways, as part of an extended Economy.

This characteristic, which may at first sight seem to be purely academic, has major implications. Firstly, it means there is no need to modify the vast majority of the standard representation of economic activity by the national accounts, which can still be clearly shown. Secondly, it means that this representation can be supplemented by the specific inclusion of certain relationships between the Economy and Nature.

The point that is considered to be essential in this context is the degradation of natural assets by economic activities. This damage, along with the extraction of natural resources, was at the heart of the first proposal for an integrated environment and economic accounting system (SEEA 1993). It was relegated to the background, so to speak, as most of the attention was shifted towards ecosystem services. In reality, it remains fundamentally important. In the absence of any actual or potential damage to nature by human activities, the environmental concerns would be limited to the disruptions caused by Nature itself.

[54] To illustrate one of the aspects of the problem, it can be noted that for 1997, the global value of ecosystem services was estimated by Costanza et al,1997, at 33 trillion (10^{12}) in 1995 dollars, which was 1.8 times the amount of global gross national product of approximately $18 trillion. The authors mention (p.157) that according to the results of the GUMBO (Global Unified Metamodel of the Biospher) model developed by Boumans et al (including Costanza) in 2002, which uses more sophisticated modelling techniques, the global value of all ecosystem services for the year 2000 was estimated at approximately 4.5 times the value of gross world product.

[55] In addition to the Report of the Commission itself, the reader can also consult my commentary on it in a paper submitted to the 13th Conference of the French National Accounting Association (2 – 4 June 2010). http://www.insee.fr/fr/insee-statistique-publique/connaitre/colloques/acn/pdf13/texte-vanoli.pdf

A series of notions has been developed around the aim of accounting for the value of the damage to natural assets that results from human production and consumption activities. They are briefly presented here[56].

Concept of "Unpaid ecological costs" This point is essentiel. The aim is not to attempt to ascribe a monetary value to the stocks of natural ecosystem assets themselves but only to the change in the state of these stocks (their degradation or possible restoration)[57].

"Unpaid ecological costs" (UECs) are the costs of damage to natural assets resulting from economic activities that have not been avoided or repaired by internalised costs borne by the economy. These are costs of damage to nature and are not the whole bulk of environmental costs.

UECs are supposed to be estimated not by the estimated value of the ecosystem services that have been lost, but by the costs that should have been borne by the economy in order to prevent damage to the natural assets, or that the economy should bear in order to restore them or compensate for them in equivalent assets. The idea is similar to that of the maintenance costs in the SEEA 1993. The UECs are interpreted as being valued in terms of equivalent transaction values.

Notion of ecological debt

Ecological debt is the economy's debt to nature. The stock of ecological debt results from the accumulation of UECs over time. It decreases if, in different ways, the economy restores damaged natural assets.

UEC and the concept of final demand at total costs

The final demand at total costs of an economy is the sum of the economic costs paid (here, the term "costs" is extended to all of the transaction values of the standard economic accounts), i.e. of the final demand at the paid costs, and of the unpaid ecological costs. It concerns two different valuation methods for the same final demand in terms of the goods and services it comprises.

In the proposed approach, all of the damage caused, and therefore the corresponding UECs, are attributed to the final demand for products derived from economic activities, whether this damage appears during their production in the broad sense, due to their use, or in relation to it.

Depending on the scenarios in question, the natural assets concerned may belong to the domestic nature of an economy, to the nature of other economies, or to nature in general at the planetary level in its entirety. Similarly, according to the scenarios, the final demand concerned may be that which is assigned to the GDP of an economy or the demand of the resident economic agents of an economy.

UECs may be analysed and measured per type of damaged natural assets (domestic, foreign or global). The estimation of the value of the degradation of the domestic nature of an economy per type of natural asset is the crucial stage of such a process. With the emergence of the issue of climate change, the estimation of the damage to global nature has, in turn, become a fundamental topic.

Ideally, the aim should be to estimate UECs according to the final demand of the residents of a given economy in which the damage to nature that can be attributed to it occurs. In this way, we could measure this final resident/national demand at the total costs.

Even more ideally, we should be able to correlate the UECs per type of natural asset and per type of goods and services comprising the final demand for the resident agents of an economy.

One of the uses of the estimation of UECs could be to calculate a ratio that is indicative of the imbalance in the relationships between the Economy and Nature. This ratio may take a variety of forms, such as the relationship between the final demand at total costs and the final demand at paid costs, which is equal to 1 when these relationships are balanced.

What needs to be done is clearly not simple, but nothing is simple in accounting when the environment is taken into significant account.

[56] A more detailed presentation was made in a contribution to the SEEIDD seminar of 19 December 2013 under the title: "Vers un enrichissement des comptes de la Nation par la valorisation de l'évolution de l'état des actifs naturels" (Towards the enhancement of the Nation's accounts through the valuation of the change in the state of natural assets), published in the proceedings [4]. It is attached as an appendix to my paper submitted to the 15th Conference of the National Accounting Association (19-21 November 2014): "Dégradation des actifs naturels par les activités économiques et cadre central de comptabilité nationale" (Damage to natural assets by economic activities and central framework of national accounting). http://www.insee.fr/fr/insee-statistique-publique/connaitre/colloques/acn/pdf15/ACN2014-Session1-4-texte.pdf

[57] On the other hand, the observation and measurement in physical terms of stocks of ecosystem assets in their entirety, and of how they change, are essential. This is an essential goal of Natural accounts, as distinct from Economic accounts (see the end of this article).

An extended central framework of national accounting

Alongside what has already been mentioned, devising an accounting system that is capable of incorporating the consideration of damage to natural assets by economic activities into the integrated central framework of national accounting is almost child's play, providing that from the outset, Nature and the Economy are considered to be two distinct entities.

This system is described in the article presented to the SEIDD seminar of December 2013 [4]:

Schéma comptable permettant d'introduire dans le cadre central intégré de la comptabilité nationale la prise en compte de la dégradation des actifs naturels par les activités économiques (An accounting system capable of incorporating the consideration of damage to natural assets by economic activities into the central integrated framework of national accounting).

"A transfer of capital from Nature to the Economy is recorded. During the course of a given period, it is equal to the flows of unpaid ecological costs.

As the inclusion of these costs in the Economic accounts increases the value of uses of its (economic) revenue, which itself remains unchanged, an equivalent amount of negative savings appears. The balance of the Economic accounts is restored by a transfer of capital from Nature. [This corresponds to the variation in the ecological debt of the Economy.]

On the Nature side, a partial account of the change in balance sheets records the value of the flows of damage to natural assets that occurred during this period, on the one hand, and the corresponding transfer of capital to the Economy, on the other.

A simplified itemised example (closed economy).

Hypothesis: gross national income (GNI) of 1,000 (equal to GDP), with 900 of final consumption (FC) and 100 of gross fixed capital formation (GFCF), and additional damage (UEC) of 50 – 45 of which is assigned to FC and 5 to GFCF

Accounts of the Economy		
GNI		1,000
	-	
FC at paid costs		900
	-	
UEC_{FC}		45 [FC at total costs 945]
	=	
Adjusted gross savings		55
	-	
GFCF at paid costs		100
	-	
UEC_{GFCF}		5 [GFCF at total costs 105]
	=	
Negative savings of the Economy		- 50
Transfer of capital from Nature to the Economy = variation in the ecological debt of the Economy): $UEC_{FC} + UEC_{GFCF}$		50

Nature's account (change in balance sheets of Nature)	
Damage to natural assets:	- 50
Transfer of capital to the Economy: = variation in the ecological debt of the Economy)	50

This partial change in balance sheets account of Nature ties into a balance sheets of Nature that is also partial. This account comprises two items, both on the asset side. The first, accounted for negatively, records the accumulated damage caused to natural assets by economic activities (accumulation of unpaid ecological costs). The second records the equivalent amount of the accumulated debt of the Economy to Nature (accumulation of capital transfers from Nature to the Economy).

Any restorations of previously damaged natural assets give rise to entries in the opposite direction to the previous entries and, in particular, to transfers of capital from the Economy to Nature.

The addition of relationships with the rest of the world, and of any re-evaluations, complicate the accounting system".

Source: The author's contribution to the SEEIDD seminar of 19 December 2013 under the title: "Vers un enrichissement des comptes de la Nation par la valorisation de l'évolution de l'état des actifs naturels" (Towards the enhancement of the Nation's accounts through the valuation of the change in the state of natural assets), published in the proceedings) [4].

A simple conceptual framework and accounting scheme but complex implementation

Preliminary work attempt to sift through the problems raised by the estimation of UECs. Those carried out by Frédéric Nauroy on the UECs relating to airborne emissions, and particularly those relating to climate change due to damage to the natural climate asset (a global public good) that they cause, were published in 2014 [3]. Jérémy Devaux presented his study of the UECs associated with water pollution in France at the SEIDD seminar of 2013 [4]. Similar approaches are being developed for marine waters in the framework of preparations for a new European directive. More recently, the question of UECs associated with damage to soils has been raised.

These initial attempts have revealed several very important methodological points, which were presented in the following manner in my paper submitted to the 15th Conference of the French National Accounting Association in 2014:

"*The assignation of unpaid ecological costs to the final demand brings into play a **principle of responsibility** (in this case, final) for the damage caused to natural assets. In this context, the principle of responsibility is understood to have the objective meaning of assignability or attributability, without any moral connotation.*

Ideally, the application of the normal rules of civil liability would mean that the estimated value of the damage should correspond to the cost of rehabilitation by the party or parties that caused it. This principle is, of course, too simple, given the complexity of the issues. It can, however, be noted that the environmental policies that determine the quality standards to be attained within a certain period for certain damaged natural assets may be interpreted as determining restoration objectives that are similar to applying the principle of rehabilitation. This "rehabilitation" can sometimes be expected of direct restoration actions in the strict sense of the term, or more frequently of changes in the implementation techniques or levels of certain economic activities. In this way, we are operating in the perspective of the "imputed maintenance costs" according to the SEEA 1993. However, even when defined in this manner, rehabilitation is sometimes impossible to envisage. This may then lead us to the question of the development of compensatory alternative natural assets, either in nature, or in the economy (crops). This point will not be touched upon in this article.

*In the context of the "imputed maintenance costs" or of "unpaid ecological costs" in my terminology, the **question of the state of reference** has been posed. As this cannot involve going back to the origins of the economic activity of humankind, what initial state of natural assets should be considered as the starting point for the measurement of their deterioration? There is no completely objective, "naturalistic" answer to this question. The answer can only be conventional. Based on the knowledge of nature, it is formulated explicitly or implicitly in the form of **environmental standards** that human societies decide to adopt as the aims of policies. This ties in with what was stated in the previous paragraph about the interpretation of these standards in terms of "rehabilitation". By deciding on environmental quality objectives to be attained within a certain future period, we define a previous state of reference **which is considered "satisfactory"** and that we wish to restore. This state of reference is not intended to be considered an absolute optimum level. It is **reviewable**, generally with a view to attaining a state that is considered to be more satisfactory due to more stringent standards. Reassessments must therefore be **carried out.***

*The next point has been revealed by the initial works carried out on estimating UECs. At least in an initial investment phase, the practical approach does not follow the order of operations that was suggested by the initial idea. Logically, the pressures exerted by economic activities cause damage to natural assets. This leads to the appearance of UECs in the current accounting period. **The accumulation** of this damage, and therefore of the corresponding **UECs,** constitutes the Economy's **ecological debt to Nature**. In practice, the existence of environmental standards – when they exist – or of analogous calculations, leads firstly to the estimation of a stock of ecological debt at a certain time in the past, and then to the measurement of the annual upward or downward variation of this stock, i.e. of the positive or negative UECs, according to events in the period*".

National or international environmental standards thus have a substantial role.

In certain domains, with the contribution of scientific experts in these fields, they establish objectives to achieve in terms of characteristics of natural assets, between now and a given time horizon Tn and in comparison to a state of reference for previous damage, which is the starting point To for the policies in question.

Other experts – in particular economists and stakeholders from the fields in question – endeavour to produce measures to be implemented in order to achieve these objectives and assess their cost.

The cost of the measures to be implemented in order to achieve the objectives set for the future time horizon Tn can be interpreted as an estimate of the value of the damaged that has been accumulated in the past up to the starting point To of the policies in question, i.e. as the value of the accumulated UECs or of the stock of ecological debt on the date To.

Comparison with other approaches

The third part of the paper presented to the 2014 Conference of the French National Accounting Association (reference in the footnote on page 73) includes a quick comparison with other approaches, in particular the SEEA 2012 – EEA, the ecosystem capital accounts proposed by Jean-Louis Weber to the European Environment Agency, the World Bank's adjusted net savings and the ecological footprint.

In conclusion

1 - For the moment, we do not know how or whether the groundwork being carried out regarding the feasibility of estimating UECs, the first examples of which have been mentioned above, can cover the entire field. Beyond the groundwork phase, making significant progress according to the approach presented in the second part of the present paper will necessitate institutional initiatives in a long-term perspective.

2 - Such an approach, although already mentioned in an embryonic form in an article published in 1995 [6], attracted no attention whatsoever in the international discussions relating to environmental accounting and the SEEA over the last 20 years.

3 - However, from the perspective of an extended national accounting, the idea of wanting to take account of the monetary value of natural capital in its broadest possible sense and integrate it into the system, seems to end in deadlock. A more in-depth examination of the questions briefly presented on this subject in the first part of this text will be required to test out this conclusion more thoroughly.

4 - Certain economists themselves appear to be wondering about related issues. For example, a recent publication (Christian de Perthuis and Pierre-André Jouvet, Le Capital vert, une nouvelle perspective de croissance [Green capital, a new outlook for growth], 2013) contained the following passage: "*Growth can justifiably be described as 'green' when it includes natural capital as one of the production factors in which investment is required on a par with labour and capital. From a conceptual perspective, this is a very simple definition. But how can it be put into practice if it is impossible to put a price on Nature, i.e. to directly evaluate the value added by all of the services provided by the stock of natural capital? We have shown that, on the other hand, it was more relevant to estimate the cost of the damage that economic activity causes to the environment… Also, it is not the stock of natural capital itself that is integrated into our approach, as common sense would dictate, but rather the damage caused to it by pollution*" (p.181)[58].

5 - It is important to bear in mind that the accounts of the central national accounting system of the Economy which are expressed in monetary value do not cover everything that one might seek to include in a nation's accounts. In particular, Nature's accounts, as distinct from the accounts of the Economy, must attach particular importance to the accounts of stocks of ecosystem assets and how they change in physical terms, while distinguishing among the different factors of this variation – and particularly what is caused by economic activities. The observation and measurement of the total stocks of ecosystem assets and their variation may allow for partial judgements of the sustainability of development, provided that environmental standards (in terms of characteristics of the health state of certain ecosystems) have been adopted by Society. This raises the question of making some type of periodic inventory of nature. A key question with a view to developing indicators of the state of Nature by combining physical data concerns the equivalences that might be envisaged among heterogeneous categories of ecosystems. National accountants are not responsible for answering this complex question. This is mainly a matter for specialists in the different fields of observation of nature. It requires cooperation among many disciplines, including economics, and involves societal choices.

[58] I shall not comment on the rest of the text.

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Unpaid ecological costs: initial attempts to estimate the increase in the ecological debt for the natural assets of "climate", "air" and "continental aquatic environments"

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Stemming from a desire to create an additional indicator to gross domestic product (GDP) that would include all aspects of sustainable development, and particularly damage to the environment, the concept of "unpaid ecological costs" (UECs) has been examined in exploratory studies carried out by the French General commission for sustainable development (Commissariat général au développement durable – CGDD). These works have allowed for the development of a general evaluation methodology and the production of initial estimates of the expenditure that would need to be devoted to the conservation of some of our natural assets that have been damaged by human activities: climate, air and continental aquatic environments. These estimates, whose amounts turn out to be particularly high, could act as a precious tool for guiding environmental policies, especially in terms of internalisation. This process has begun in the water sector, for example, with the Water Framework Directive (a planned restoration programme for aquatic environments, which in theory allows for the conversion of UECs into paid costs from one year to another and the eventual cancellation of the ecological debt to this natural asset).

The different estimates presented in this article are derived from exploratory studies at different stages of progress. The "climate" and "air" components have been covered in a publication within the CGDD's "Etudes & documents" collection. The "continental aquatic environments" component offers an initial interpretation of a possible methodology for evaluating the size of the ecological debt pertaining to this natural asset.

The research undertaken over the past few decades in the field of environmental accounting has not led to a consensus regarding the creation and adoption of a new indicator of production or sustainable national savings. Originating from this desire, the concept of "unpaid ecological costs" (UECs), developed by André Vanoli[59], allows us to identify the most important relationships between the economy and nature.

UECs evaluate the total amounts that should have been paid by economic agents with a view to preventing damage to different natural assets (climate, air, continental aquatic environments, soils, marine environments, biodiversity, etc.) or to restoring their status. Practically speaking, two distinct types of evaluation can be carried out: the estimation of UECs over a given year (measurement of flows) and an estimation of the amount of the ecological debt, i.e. of the total annual UECs accumulated since the moment at which the capacities to absorb pressure by nature were exceeded (measurement of stock). By comparing them to the major aggregates of the national accounting system such as gross domestic product (GDP), UECs allow for the evaluation of the unpaid charges resulting from the pressures of the current development mode on nature.

To carry out evaluations of UECs, two types of costs may prove to be pertinent: avoidance costs and restoration costs. The choice of either one depends on the natural environment and the nature of the damage that is observed (or can be predicted). If both types of costs can be applied to a single natural asset, then the costliest solution is adopted.

This process, which is still experimental, has been the subject of recent works carried out within the French General Commission for Sustainable Development (CGDD). These works do not yet, at this stage, allow for a breakdown of complete, renewable accounts each year, but they have nevertheless resulted in initial evaluations of the total amount of UECs for France, not for the entire natural patrimony, but for certain specific assets: "*climat*", "*air*" and "*continental aquatic environments*". This article sets out these initial estimation attempts.

[59] President of the French national accounting association and author of the article entitled "National accounting and consideration of the natural heritage" in this Review.

Unpaid ecological costs, "climate" component

Context

Considering the growing impact of climate change, numerous reports and evaluations are published on a regular basis with a view to proposing possible ways to reduce greenhouse gas (GHG) emissions in a sustainable manner. The Intergovernmental Panel on Climate Change (IPCC) has recently published its fifth evaluation report. For France, the Factor 4 report – published in 2013 by the French General council for the environment and sustainable development (Conseil général de l'environnement et du développement durable, CGEDD) – mentions five reports and exercises carried over the past ten years or so on ways to obtain a fourfold reduction in the levels of GHG emissions in France between 1990 and 2050 and the costs of these approaches.

The aim here is not to undertake a new evaluation of the costs required to attain the Factor 4 target, but rather to use the findings of certain recent works on estimating UECs to support proposed new avenues of exploration in the field of environmental economic accounting.

The approach will be based on avoidance costs. In fact, for climate issues, the problem is not presented in terms of restoration. Indeed, this is now virtually impossible given the residence time of the main GHGs in the atmosphere and their increasing accumulation over recent years. An avoidance and prevention-based approach has thus been adopted.

The maintenance of climatic equilibria is a global issue that cannot be broken down at the local level by setting ecological targets or thresholds designed to restore or maintain the status of natural assets in a given territory. Even if it only makes a very small contribution to maintaining climatic equilibria, given the small proportion of French emissions in the global total, we shall use the target set by France for reducing its GHG emissions (the POPE Act of 2005) as a reference. As explained above, this target, referred to as "Factor 4", provides for a fourfold reduction in the annual level of GHG emissions between 1990 and 2050. Additional UECs should appear once the annual emissions exceed those of the annual emission level allowing for the attainment of "Factor 4". This supposes the definition of an annual emission trajectory over nearly 40 years that converges towards the final target emission level.

Estimation of ecological debt (measurement of stock) and UECs (measurement of flows)

To estimate the amount of ecological debt, we shall refer to work that has evaluated the total cost that would need to be met in order to attain "Factor 4", namely the work of the Quinet Commission (2008) on the "guideline carbon value" and the Perthuis Committee report "Trajectoires 2020-2050 vers une économie sobre en carbone" (2020-2050 Trajectories towards a low-carbon economy) (2011). This report provides information about the global cost to be paid in order to attain the Factor 4 target, based on three different trajectories between 2012 and 2050. The cumulative total of the annual costs over the period is between €260 and 440 billion. These estimates do not take account of a certain drop in GHG emissions, however, which is foreseeable even without the application of supplementary measures. Indeed, the measures implemented during recent years with a view to reducing emissions should continue to have an effect in the years to come. The estimates mentioned above have been made with the implicit assumption of GHG emissions remaining stable over the period if the current conditions are maintained (without an increase in costs). It is on this basis, and therefore with a certain amount of caution, that a connection can be made between these amounts and the notion of ecological debt.

For the estimation of UECs, three scenarios can be envisaged:

- annual rises in GHG emissions leading to new UECs and an increase in the ecological debt;
- a regular drop in emissions conforming to the attainment of "Factor 4" in 2050: instead of UECs, new costs appear in economic transactions (environmental taxes, protection expenditure, investments in low-carbon technologies, etc.) leading to a partial reduction of the ecological debt (or negative UECs);
- interim situation: drop in emissions, but not enough to attain the target within the deadline. UECs must be considered if any transfer of emissions from one year to another at the same unit cost is considered impossible. The variation in ecological debt is harder to estimate in such a case.

The marginal cost per tonne of carbon avoided can be used to assess the cost of the quantity of emissions that is considered excessive in relation to the trajectory determined in view of the target. The "Trajectories" report proposed that this marginal cost should change according to three profiles, each leading to Factor 4. The scenario adopted here is the T30 scenario which provides for the sharpest drop in emissions between now and 2020. Throughout the entire period, the price of CO_2 rises regularly, from €35 per tonne avoided in 2012 to just over €300 in 2050.

A precise trajectory must be established to discover the annual effort that must be made to reduce emissions over the period. Different types of profiles, which are relatively consistent, are produced by the models, but in terms of UECs, a constant annual effort (equivalent drop in emissions each year) can be retained.

The trajectory that has been adopted consists of reducing the annual level of GHG emissions by 9 million tonnes of CO_2 equivalents per year, with nine-tenths concerning CO_2 itself. This is a simpler profile than that defined in the "Trajectories" report, which is not completely linear.

Estimates of UECs have been calculated for three years (2010, 2011 and 2012), based on the annual GHG emissions provided by the emission inventories of the French Interprofessional technical centre for the study of atmospheric pollution (Centre interprofessionnel technique de la pollution atmosphérique – CITEPA). New UECs appear when the emissions observed are higher than the levels recommended by the "ideal" trajectory. This difference is evaluated by the marginal cost of CO_2 at the start of the period (€35, and then €36 per tonne).

2010 is notable for a rise in GHG emissions and the resulting UECs are estimated at €560 million, which amounts to 0.03% of GDP or of the national final demand.

In 2011, the emissions decreased to a much greater extent than expected (-28 Mt compared to -9 Mt). This reduced pressure on nature led to a reduction of the ecological debt estimated at nearly €1 billion.

Finally, GHG emissions remained stable in 2012. Additional UECs are measured on the basis of the 9 $MtCO_2$ that should have been eliminated. The total amount is estimated at €400 million.

Unpaid ecological costs 2010-2012

Year	Annual variation in emissions (in $MtCO_2e$)	GHG emissions / Required trajectory F4	Annual amount of UECs (in € million)	Direction of variation of ecological debt
2010	+6	Too high	560	Increase
2011	-28	Stronger decrease than required trajectory	-970	Decrease
2012	0*	Too high	400	Increase

* Calculations of SOeS, according to preliminary estimates of Citepa

Unpaid ecological costs, "air" component

Context

Beyond the disruption of climatic equilibria, the quality of the atmosphere can deteriorate due to the emission of substances other than GHGs.

In contrast to climate change, the causes of atmospheric pollution are found at the local and regional levels, although there are also diffusion phenomena from one region to another.

In the framework of UECs, the aim consists of measuring the annual cost of eliminating atmospheric pollution which would allow for the attainment of regulatory objectives or those recommended by competent authorities, which are currently not met.

Two initial questions arise: the choice of substances that affect air quality and the desired level of restoration or quality that is sought. In practice, it is impossible to estimate the UECs for the total quantity of airborne emissions. Furthermore, it is accepted that the complete restoration of the atmosphere to the point at which it would show no signs of the slightest damage (or impact) of anthropic origin, is now unattainable as the associated costs would be exorbitant.

The attention shall focus on a list of substances that have a negative impact on both human health and ecosystems with regard to acidification, eutrophication and photochemical pollution. These substances are alveolar particles with a diameter of less than 2.5 µm ($PM_{2.5}$), sulphur dioxide (SO_2), nitrogen oxides (NOx), ammonia (NH_3) and volatile organic compounds (VOCs). Some of them (NOx and VOC) are tropospheric ozone precursors – gases that have harmful impacts on human health and the environment. These five substances have been strictly regulated for several decades and are subject to regular evaluations, including in the framework of strategies developed by the European Union (EU).

Given the proliferation of existing standards and strategies, setting threshold values adapted to the estimation of UECs is a difficult task. The situation is made even trickier due to the current period of transition in Europe. While action was taken in 2012 to follow up the Gothenburg Protocol (GP), which provides for new reductions in the emissions of the five target substances by 2020, the NEC (National Emissions Ceilings) directive on national emission caps (for the same substances as the GP) is currently being revised: in December 2013, the European Commission published a "Clean Air Programme for Europe" comprising new itemised targets for reducing atmospheric pollution emissions by 2030.

Given the lack of clear standards in the current situation, the Commission relied on modelling carried out by the International Institute for Applied Systems Analysis (IIASA), based in Austria, as the basis for determining the targets of the "Clean Air Programme for Europe". The emission reduction targets calculated for France according to the IIASA "GAINS" model were directly included in the draft directive for emission caps published by the European Council and Parliament in December 2013, in the framework of the "Clean Air Programme for Europe".

In late 2013, IIASA developed a scenario conforming to the targets of the new European strategy. This "target scenario" allows for significant reductions in the impacts of atmospheric pollution with the application of higher costs. To estimate a total amount of UECs, the results concerning costs by 2025 must be compared to the amount of the cost that is currently borne by the French economy in order to determine the additional amount that would allow for the attainment of the targets that have been set.

Estimation of ecological debt (measurement of stock) and UECs (measurement of flows)

Results to be achieved for 2030		
	Variation 2030/2010 EU (percentage)	Variation 2030/2010 France (percentage)
Ecosystems areas with nitrogen deposition exceeding critical loads	-27.7	-39.3
Years of life lost related with exposure to $PM_{2.5}$	-44.5	-44.8
Premature deaths due to ozone exposure	-31.3	-31.7

Source : IIASA, calculations of SOeS

This requires levels of air quality (not clearly stated in the new strategy) that will make such reductions of impacts on health and ecosystems possible. The transposition of these targets to France could produce similar improvements to those calculated for the EU with regard to human health and even greater in relation to protecting ecosystems from eutrophication.

This level of restoration requires greater efforts regarding the reduction of emissions and the additional costs to be borne.

The quantities of emissions to be attained by 2030 in view of the targets defined in the table above demand significantly higher reduction efforts than those relating to the regulations still in force and the new GP. The associated costs increase as a consequence. The total annual cost calculated for France by the GAINS model amounts to €12.5 billion in 2025. This amount encompasses all of the costs that allow for the attainment of the targets by 2030, be they costs that are already borne today or representative of the new efforts to be made. In fact, a not insignificant proportion of this sum has now been paid for (internalised), particularly after the efforts made during the 2000s which allowed for significant reductions in emissions. To have an idea of what "remains outstanding", we need to know the amount of the costs that are currently borne by the economy. The GAINS model estimates that the cost borne by France in 2010 with a view to reducing or containing atmospheric emissions amounted to €8.1 billion. The difference between this amount estimated for 2010 and that predicted for 2030 in order to meet air quality improvement targets represents a total amount of UECs. This corresponds to the ecological debt relating to the baseline status, which corresponds to the targets defined and estimated on the basis of the situation in 2010. This total amount of UECs is estimated at €4.4 billion, which amounts to 0.2% of GDP or of the national final demand. This gives an idea of how much progress still needs to be made (with the annual internalisation of a fraction of this sum so that it can be completely cancelled between now and 2030) in order to attain a standard of air quality that is deemed to be acceptable.

In contrast to the "climate" component, it has not been possible to fully develop this strategy by estimating an amount of UECs for a given year according to a level of emissions. It has only been possible to estimate the stock of ecological debt. The functionalities of the GAINS model could allow for the calculation of the annual

UECs for a particular pollutant, but this would be more difficult to do for all of the five substances being considered.

Unpaid ecological costs, "continental aquatic environments" component

Context

The Water Framework Directive (WFD) of 23 October 2000 defines a framework for a Community policy on water. It requires European Union Member States to achieve "good status"[60] for all of their water bodies by 2015.

To meet this target, the Member States have had to identify and calculate the cost of all of the measures to be implemented. This exercise is based on the diagnoses made by territorial commissions according to the audits carried out by each water agency (agence de l'eau) for the river basins in metropolitan France[61] and each water office (office de l'eau) for overseas *départements* of France[62].

The measures finally adopted were considered to be the most cost-effective for attaining the targets in question and thus constitute a sort of "ideal scenario" for achieving good water status by 2015. They concern all of the stakeholders that can subsidise, finance or carry out water protection actions (European Union, French government, regional and département-level councils, water agencies, water services, households, farmers, manufacturers, etc.).

However, although the "ideal scenario" for the achievement of good status has indeed been defined for each river basin and hydrographic district, it has not been applied in to the letter. In fact, the assessment of the feasibility of the measures, carried out in each water agency and office, has allowed for the identification of the areas in which the financial efforts were too great to be achievable by 2015 and for which the deadlines thus needed to be deferred. Article 4 of the WFD provides for this eventuality. In this way, if the costs are too great in relation to the expected benefits, the Member States can spread the costs of achieving good status over longer periods, i.e. up to 2021 (in what is referred to as the second cycle of the WFD) or 2027 (third cycle of the WFD).

Following negotiations over deadlines in each river basin, each water agency or office then produced a document referred to as "programmes of measures" to be implemented over the period of the first cycle of the WFD, extending from 2010 (date scheduled by the WFD for the start of the implementation of the measures) to 2015. Two other programmes of measures will follow, identifying the measures specific to water bodies for which the deadlines have been deferred. The second programme of measures will thus cover the 2016-2021 period, while the third programme of measures will cover the 2022-2027 period.

Estimation of ecological debt (measurement of stock) and UECs (measurement of flows)

The legislative framework and the work carried out in the framework of the WFD make it possible to envisage an evaluation of the ecological debt and the UECs for continental aquatic environments by the restoration cost method.

The costs of the "ideal scenario", already estimated by water agencies and offices, provide an approximate idea of the ecological debt, using 2010 as the baseline year. By compiling the different financial documents produced by the water agencies and offices, which provide information about the implementation of the "ideal scenario", the ecological debt relating to continental aquatic environments can, in an initial approach, be estimated at just over €51 billion in 2010.

The spending actually carried out each year by the different stakeholders in the context of the "ideal scenario" can be used to estimate the annual UECs. In reality, these correspond to negative UECs which are deducted from the ecological debt. Each year, these UECs will reduce the ecological debt which, in 2027 (the end of the third cycle of the WFD), will be theoretically nil. This reasoning is summed up in the following diagram.

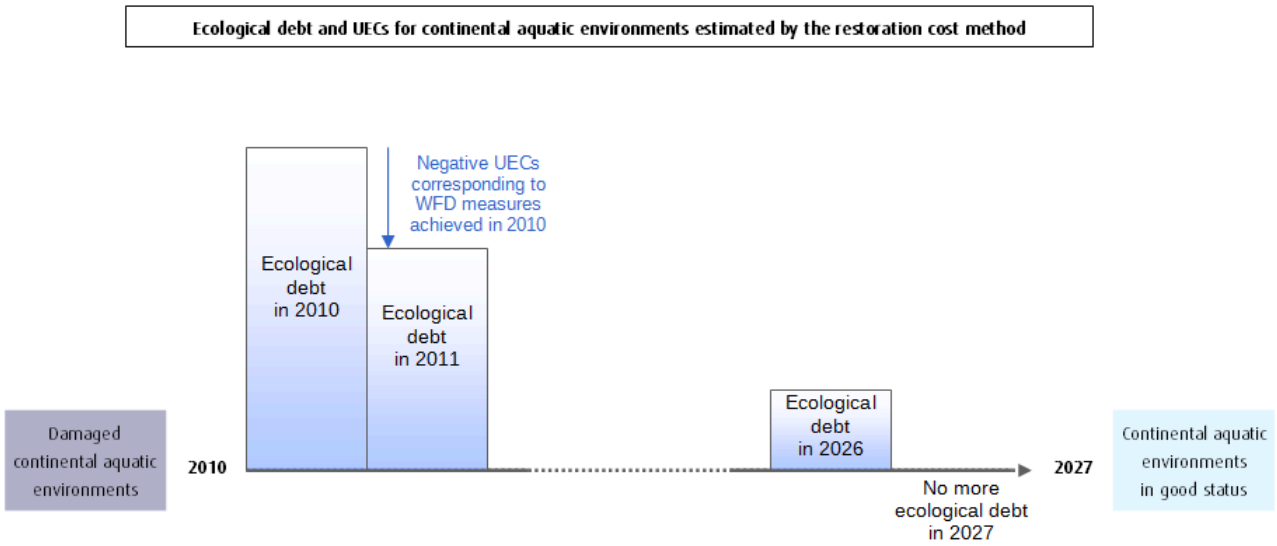
[60] "Good status" is achieved for a water body when several criteria have been met. These criteria vary according to the type of water body (surface or ground water) in question.

- The status of a surface water body is good when its ecological status (sufficient presence of plant and animal life to allow for the efficient operation of the ecosystem) and chemical status (concentrations of pollutants including priority hazardous substances) are considered to be at least "good".

- The status of a ground water body is good when its quantitative status (balance between the abstractions and natural recharging of a ground water body) and chemical status (concentrations of pollutants including priority hazardous substances) are considered to be at least "good".

[61] Adour-Garonne, Artois-Picardy, Loire-Brittany, Rhine-Meuse, Rhone-Mediterranean-Corsica, Seine-Normandy.

[62] Guadeloupe, Réunion, Martinique, Guiana, Mayotte.



To evaluate these annual UECs, the measures undertaken by the different stakeholders in the framework of the WFD must be monitored. However, in an empirical manner, access to this type of data is complicated for several reasons. On the one hand, it is sometimes difficult for water agencies and offices to obtain data relating to the expenditure of other stakeholders. On the other hand, within the water agencies and offices themselves, it is sometimes difficult to distinguish between the annual expenditure that is committed to the WFD programme of measures and the spending relating more generally to their general programmes of intervention in the water sector. A final difficulty also resides in the fact that it is not always possible to distinguish clearly and accurately between the scheduled actions and those already underway or completed.

Developments and limitations

In spite of being of a still exploratory nature, the UEC cost evaluations carried out by the CGDD on certain natural assets have shown that the creation of an indicator of sustainable national savings or production is a possibility. The methodologies developed allow us to envisage estimates for other natural assets such as marine environments (cf. box hereafter).

To envisage their integration into the accounts of the national accounting system, certain elements must of course be improved according to the limitations identified during the performance of this initial run through:

- For the "climate" component, the measurement of UECs was based on the domestic emissions. In an open economy, it would have been more relevant to base them on the carbon footprint of the final demand, which measures the GHG emissions relating to the products of final consumption and investments in France (emissions within the national territory + emissions linked to imports – emissions linked to exports). As the emissions from the carbon footprint are higher than the domestic emissions, the estimates proposed in this article should be considered underestimates.
- For this same component, the work carried out shows that the link between annual UECs and the variation in ecological debt must be explored in greater detail. In the event of a failure to conform to the trajectory leading to Factor 4 in a given year, it would seem wise to carry out a new estimate of the ecological debt for the entire remaining period. This calculation could be more reliable than that consisting of adding the UECs estimated for the previous year to the ecological debt estimated at the start of the year.
- For the "air" component, the results obtained are highly dependent on the standard chosen to estimate the ecological debt. Several possibilities had been envisaged during the performance of the exploratory work presented in this article: NEC directive, revised Gothenberg protocol and the "Clean Air Programme for Europe". The last option had been chosen. However, considering the changes in the international context (this programme has since been abandoned by the European Commission), a new estimate may be required. This could be based on the new NEC directive, once an agreement is concluded on it.

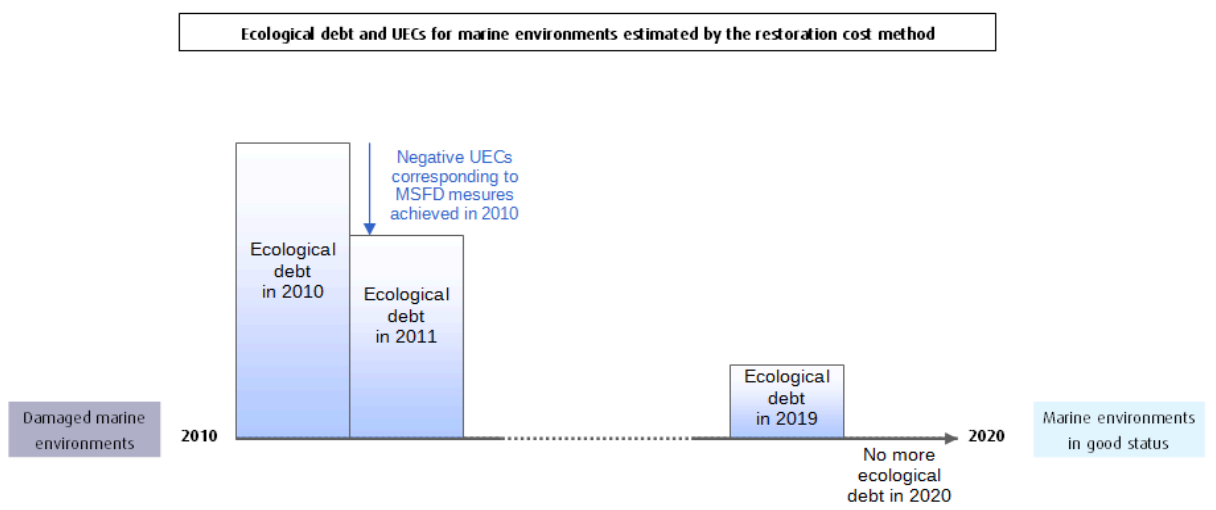
Inset: Marine environments, estimating UECs and the ecological debt via the MSFD?

As for the "continental aquatic environments" component, the evaluation of UECs for the "marine environments" component can be based on the existing legislation, via the Marine Strategy Framework Directive (MSFD). Adopted in 2008, this scheme requires European Union Member States to implement the measures required for the achievement of the "good ecological status"[63] of the marine environment by 2020 at the latest.

Operational implementation involves the definition of Marine environment action plans (Plans d'Action pour le Milieu Marin – PAMM), at the scale of the marine sub-regions (sous-régions marines – SRM) of metropolitan France: English Channel – North Sea, Celtic Seas, Gulf of Gascony and Western Mediterranean. Each PAMM starts with an initial evaluation of the status of the marine environment and ends with the implementation of a programme of measures. These programmes, specific to each SRM, must be adopted in 2015, for implementation from 2016.

The evaluation of ecological debt and of the UECs for marine environments could therefore follow similar reasoning to that for continental aquatic environments (summarised in the diagram).

In the framework of this evaluation, special attention must be paid to the measures, presented in the MSFD, which allow for the reduction of marine water contamination via basin areas. Some overlapping of costs is likely to exist between the WFD measures and the MSFD measures.



- The use of the restoration cost method for the "continental aquatic environments" component has shown that the estimates should be considered with caution. Indeed, a significant period of time had elapsed between the start of the audits (2004) for the WFD, the estimation of the measures to be implemented in order to achieve good status (2007) and the start of the performance of the first measurements (2010). During this time, it was possible for the deterioration of certain water bodies to continue and thus render the corresponding measures insufficient.
- On this same topic, it is important to specify that the effectiveness of the baseline scenario is of paramount importance in the estimation of UECs. Therefore, while the WFD measures adopted with a view to restoring the water to good status have been considered, in principle, to be totally effective, it will not be possible to observe their real final effects until after they have been carried out. The ex-post analysis of the impacts of the actions on the status of the environments will help to formulate opinions about the meaning and magnitude of the variation of the ecological debt and therefore to reassess the reliability of the ex-ante estimation of the costs.

[63] The definition of good ecological status is based on eight descriptors (e.g. micropollutants) and a list of pressures and impacts derived from the initial evaluation of the environments.

Main references

CGDD (2014) – *« Les coûts écologiques non payés relatifs aux émissions dans l'air »*

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Towards environmental accounting tools at the international level

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The UN and its international partners have recently revised the System of Environmental-Economic Accounting. In 2012, initial first volume – the SEEA-Central Framework (SEEA-CF) was adopted by the UN Statistical Commission (UN, European Commission, OECD, World Bank, IMF and circa thirty national statistical institutes) as an international statistical standard, on par (in principle) with the System of National Accounts. In 2013, the SEEA-CF was supplemented with a second volume entitled SEEA-Experimental Ecosystem Accounting. These publications are significant milestones in a process that began some time ago. Concurrently with the main stream, other initiatives targeted to climate change or ecosystems and biodiversity policies have produced accounts that have aroused a certain interest by policy makers.

The application of accounting to the environment or natural resources can be traced back to William Pitt, Vauban and the Physiocrats. Its modern history begins at the 1972 Stockholm Conference and the national experiments that followed in Norway, Canada, France, the Netherlands, Spain and the United States (on the initiative of the World Resource Institute in particular). International organisations started showing interest in this suject at a very early stage. The first initiatives came from the OECD Environment Directorate and the UN Economic Commission for Europe (UNECE), followed by the World Bank (WB) and the UN Statistics Division (UNSD). From this moment on, two different approaches emerged, from an initial interest in physical accounting, on the one hand (OECD and UNECE), to monetary accounts, on the other (WB and UNSD). Eurostat joins the process in the 1980s with the development and experimentation of environmental protection expenditure accounts[64] and multiple tests of physical accounts through national statistical institutes. The first key event in the history of economic environmental accounting is the Rio Conference of 1992 and the adoption of Agenda 21 which recognises the need for it. In the following year, the System of Environmental-Economic Accounting (SEEA 1993) is published by the UN.

The SEEA 1993, in contrast to the revised System of National Accounts (SNA) published in the same year, is an approach to accounting that is more theoretical and ideological than statistical. The physical-units accounts are limited to the analysis of input and output flows of an economic nature and exclude Nature itself. To a great extent, the monetary accounts conform to the prevailing school of thought of neoclassical economic theory, particularly with regard to the interpretation of national income as an indicator of economic welfare[65]. This interpretation, which can be traced back to one of the founders of national accounting – Simon Kuznets – considers that macro-economic aggregates (Product and Income) include negative components that must be subtracted in the same way as intermediate consumption is deducted during the calculation of value-added[66]. This may either concern "defensive expenditure" generated by economic growth (e.g. due to the cost of treating diseases caused by air or water pollution), or the cost of damage not accounted for in the SNA, be it damagecaused to others or borne. The evaluation of the cost of damage **caused** relates to the cost of the restoration or conservation of the natural environment; the evaluation of the damage **borne** is subject to the perceptions of agents – an important distinction that disappeared from later versions of the SEEA. In all of the cases mentioned, the damage is understood to correspond to losses of economic welfare. The ultimate aim is to calculate "green", net or adjusted gross domestic product.

[64] European System for the Collection of Economic Information on the Environment (SERIEE)
[65] It is important to make the distinction between welfare, in the sense of "economic welfare", and well-being, which is broader in scope.
[66] A very clear account of the controversy surrounding Income, in the context of national accounting in general and also of environmental accounting, is presented by André Vanoli in his article on "*National Accounting at the beginning of the 21st century: Wherefrom? Whereto?*", EURONA no. 1, Eurostat, 2014

The discussion of the depletion of natural resources has a broader dimension but is partly based on the same presuppositions. As natural assets market prices are purportedly difficult to observe, the standard model of neoclassical economic theory is recommended for their estimation (as occurs in the SNA). The value of the assets is then presumed to be equal to the discounted value of net future benefits, and assets depletion must be calculated as the difference between stock values at two dates. It is then possible to subtract the depletion of natural resources from GDP in the same way as for the consumption of fixed capital, and to calculate the "net" aggregates from their "gross" measurement.

At this stage, one may note that the "standard" measurement of assets and of their depletion and its aggregation with the traditional indicators of the SNA poses serious statistical problems. In particular, the price volatility of subsoil resources could lead to a final adjustment which magnitude and variability limits the practical interest of subtracting it from GDP or Income. Probably for this reason, chapter 20 of the 2008 SNA which proposes an alternative "capital services" approach and describes the calculation of subsoil assets depletion, refrains from attempting to record all of its implications. After explaining the principle of the calculation and explaining that depletion should be deducted from income, the SNA leaves the performance of the exercise to the SEEA…

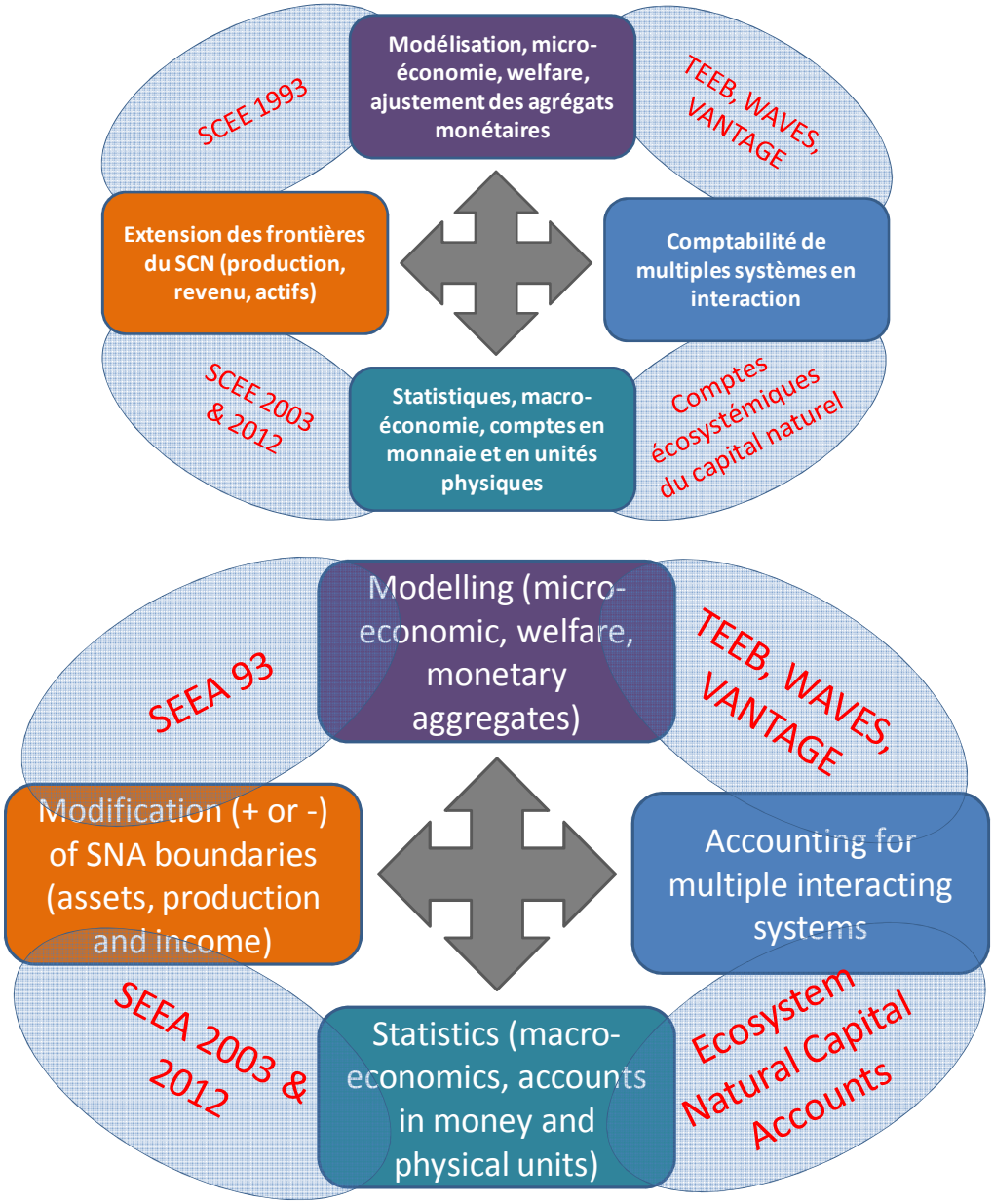
It should be noted at this stage that there is another way to measure the depletion of natural resources in monetary terms. It is known as the El Serafy method, after the economist who defined its formula and politicy purpose. This method is based on the measurement of assets physical depletion and allows for the estimation of the proportion of the income (referred to as the "user cost") that must be reinvested in other assets each year and therefore deducted from revenue when calculating available income, so that this flow of income is maintained in the future. This is a clear message for countries that depend on their natural resources and an exhortation to refrain from wasting income from subsoil resources. The World Bank published estimates of user costs in the 1990s. *De facto* and without any theoretical reference, the most responsible (or the richest) oil-producing countries reinvest a significant proportion of their revenue in financial or other assets. It is thus surprising and regrettable that the El Serafy method is no longer mentioned in the new SEEA 2012, which exclusively favours the neoclassical method of valuation by the discounted future benefits.

Problems of compatibility between the valuation systems used in national accounting and the neoclassical theory have been the subject of long-running controversies. Firstly, they relate to the difference between the transaction prices which can be observed by statistics and the prices of the theory of economic welfare, which relate to what the consumer is willing to pay – and generally include a surplus. If we are seeking to value in money non-economic values, and in the case when there are no similar products which market prices can be referred to by way of comparison, the methods relate directly or indirectly to the user's willingness to pay. Although it is justified in the case of cost-benefit studies as long as the stakeholders are properly represented, the measurement of willingness to pay is not consistent with the national account's price system. Furthermore, the subtraction/addition of new products from/to the balance of goods and services will inevitably have some impact on the prices and quantities exchanged. National accounts measure the flows that occurred during the accounting period. They primarily looks backwards to the past, that it is powerless to change. The balance of quantities and prices can only be changed in prospective modelling, as shown by the GREENSTAMP study (Brouwer et al. 1999), contracted by the European Commission.

The SEEA 1993 inspired several limited and unfruitful application attempts[67]. Very quickly, it became obvious that the deadlock needed to be broken, and on the initiative of Statistics Canada and Eurostat, a UN working party was established in London in 1994, at the invitation of the UK Office for National Statistics. This "city group" had (and still has) the task of discussing environmental accounting issues and monitoring the progress of accounts implementation. In 1998, the meeting of the London Group, held in Fontevraud, France, having taken note of the developments in progress – especially in Europe – made the decision to revise the SEEA 1993. This decision was confirmed at the Canberra meeting, held in the following year. It should be noted that this meeting saw a confrontation between supporters of a "monetary" approach and those wishing to attach more importance to physical accounting.

[67] The case of Mexico, where environmental accounting had been implemented in the context of the first SEEA, can be seen as an exception. The INEGI (Mexican national institute of statistics and geography) continues to publish its key aggregate – "net green GDP" – which equates to GDP adjusted for the costs of remediation or restoration of the depletion and deterioration of natural resources and the environment.

Figure 1: Main tensions in the development of environmental accounting



The resulting SEEA 2003 benefited from important contributions by Eurostat, the OECD and national statistical institutes – particularly those of Canada and the Netherlands. However, its theoretical framework and its aim are less clear than those of the SEEA 1993. The SEEA 2003 is, to a large extent, a coherent presentation of the progress in accounting based on the best national experiments. By providing examples, it seeks to support the growing number of tests within countries, generally on the initiative of the statistical institutes. The SEEA 2003 aknowledges its status as a satellite account of the SNA. The general presentation of environmental economic accounting in the introduction to the report was written at the last minute and is not absolutely essential to the understanding of the following chapters. Although modest in size, one innovation of the SEEA 2003 is worthy of mention: the presentation of land and ecosystem accounts as they emerge in pilot projects by the French Institute for the Environment Ifen), the German Federal Statistics Office and the UK Ministry of the Environment, projects initiated by the UN ECE and continued with Eurostat's support.

2008 sees the creation of the United Nations Committee of Experts on Environmental-Economic Accounting (UNCEEA) which first initiative is to propose a new revision of the SEEA that would split it into two, with a first volume covering the accounts for which there is sufficient experience and a consensus is possible, and a second dedicated to the other accounts at a less advanced, experimental stage. The first volume is intended to be an international statistical standard on par with the SNA, with a view to sending a strong message to governments and to supporting statistical institutes that wish to embark on this process. The second volume was initially intended to be a "catch-all" document combining subjects such as accounting for environmental taxes and subsidies that are difficult to classify, in addition to diverse and varied unsolved issues and to ecosystem accounting. The situation changed quickly due to the growing political interest in ecosystems provoked by the 2005 Millennium Ecosystem Assessment and the TEEB reports produced in 2009 and 2010 following a request from the G8 in Potsdam that was prompted by the German government and the European Commission. Within the community of environmental accountants, the fact that the European Environment Agency joined the London Group and then the UNCEEA alongside Eurostat was also a contributory factor, thanks to its incessant demands to place ecosystem accounts on the agenda[68]. The SEEA 2012 thus consists of two volumes, the first entitled "central framework" (SEEA-CF) and adopted by the Statistical Commission as an international statistical standard, on par (in principle) with the System of National Accounts (SNA), and the second volume entitled SEEA-experimental ecosystem accounting (SEEA-EEA).

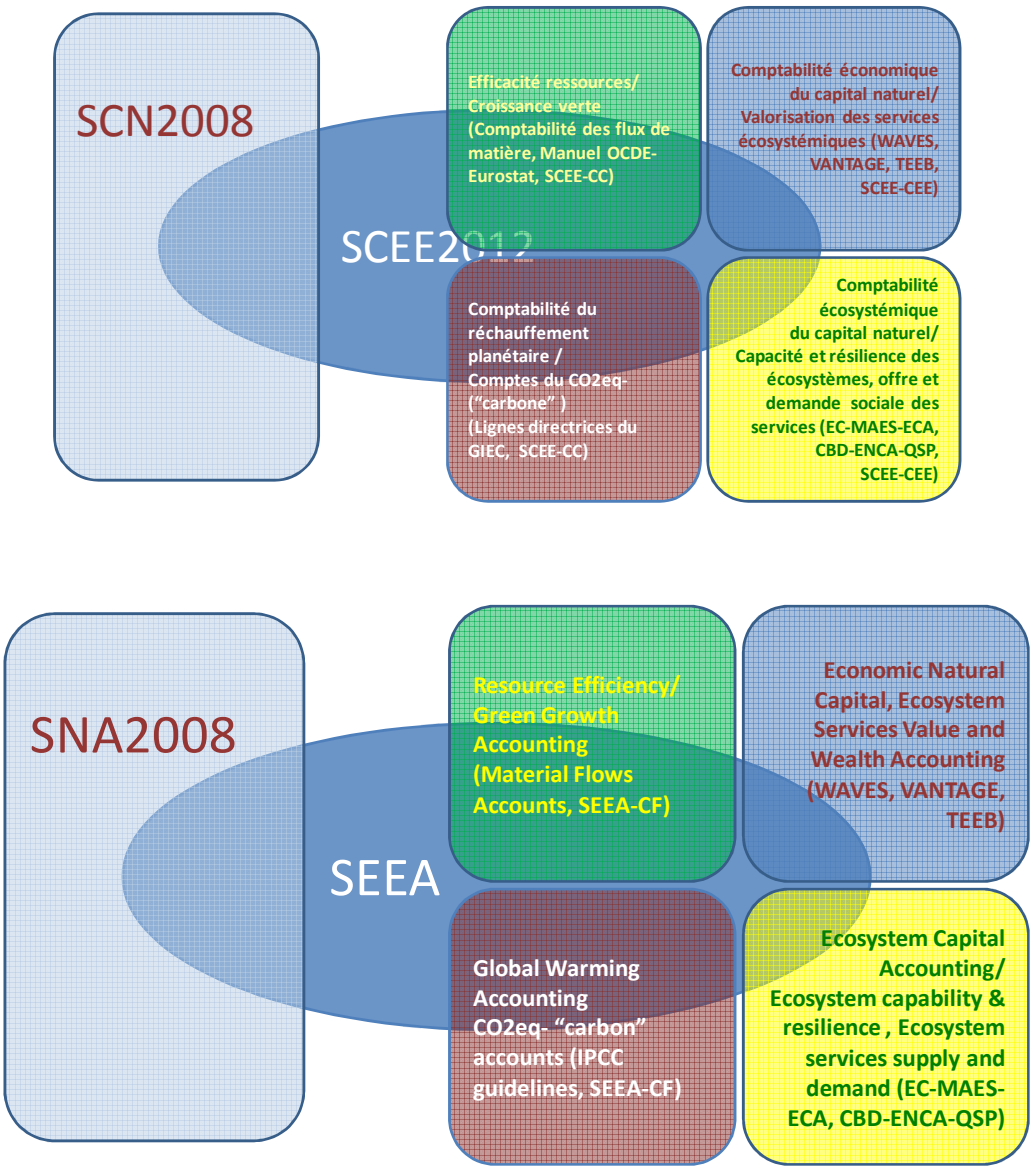
The status of ecosystem accounts is currently experimental. As the SEEA-EEA is, in its own terms, a *conceptual* framework, practical guidelines are required to supplement it for experimentations to take place. The World Bank produces such guides for its pilot studies in the framework of WAVES and the UNEP[69] in the context of the green economy programme. The Secretariat of the Convention on Biological Diversity (CBD) has published an application manual for the SEEA-EEA with a view to helping member countries meet the second target of the strategy adopted at Aichi Nagoya in 2010. This target stipulates that biodiversity values must be incorporated into decision-making processes and the national accounting system by 2020. The CBD manual was launched at the Conference of the Parties to the CBD held in South Korea in October 2014. Entitled "Ecosystem natural capital accounts: a quick-start package". The manual prioritises physical-units accounts and proposes a composite measurement of the degradation or improvement of ecosystem state. The principle of the measurement unit used has points in common with CO_2-eq which quantifies the contribution to climate change. Like CO_2-eq, which can be used to calculate "carbon" credits and debits, the composite measurement of the sustainable capacity of ecosystems can be used to compile an ecological balance-sheet (Weber, 2014).

Not all developments in economic environmental accounting have taken place solely within the framework of the SEEA, although they have been extensively assimilated into the latter, which constitutes a common reference document and a link to the SNA.

[68] An important milestone is the EEA's publication of the "Land Cover Accounts for Europe 1990-2000; Towards Ecosystem Accounting" report in 2006 and the holding of an international seminar in Copenhagen at which the broad outlines of an ecosystem accounting system were discussed.

[69] For example the UNEP published the “Guidance Manual on Valuation and Accounting of Ecosystem Services for Small Island Developing States” in January 2015, in the framework of VANTAGE (Valuation and Accounting of Natural Capital for Green Economy).

Figure 2: SNA, SEEA and the main environmental accounting frameworks



Several important initiatives need to be mentioned.

The World Bank, after publishing valuations of the depletion of non-renewable resources according to the El Serafy method, decided to develop and publish a "genuine" (or "adjusted net" savings) measurement. Genuine savings are obtained by deducting from the SNA savings the depletion of natural resources and the cost of environmental damage and by adding the total amount of education expenditure[70]. In this line of thinking, the WB published an estimate of the "The Changing Wealth of Nations" in 1995, 2000 and 2005. The report and the data per country on "total" wealth and "genuine" savings, in addition to indicators of income from non-renewable resources can be consulted on http://data.worldbank.org/data-catalog/wealth-of-nations. In 2010,

[70] An in-depth critical analysis of the creation of the "genuine savings" aggregate is presented in the Stiglitz/Sen/Fitoussi report of 2009. A different adjustment of the national accounting savings, but with a similar significance regarding the consideration of natural resources, could be calculated by deducting the "unpaid costs" as recommended by Vanoli (Vanoli, 2014). The SEEA-CF makes no mention of "genuine savings", while the SEEA-EEA mentions it once.

the WB launched the WAVES (Wealth Assessment and Valuation of Ecosystem Services) programme – a partnership intended to promote experiments on calculating the monetary value of ecosystem services.

From the start, the OECD has been attentive to environmental accounting and has taken initiatives to encourage its development, particularly in the framework of its Working Group on the State of the Environment. At the G8 Evian Summit in June 2003, a "G8 action plan on science and technology for sustainable development" was adopted on Japan's initiative in order to improve the understanding of material and resource flows and continue the work on resource productivity indices, particularly at the OECD. A general accounting framework for material flows was then jointly developed by the OECD and Eurostat according to the general principles of the SEEA 2003. It covers the balances of specific products and economy-wide material flow accounts, used in the framework of Green Growth strategies (OECD), Resource Efficiency[71] (European Union) and also within the UNEP Green Economy programme.

It is important to note the important role played by Eurostat in all of the processes, from the creation of the London Group to the second revision of the SEEA. Substantively, in addition to the material flow accounts mentioned previously, Eurostat has supported the production of national accounting matrices that combine environmental accounts according to the NAMEA[72] model designed by Netherlands Central Statistical Office. Particular efforts have been made to convert the IPCC reports presented in the form of sectors defined according to technical criteria into tables using the nomenclature of economic industries of national accounting. This modification is essential for the economic analysis of the origin of greenhouse gases. The accounting system for environmental protection expenditure has also been generalised by Eurostat and adopted in the SEEA. This role of Eurostat has been confirmed by EU regulations no. 691/2011 and 534/2014 relating to European economic environmental accounts, which provides a legal basis for their progressive implementation. It should be noted that in a task-sharing arrangement, Eurostat is responsible for accounts that relate to the SEEA-CF whereas the European Environment Agency and the European Commission's Joint Research Centre are responsible for ecosystem capital accounts (sometimes referred to in the European context as "natural capital accounts", which is incorrect as they do not cover subsoil resources) and ecosystem services.

Outside the statistical community, several environment and natural resource accounting programmes have made a certain impact.

The main one is greenhouse gas (and now carbon sequestration) accounting, implemented by the IPCC and the World Meteorological Organisation with major contribution from the scientific community in support of the UN Framework Convention on Climate Change. This accounting system has allowed for the immediate implementation of the Kyoto Protocol mechanisms. Efficiency has overridden conceptual refinement, which has allowed this type of accounting to play its role. The IPCC's accounting system has been implemented in stages. Starting from a sector approach, it is developing into a spatial approach that has points in common with ecosystem accounting. This convergence should increase with the implementation of "carbon" flow accounts incorporated into international trade and a clearer view of demand effects.

Other initiatives are making a significant contribution to the development of environmental accounting. They do not always directly relate to the SEEA, but they make a decisive contribution through the powerful messages they convey and the knowledge and data they help to accumulate. They include physical-units and monetary value accounting.

In physical units, the available accounts are established at the global level. The first to be noted are Ecological Footprint Accounts (Ecological Footprint Network, EFN). EF's popularity with governments and companies (despite the debatable formula used to calculate footprint) calls into question the very technicist nature of the SEEA.

Another indicator (with the corresponding accounts and databases) is the Water Footprint (University of Twente) compiled for the entire planet. This uses a different approach to the traditional accounts as it measures appropriation of water rather than consumption. The difference concerns water that has been modified without being extracted, particularly by in situ uses. However, the database follows the general hydrological concepts and constitutes an interesting resource. Other appropriation "accounts" focus on biomass: Human Appropriation of Net Primary Productivity (HANPP). Finally, an important inventory should also be mentioned which, when updated, will constitute a global account of ecosystem services: the Millennium Ecosystem Assessment (MA 2005).

Outside the SEEA scope, monetary accounts of cost-benefit analysis type are generally compiled at the local or regional level,. One exception can be noted with regard to the evaluation of "total" or "inclusive" wealth, but this is more of a modelling rather than an accounting exercise. In addition to WAVES, which specifically relates

[71] "A resource-efficient Europe – Flagship initiative of the Europe 2020 strategy" http://ec.europa.eu/resource-efficient-europe/index_en.htm

[72] NAMEA: National Accounting Matrices with Environmental Accounts

to the SEEA framework, the programmes that prioritise the monetary valuation of ecosystem services are either academic research projects or United Nations Environment Programme driven programmes, such as TEEB (The Economics of Ecosystems and Biodiversity[73]), VANTAGE (Valuation & Accounting of Natural Capital for Green Economy) or ProEcoServ (with the involvement of the Global Environment Facility).

As we reach the end of this chapter, one has to acknowledge the abundance of work that has been carried out but also the lack of a clear response to the nagging question of – to paraphrase Norgaard – the "tyranny of GDP". The primary cause of this situation is certainly confusion due to the inappropriate management of prolifering approaches. The blame for this can be attributed for part onto the theoretical vagueness of the SEEA. A second source of confusion concerns the actual aims of environmental accounting. During the period in which the production of an SNA satellite account was the paradigm, the situation was quite clear and facilitated the progress made by Eurostat and the OECD. There was a champion (the government), a method (the extension of national accounting) and aggregates: national expenditure on the one hand and resource use efficiency on the other. Not all of the successive developments have produced the expected results because in many cases, the technical improvements have obscured the purpose of the endeavour. This is reflected in the expression "central framework", attributed to the SEEA first volume, to which we are unable to attach a "central" message. Consequently, it is not surprising that the question of communication repeatedly comes back into the debate as an explanation for the difficulty in “selling” the accounts to decision-makers. Things began to change with the initiative to implement "carbon" accounting with a clear aim. An essential addition to the current "carbon" accounting system is ecosystem accounting. The SEEA's recognition of the importance of such an account and, even more so, the publication of an operational manual by the Secretariat of the CBD, allow to foresee the formation of a coherent system of accounts supplementing the SNA. It remains to be seen whether the ambiguities that threaten to compromise the process can be clarified. In particular, it is important to identify champions for the various accounts, those who will support the project forward and state which aggregated accounting indicators they require. In general, the SEEA-central framework, being an SNA satellite account, is championed by national statistical institutes which are the usual producers of national accounts. The UN Statistical Commission has consequently asked the Statistical Division to define an implementation programme for the SEEA-CF under the aegis of the UNCEEA. In the field of climate change, the accounting system established by the IPCC (with the backing of the WMO and the scientific community) is an example of pragmatism and efficiency. Its linkage to national accounts nomenclatures via the SEEA provides a tool that can be directly used by macroeconomic policies.

The same should apply to ecosystem accounting for which a wide range of experimental programmes have started to be established with the increasing involvement of the UNEP and the CBD, their national constituents (ministries and agencies in charge of the environment and natural resources) and the scientific community. It is essential for the UNEP to assume its role of champion so that when the time comes, at the end of the experimentation period started in 2014, a SEEA-EEA revision can allow for the implementation of the tools required for integrating ecosystem and biodiversity dimensions to sustainable development and climate change decision-making processes.

This is a major challenge that must be placed in the context of the data revolution. "A World That Counts"[74] – the report prepared at the UN Secretary-General's request by the independent group of experts on the "data revolution for sustainable development" – depicts the broad picture of possible and essential developments required for the implementation of indicators needed for monitoring sustainable development targets. This concerns all fields of statistics, from official socio-economic statistics to the new fields opened up by in situ and remote-sensing monitoring of nature, and data management systems. Physical-units ecosystem accounting is particularly likely to benefit from these developments. They will allow it to make the necessary leap forward and soon be able to provide tools for the measurement of the degradation (or improvement) of ecosystem capital and the production of ecological balance-sheets, which will offset the commonly used decision-making tools: economic national accounting and economic calculation.

[73] TEEB goes far beyond accounting issues and a series of reports addressing different stakeholders broadly and very comprehensively covers ecosystem valuation issues. They also present physical-units accounts.
[74] http://www.undatarevolution.org/report/

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Indicators of biomass use: the HANPP family

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Humans appropriate a significant proportion of the biomass produced each year by ecosystems – 40% for Western Europeans – with a global average of approximately 25%. This appropriation takes place in three ways: the harvesting of biomass – some of which is directly consumed, non-used extraction, and the loss of productivity resulting from the human transformation of habitats.

This appropriated biomass is a quantitative evaluation of the human pressures exerted on biodiversity, because it measures the quantity of resources no longer available to biodiversity.

Biomass, or the mass of living organisms, is dependent on the availability of the physico-chemical resources on which they depend (water, CO_2 and mineral elements). This biomass determines the status and structure of biodiversity, the abundance of living organisms – in number of individuals or in biomass, biological diversity (genetic, specific and functional) at the different levels of the food or trophic chain, plants, herbivores, carnivores, etc. This availability of resources can be qualified by the net primary production of ecosystems: NPP[75], or Net Primary Production.

Consequently, the human appropriation of a proportion of this NPP must have impacts on biodiversity. Its quantification is an integrative measurement of the human pressures exerted on this natural heritage[76]. It must allow for the anticipation and prediction of its status and the quantity of biodiversity that can be maintained.

We shall examine how the human appropriation of biomass is described, followed by the consequences that can be drawn from it for the dynamics of biodiversity, which depends on the relationship between biological diversity and biomass. We shall conclude with the opportunities to analyse public policies offered by this approach with a view to capping human impacts, as they threaten our natural heritage, biodiversity.

The analysis of NPP flows involves variables whose names vary in the literature. In this article, we shall use the terminology of Krausmann et al. (2008, 2013). Certain flows can be calculated directly, while others are estimated. For the sake of clarity, we shall identify the elementary flows and then their aggregations.

1. Four biomass flows

Four annual biomass flows can be identified, three of which are appropriated by humans.

NPPue

NPPue (or 'used extraction') represents what is extracted and used by humans, directly or by processing. Four types of use can be identified:

- direct, or plant-based food;
- indirect food via animals;
- biofuels;
- materials, for housing (timber, etc.), clothing (cotton, wool, etc.), tools, colourants, medication, paper, etc.

NPPue amounts to just over 10% of the NPPpot – or potential total annual production of ecosystems – throughout the world, and 25% in Western Europe. Food for animals – in the form of pastures but also a proportion of crops – accounts for the majority of this flow, around 60%. Plant-based human food amounts to approximately 15 to 20%, i.e. less than 5% of the total NPP at the global level. Losses during processing, between harvesting and consumption, generally account for a large proportion of NPPue (Figure 1).

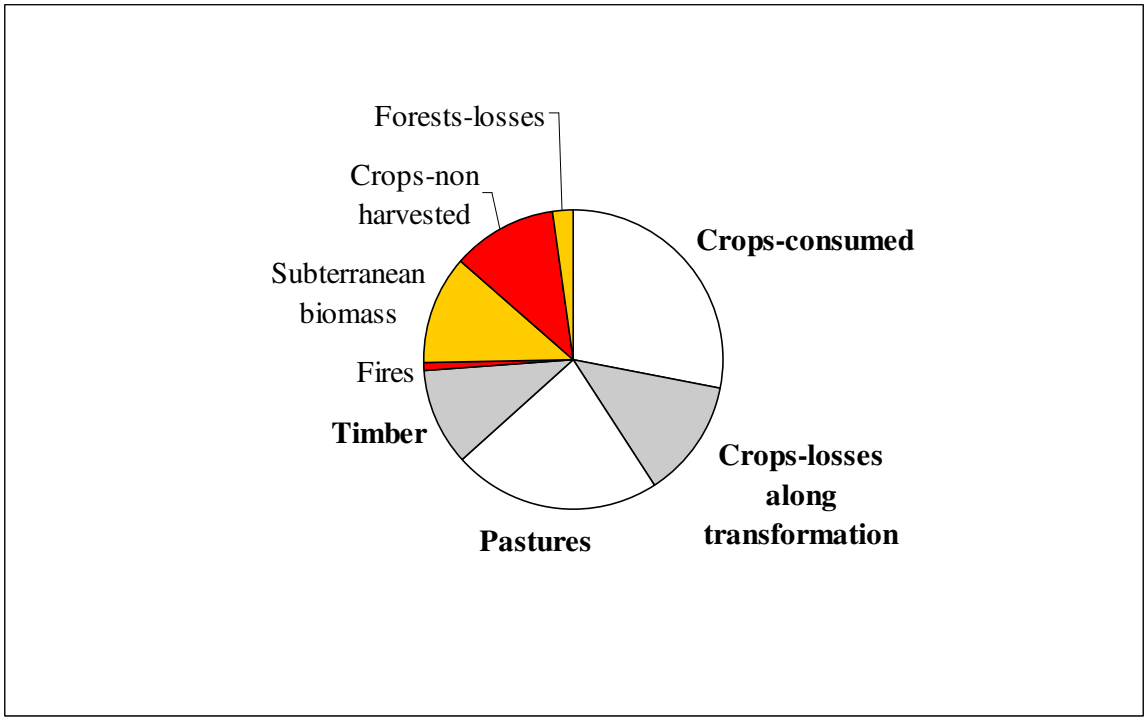
[75] However, for the same availability of physico-chemical resources, the NPP has increased through the ages. Over millions of years, evolution has led to the increasingly efficient conversion of physico-chemical resources into organic matter while accelerating the speed at which they are recycled.

[76] This is sometimes referred to as "natural capital" in economics, but the notion of capital does not allow for the consideration of all of the socio-economic and anthropological dimensions of biodiversity.

NPPnue

NPPnue (or 'non-used extraction') is the primary production extracted by humans, but which is not harvested and, *a fortiori*, not used. This flow consists of non-harvested crop residues, losses due to fires of anthropic origin or of wood during forestry operations. NPPnue amounts to around 5% of NPPpot, and nearly 10% in Western Europe. NPPnue is significantly lower than NPPue (Figure 1).

Figure 1: The different components of NPPue (white/grey, in bold) and NPPnue (orange/red): global averages, as % of NPPue+NPPnue.



Source: From Krausmann et al. 2008).

NPPluc

NPPluc (or 'land-use change') quantifies the losses or gains due to the human conversion of habitats. It is the difference between NPPpot (NPP in the absence of humans, see below) and the three other elementary flows, NPPue, NPPnue (above) and NPPt (below, corresponding to what is available for biodiversity).

NPPluc encompasses the deterioration of habitats (soil salinisation, etc.) and the decreases in productivity associated with reduced productivity of artificial vegetation, compared to natural vegetation. Indeed, even the most productive forms of agriculture do not match the productivity of 'natural' ecosystems (i.e. those that have not been subject to a recent direct human intervention, sowing, inputs and/or farming).

NPPluc has a negative value when the human conversion of habitats leads to an increase in NPPpot. This applies to irrigation in arid regions (Nile and Indus valleys, Häberl et al. 2007), and, to a lesser extent, to different development activities in Northern Europe (polderisation, liming, etc.).

Overall, NPPluc amounts to approximately 10% of NPPpot. NPPluc varies according to the ecosystems and amounts to approximately 1/3 in crops (Figure 2).

NPPt

NPPt is the annual primary production not appropriated by humans, and which remains available to biodiversity (see part II). At the global level, it amounts to approximately 30 to 35 Gt of C per year, and varies according to the regions (see Figure 6).

NPPpot, the sum of the preceding flows

NPPpot (or 'potential') – the sum of the four preceding flows – represents the net primary production (after

respiration) of ecosystems that have not been converted by humans. Usually, this potential value – a baseline value – is not directly measurable. It is required to estimate NPPluc (above).

NPPpot is estimated using dynamic global vegetation models, especially the LPJ 'Lund-Potsdam-Jena' model (in Haberl et al. 2007). NPPpot amounts to an approximate total of 50 GT of Carbon[77] per year, in dry weight, with several variations depending on the methods and models used (Smil, 2013, Kastner et al. 2014).

HANPP – the sum of the flows appropriated by humans

HANPP, or Human Appropriation of NPP, is the total NPP appropriated by humans; it is the sum of NPPue, NPPnue and NPPluc. Corresponding to approximately 25% of NPPpot in absolute terms, it amounts to approximately 15 to 20 GT C/year; this quantity is comparable to GHG emissions. 53% of the global HANPP is extracted (NPPue+NPPnue), a large proportion of which is not consumed, and 47% is co-opted (NPPluc, Haberl et al. 2007).

2. Relationships between the human appropriation of biomass and biodiversity

The relationship between the human appropriation of biomass and biodiversity can be envisaged in two ways – according to the existing biodiversity or the endangered biodiversity. These relationships depend on NPPt and HANPP.

Existing biodiversity

The biomass produced by vegetation, available, is a key determining factor in the biomass of other organisms throughout trophic chains. The amount of biomass determines the number of individuals per taxon or per functional group, throughout the entire trophic chain, genetic and species diversity (see Robertson, 1960 and Hubell, 2001, respectively) – two major components of biological diversity; henceforth, the functioning of ecosystems, the status of ecosystem services (Millennium Ecosystem Assessment, 2005). Genetic and species diversity determine both the potential for the renewal of biodiversity and for future human consumption.

Consequently, the status of biodiversity, as a result of the state of these major properties, depends on NPPt.

A correlation can indeed be observed between NPPt, animal biomass and the number of individuals, for different groups, at different spatial levels, from the global to the national level. Energy is sometimes used as an alternative to the biomass produced annually (Wright, 1990). The available biomass must be correlated to other properties of biological communities – in particular the length of the trophic chain – as observed for birds in the Ile de France region (Pellissier et al. manuscript). It remains to be seen whether these relationships can be generalised, by examining the role of other variation factors.

These other factors are numerous (and see below): seasonality, the disturbance regime, the diversity of resources and ecological interactions, predation mechanisms and resistance strategies, human-caused and natural toxicity (from pesticides to secondary compounds of plants). The latitudinal variations observed in biomass throughout trophic chains are successfully explained by formalising the influence of these different factors (Harfoot et al. 2014). The impact of these different factors on biological diversity has often not yet been taken into consideration.

The status of biodiversity should also depend on in situ biomass, which is the accumulation, year after year, of what remains on an annual basis, or NPPt. This accumulated biomass offers habitats and resources for living organisms, although its availability may be quite limited, as is the case for lignin from trees. This plant biomass stored in ecosystems amounts to between 15 and 20 years of annual production – i.e. 500 to 800 GT of carbon – with some estimation uncertainty (Smil, 2013). Prior to the human population explosion, this biomass may have amounted to around 1,000 GT, with approximately 20% of variation during glaciations. The current reduction resulting from the extension of human activities may amount to approximately 40%, with 20% occurring by the end of the 18th century and an additional 20% being removed over the course of the last two centuries (Smil, 2013). This reduction should also have an impact on biodiversity, a relationship yet to be examined.

Endangered biological diversity – the delayed effects of the extinction debt

NPPt should have a more complex relationship with species diversity, which was verified in Austria (Haberl et al. 2005), than with biomass. All else remaining equal, a reduction in the available resources should lead to a decrease in genetic and species diversities. However, local extinctions of genes and species, which are symptomatic of this reduction, are not immediate, as declining populations survive for a certain number of

[77] Different units may be used: biomass, dry weight and carbon. Dry weight shall be the unit used, unless otherwise specified.

generations. Extinction debt is representative of this phenomenon. It is the proportion of species that should become extinct because their resources and habitats have disappeared, but which have not yet become locally extinct.

This debt is observed Europe-wide. The percentage of endangered species in seven groups (vascular plants, bryophyta, grasshoppers, dragonflies, fish, reptiles and mammals), is more correlated to human pressures – land use – in 1950, or indeed in 1900 for vascular plants and bryophyta, than in 2000 (Dullinger et al. 2013). The differences among groups may be explained by species generation times and their dormancy capabilities, e.g. plant seed banks in the soil, which buffer short-term environmental variations. From this we can infer that a large part of the impacts of the doubling of HANPP in Asia during the 20th century (Krausmann et al. 2013), on biodiversity and ecosystem functionalities, have not yet been felt. Other indicators confirm the environmental constraints[78] imposed on this continent, including the 'aquifer stress indicator' (Gleeson et al. 2012).

The European comparison by Dullinger et al. (2013) shows that animals, in terms of endangered species, are more sensitive to other human pressures – human population density and GDP – than land use. This difference may be explained by additional removals of animals, e.g. due to hunting (in addition to ecotoxicity, see below), which also leads to additional reductions of biomass in the higher trophic levels. Indeed, while vegetation has diminished by approximately 40%, the reduction of animal biomass – or zoomass – could be higher, up to 50% during the course of the 20th century for wild mammals (Smil, 2013). These collateral effects could explain lower trophic chains, with the loss of the higher trophic levels to the benefit of the lower trophic levels.

Conversely, organisms that are reliant on the residues, conversion losses and waste products relating to human consumption could benefit from an increase in human consumption. This concerns detritivores – organisms that feed on organic debris, mainly bacteria, fungi and invertebrates. The composition of micro-organism communities could also change, in favour of micro-organisms that benefit from these flows.

Collateral impacts of biomass appropriation modes

Biological groups are exposed to different collateral effects of any appropriation of biomass, such as ecotoxicity and the fragmentation of habitats, etc. Some of these effects reduce NPPpot and its transfer throughout the food chain. This includes ecotoxicity, which is associated with pesticides and a variety of other pollutants, whose effects could be significant (e.g. Hallmann et al. 2014).

Other collateral effects include changes in environmental conditions, which require the adaptation of living organisms. Changes include the homogenisation and fragmentation of habitats, local and global climate changes and biological invasions. Some of these changes may have a positive impact on biomass, e.g. by increasing the temperature in cold regions. Irrespective of their effects on biomass, these changes should, in the short term, have a negative impact on biological diversity, all the more so because they occur quickly, leaving insufficient adaptation time. Indeed, the speed of the selection process leads to significant changes. Certain alleles (species) multiply, to the detriment of the many other alleles (species) that are eliminated, leading to a net loss of diversity. This loss is gradually offset by immigration, mutation and speciation when the selection pressure decreases or when the populations and communities have adapted to the new environment. It is indeed observed that species endangered by climate change are more numerous than those that benefit from it. Consequently, the relationship between HANPP and the existing, endangered biological diversity, should also depend on the type and magnitude of the recent environmental changes.

Tipping points? Possibility of a threshold value for HANPP and NPPt

There could be threshold values for HANPP and NPPt above or below which there could be a significant decrease in biological diversity, and a substantial deterioration in the functionalities of ecosystems. An accelerated deterioration of bird communities is indeed observed in neotropical agricultural landscapes with less than one-third of their surface area covered by forests (Banks-Leite et al. 2014). It should be noted that the extinction debt makes the identification of this threshold value all the most difficult.

These threshold values also depend on the speed of the global changes, because the adaptation required increases with the speed of change in the environment of living organisms, which itself depends on the existing biodiversity (Richardon, 1960 and Norberg et al. 2001), and therefore on NPPt and HANPP. The research on such threshold values contributes to the framework on the planetary limits of human activities. Two variables have been proposed to determine biodiversity thresholds: phylogenetic diversity and ecosystem integrity (Mace et al. 2014); how they relate to HANPP and NPPt may need to be clarified.

[78] These are constraints imposed on the environment rather than requirements of public environmental conservation policies.

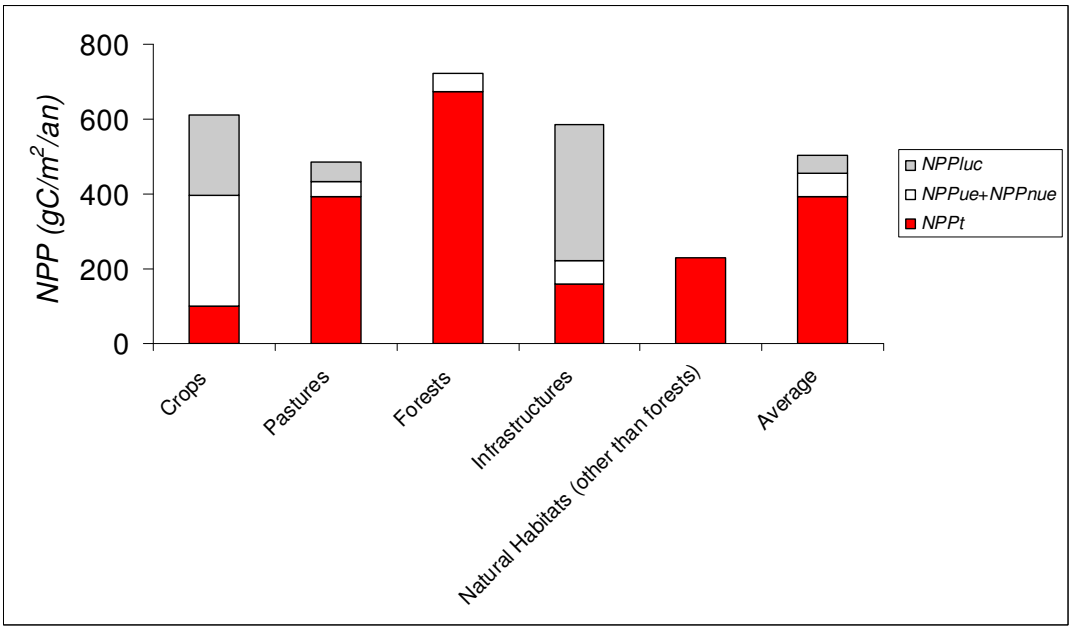
3. Variations in the human appropriation of biomass

The human appropriation of biomass varies significantly according to the types of ecosystem and their protection status.

Variations in HANPP according to land use

Crops, forestry – especially towns and cities (but also dwellings and roads, etc.) – have been deployed in the most productive ecosystems, in terms of NPPpot (Figure 2). In relation, human infrastructures –towns and cities (but also dwellings and roads, etc.) were more likely to develop in the most productive agricultural regions, due to the difficulties to transport large quantities of biomass over long distances before the industrial revolution, As such, towns and cities depended on the agricultural production of their surrounding region or "hinterland". This specificity justifies the pertinence of ecological compensation for urbanised agricultural land, particularly on the outskirts of towns and cities, as they are often highly productive.

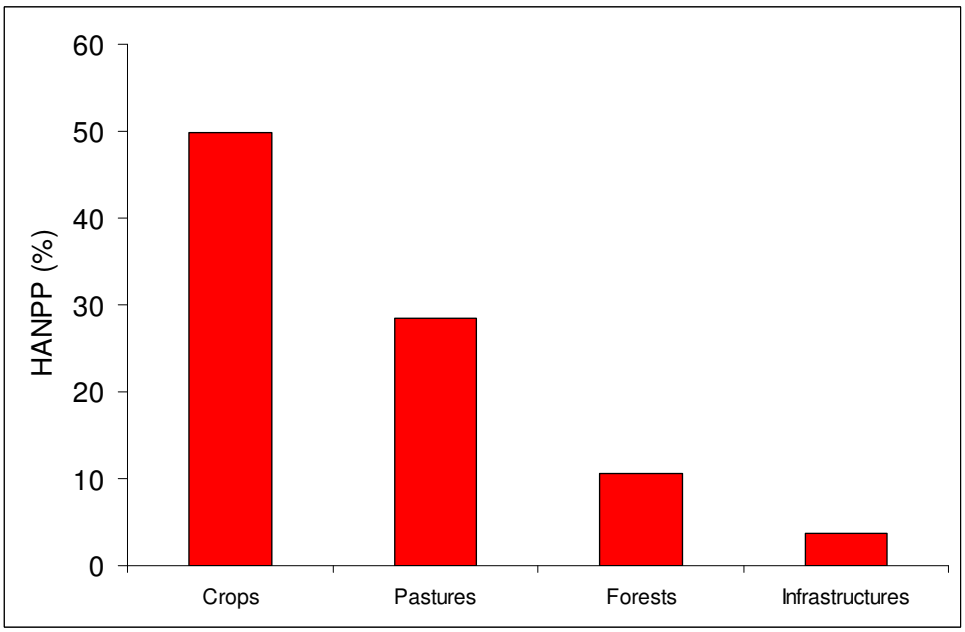
Figure 2: Average values of the four biomass flows: NPPt, NPPue+NPPnue and NPPluc, the sum of which is NPPpot, according to the type of land use



Source: Global averages, from Haberl et al. 2007.

Human appropriation has significantly modified the hierarchy of the most favourable ecosystems for biodiversity. It currently depends on the value of NPPt (see part II), whereas this hierarchy was determined by NPPpot values prior to the arrival of humans (as NPPt was equal to NPPpot, with HANPP being nil). Figure 2 thus shows that ecosystems now occupied by 'crops' and (human) 'infrastructures' were formerly the most favourable to biomass production and therefore to the maintenance of biodiversity. They currently have the lowest NPPt values – twice below the average – and four times below the average for grasslands (Figure 2). From this, it can be inferred that in urban or agricultural landscapes, a small proportion of forests and meadows have a major quantitative impact on biodiversity. According to the values shown in figure 2, if 1/7 of the surface of an agricultural landscape is covered by forests, it doubles the available resources for biodiversity and NPPt at the level of the landscape.

Figure 3: Contribution of different types of land use to HANPP



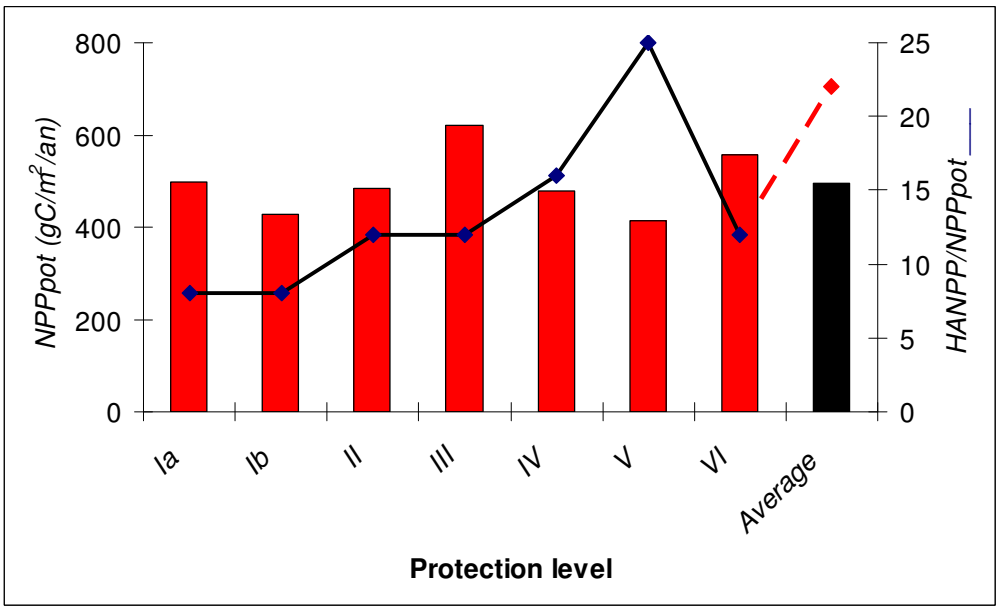
Source: according to Haberl et al. 2007).

As a result of the greater productivity of the ecosystems they occupy, crops, which only take up 10% of the surface area of land mass, account for nearly half of HANPP (Figure 3). Globally, agriculture represents over ¾ of HANPP. HANPP associated to livestock rearing, including animal feed in cultures and prairies, accounts for half of this agricultural HANPP (Foley et al. 2011). Human infrastructures (corresponding to habitat, transport and industry) account for a small proportion of HANPP.

Variations in HANPP due to protected areas

The productivity of protected areas ('parks') corresponds to the average value (Figure 4).

Figure 4. Global NPPpot (bars) and HANPP (%, dots), according to the level of protection of parks

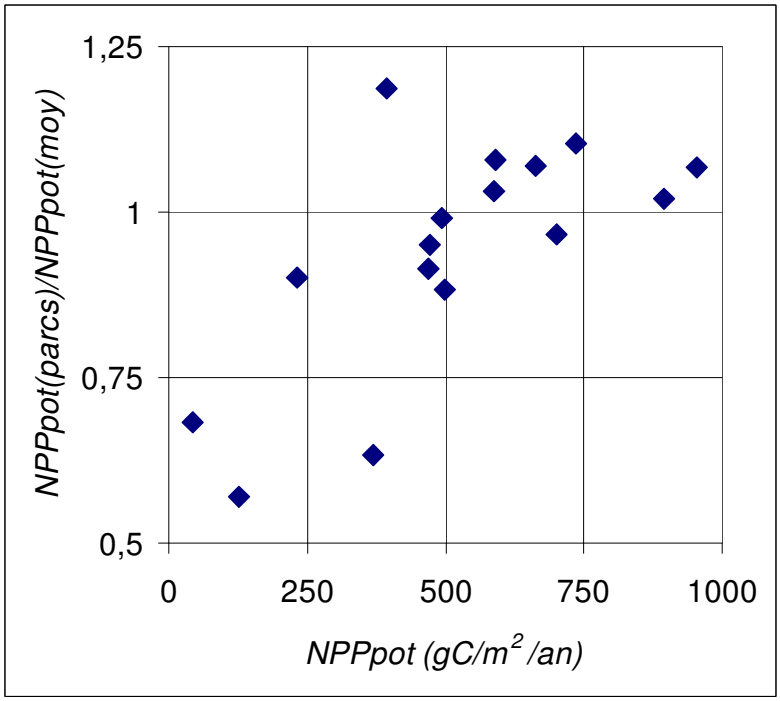


(IUCN typology: the highest corresponds to lower protection, regional nature parks (PNR) correspond to level 5); 'average': average value of land mass, including unprotected areas.
Source: according to O'Neill and Abson (2009)

Protected areas are representative of average productivity, except in certain countries, especially the USA,

where they are situated within less productive ecosystems (O'Neill and Abson, 2009). NPPpot does not vary according to the level of protection of areas. On the other hand, the HANPP/NPPpot ratio (% HANPP in figure 4) increases with the level of protection (Figure 4). In parks with level 5 protection, this proportion is even higher than the global average, prompting the question of the ecological significance of protection in these areas. Such a situation may correspond to areas with a very large and long-established human presence, suggesting that the cultural value of biodiversity is not associated with a large biomass in these areas.

Figure 5: NPPpot: average, relative value in parks, according to the 16 major biomes (deserts, steppes and grassland, forests, cold temperate and tropical)



Source: (O'Neill and Abson, 2009)

At the global level, differences in average productivity among biomes are magnified in protected areas the. Protected areas are the least productive in the poorest biomes and vice versa (Figure 5). This differentiation could correspond to a quest for originality in protected areas

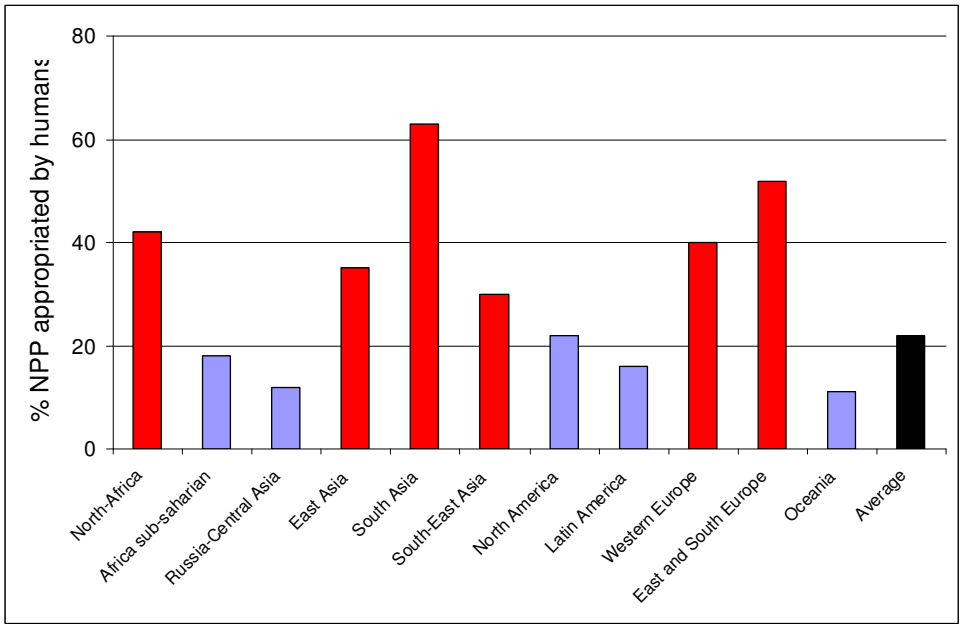
4. Biomass flows and public policies

In order to maintain and improve the status of biological diversity and ecosystem services, it seems important to control and indeed reduce HANPP, or its three integrated flows – NPPue, NPPnue, and NPPluc – while avoiding the collateral effects (see III.3). The analysis of production and consumption modes must help to determine the pertinence and effectiveness of any public policy seeking to control these flows.

Production modes

There are major regional disparities in the HANPP/NPPpot ratio (Figure 6), very high in Asia, and in Europe to a lesser extent. The ratio in America is well below that of the other continents. As a result, the key issues for the management of HANPP vary according to the continents. These differences among continents may explain the inter-regional dynamics of land grabbing, for example in Africa, initiated from Asia.

Figure 6: Regional variations in the proportion of biomass appropriated by humans (HANPP/NPPpot).



Source: according to Haberl et al. 2009a

Very high levels of appropriation are observed in Europe and Asia. Due to the extinction debt, many impacts of the recent increase of HANPP in Asia on biodiversity have not yet become apparent (see above)

In general, HANPP doubled during the 20th century. However, as there was a fourfold rise in the global population, the per capita HANPP was halved and there was an eightfold reduction per unit of GDP. Scenarios considering social and economic mechanisms predict that the consumption of food products will double in the 21st century, which could lead to a sharp rise in HANPP and a significant drop in NPPt.

Nevertheless, HANPP may vary significantly for the same level of human consumption, according to the amount of residues and losses associated with the conversion of habitats. In this regard, a decrease in NPPluc was observed in OECD countries during the 20th century. Such decrease is due in particular to efficiency gains; For example, the biomass of winter wheat produced in France rose from 4.3 t/ha to 15 t/ha in one century (Smil 2013, p. 201). As a result, despite a significant increase in the absolute quantity of the biomass produced during the 20th century, there has been little variation in the proportion of HANPP in relation to NPPpot. Advances in agronomy lead to a significant decrease in losses, NPPnue and NPPluc. Consequently, the variations of HANPP in proportion to NPPpot during the course of the 20th century may be totally contrasting in different countries, despite the increases in NPPue. These variations depend on the relative influences of the increase in the human population and the improvement in agronomic techniques (Erb et al. 2009).

However, intensification in agriculture – defined here as the use of larger amounts of inputs – has ambiguous impacts on biodiversity. On the positive side, intensification leads to an increase in NPPt in cultivated areas and on pastures, while reducing both NPPluc and NPPres. On the negative side, intensification has collateral effects, such as ecotoxicity and changes in environmental conditions, including the fragmentation of habitats (see part II). Additionally, through market mechanisms, intensification could trigger an increase in consumption, beyond basic physiological needs (Desquilbet et al. 2013). As a reslat, agricultural scenarios require integrating the effects of economic exchanges through which these intensification effects are transmitted, considering the relationship between production and consumption.

Consumption modes

eHANPP, or 'embodied' HANPP, is the NPP directly or indirectly involved, for one unit of biomass consumed, in terms of food, energy or biological materials. This eHANPP corresponds to a life-cycle analysis (LCA) results, integrating the effects of the entire production chain. By analysing the components of eHANPP, we can examine different ways of reducing HANPP. Reducing the proportion of animal proteins in our diet could reduce HANPP by up to 30% (from Foley et al. 2011, Bonhommeau et al. 2013).

Concerning energy, feed for plowing animals was a major source of biomass consumption in the agri-ecosystems of the 19th century, amounting to approximately ¼ of the agricultural surface area, both in France and Austria (Erb et al. 2009). The stability of HANPP in Europe during the 20th century is linked to the replacement of these animals by machines driven by fossil fuels. *A contrario*, energy scenarios relying on biofuels will have the opposite effect on eHANPP. Some of these scenarios suggest that HANPP will double in the 21st century at the global level (Krausman et al. 2013). To assess the impact of such production on biodiversity, comparisons with the impacts of alternative energy sources, wind energy, solar energy and fossil energy sources are required. Biofuel production should prioritise the preservation of NPPt, and be based on the use of NPPnue, the use of NPPue associated to conversion losses, or on reducing NPPluc – by fertilising grasslands, for example. Nevertheless, the collateral effects associated any intensifications of production modes should also be incorporated in order to obtain a comprehensive assessment of biodiversity.

More generally, the same type of comparison must be carried out for any bio-economy plan, or the use of biomass in the economy, e.g. biomass-based materials, hemp for insulating buildings, etc. Its net impact on biodiversity should vary according to the flow affected, according to whether it corresponds to an increase in NPPue, a use of NPPue conversion losses, or a use of NPPnue. To be comprehensive, this assessment should consider alternative lifestyle, saving up the bio-economy resources.

As opposed to numerous final consumption indicators (fossil energy sources, and for biomass NPPc, etc.), there is no correlation between per capita HANPP and GDP (Haberl et al. 2009b). One reason for this could be that gross consumption and transformation efficiency both increase with GDP (see part I), which leads to two contradictory impacts of GDP on eHANPP.

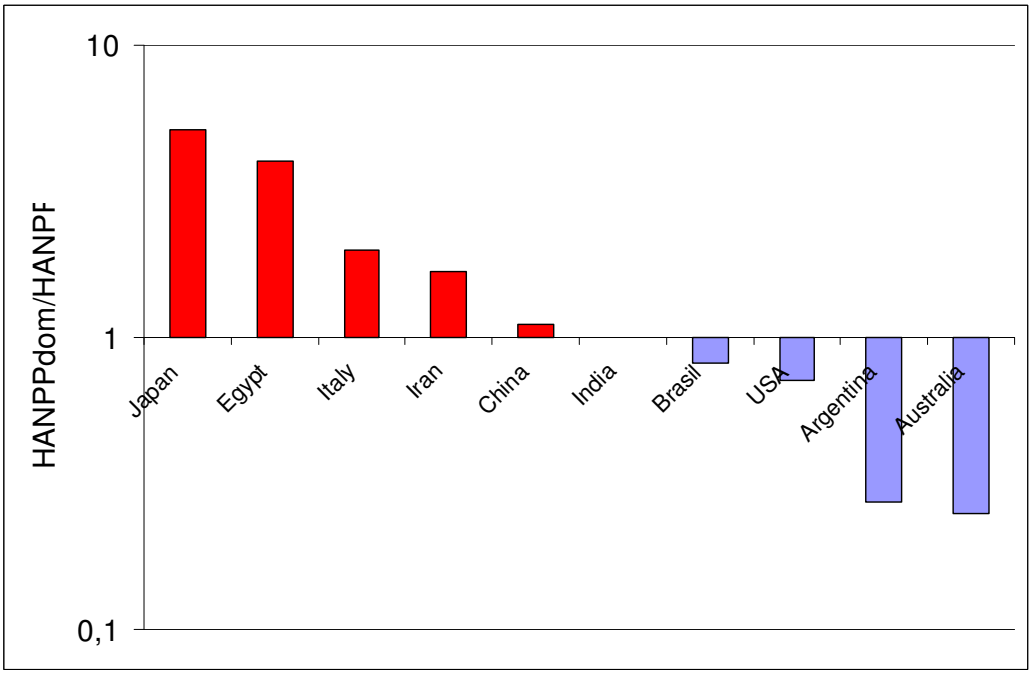
To examine the impacts of HANPP on biodiversity, the comparison of consumption modes seems to incorporate all of the significant economic and social impacts linking production and consumption. Such integration suggests that increasing HANPP in order to meet human needs in the 21st century might have more detrimental than beneficial social effects (Bateman et al. 2013).

Relationships between production and consumption, via international exchangesPrecise estimates of eHANPP – per product or per home – are rare. eHANPP has been calculated at the scale of countries and of international trade. The ratio between eHANPP and the quantity of biomass traded at the international level generally varies by a factor of 5 to 15, from around 4 for India to 18 for Brazil (Haberl et al. 2009a). Any unit traded thus corresponds to many more units appropriated.

eHANPPdom is the eHANPP resulting from consumption by the country's inhabitants. The eHANPPdom/HANPP ratio at the level of a country measures the ratio between the appropriations corresponding to its domestic consumption and production. This ratio distinguishes between biomass importing and exporting countries. It varies according to human density and the productivity of their ecosystems (Figure 7). Japan and Egypt thus consume nearly 10 times more than they extract from their ecosystems, while Australia and Argentina are in the opposite situation. The virtual self-sufficiency of India and China appears to be coherent Given their very high HANPPdom, neither of these countries can cover a significant proportion of their needs through international trade. Meeting 1/3 of the needs through international trade for these two countries would absorb all of the international trade in biomass.

Finally, within the European Union, France is the sole exporter of biomass, and is one of the 10-biggest exporters in the world. Consequently, key political issues for reducing the impact on local ecosystems, through the regulation of imports and consumption, might vary significantly from country to country, even within Europe.

Figure 7: eHANPPdom/HANPP ratio. Low-density countries shown in purple (<30 inhab./km²)



Source: according to Haberl et al. 2009a

5. Conclusion: HANPP family indicators

In light of the analysis of these biomass flows, two indicators for evaluating the status of the natural assets and quantifying human pressures can be proposed. HANPP and NPPt respectively measure our impacts on ecosystems, all of the plant biomass consumed and "diverted" by human activities, on the one hand, and the biodiversity that we can expect to maintain, on the other. Their spatial, dynamic and temporal variations can inform public policies.

Determining the opportunities for biodiversity maintenance, NPPt should be a wealth indicators, while HANPP could be an indicator of human pressures.

NPPt and HANPP could also be incorporated into composite indicators: MEW (mean economic welfare), ISEW (index of sustainable economic welfare), GPI (genuine progress indicator) and SPI (social progress indicator). See the report of the Stiglitz-Sen-Fitoussi commission for discussion of these different indicators. In this regard, HANPP could aggregate, replace, three sub-indicators of GPI: the loss of 1) wetlands, 2) agricultural lands and soil quality, 3) forests, giving an integrative estimate of the human pressures exerted on biodiversity.

The precise mode of integration of NPPt and HANPP will depend on the method used to create these indicators, and the manner in which they integrate indicators of pressure and wealth.

HANPP and NPPt would thus give a quantified and integrative view of a significant proportion of our impacts on biodiversity and of the possibilities for biodiversity that we leave in place to thrive. In this regard, they are more comprehensive than land use indicators. These indicators should help to determine the social significance of an increase in agricultural production in Europe. They should also help to determine the costs and benefits of such an increase, in particular associated with the losses of biological diversity and ecosystem functions generated by an increase in the human appropriation of biomass. Nevertheless, to aggregate the different anthropic impacts, they would need to be associated with indicators of the collateral effects of the human appropriation of biomass, from ecotoxicity through environmental changes. Such integrative indicators should help, quantifying the adaptation required of living organisms (see III.2).

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The value of the climate externality

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Climate change is now perceived by the international community as a credible threat to the pursuit of sustainable prosperity. Economists, however, disagree on how to estimate the "social value of carbon" (SVC), which gives a value to the climate externality or, to put it otherwise, reflects the social wealth created by reductions in CO_2 emissions. An in-depth look at the models that measure SVC reveals theoretical sources of divergence in the results such as the scientific uncertainty about certain socio-economic and climate parameters. In practice, the choice of a value is basically a question of political compromise. We argue that the SVC could become the cornerstone of innovative instruments for financing low-carbon investments, paving the way for a gradual implementation of more traditional carbon pricing instruments such as carbon tax or emission trading scheme.

Climate is emblematic of global externality. By committing to the target of 2°C, the international community considers climate stabilisation to have a value. Society will be richer in a world with a stabilised climate than in a world with an uncontrolled climate. Reducing CO_2 emissions thus creates wealth. The "social value of carbon" (SVC) concept seeks to take account of this wealth.

The monetary valuation of a public good consists of putting a price on an item that, by definition, has no commercial value**. Such an operation takes place at the "limits" of economic calculation.** Monetising avoided CO_2 emissions is not straightforward and arouses considerable controversy among economists. Some consider that the uncertainties on climate damages are so strong that it is pointless to assign a precise monetary value to it. They believe that the only credible way to protect ourselves from the potential threats of climate change would be to establish caps – that would be necessarily arbitrary – on concentrations of greenhouse gases and temperature rises. Others, on the contrary, believe that assigning a monetary value to avoided CO_2 units is necessary to ensure that climate "does not count for nothing" in public policies. The choice of the monetary metrics for CO_2 is not just a technical option. It relies on confidence in the ability of the cost-benefit analysis to provide a rational language of negotiation for stakeholders in the climate debate, and reflects a judgement on the quality (and future improvement) of the available scientific information about the evolution of climate change.

The aim of this article is not to untangle the controversies about the legitimacy of the monetary valuation of CO_2 but to analyse the creation of the SVC and assess the extent to which this signal about the value of climate remains beneficial to public decision-making.

To understand why the measurement of a single reality – the social wealth destroyed by each unit of carbon emitted into the atmosphere – can have such variable results, ranging from $5 to $250 per tCO_2 in 2020 in the last IPCC report, we need to carry out a detailed examination of the architecture of integrated assessment models (IAM) of the economy and climate that generate estimates of SVC. If we consider the models as eyeglasses for observing reality, we need to pay particular attention to the different types of lenses used in order to understand the differences in the results.

The theoretical analysis of the controversies about the parameters and functional forms that shape the IAMs may reveal the magnitude and mechanics of the differences in the results. But in practice, the choice of a trajectory for the SVC is always an arbitrary decision or a compromise between the results of the models. No single model can reveal a "truer" SVC than the others because this is a social price of a fundamentally political nature. This is reflected by the decision of the American administration in May 2013 to apply a sudden 60% increase to the chosen range of the SVC (rising from [$7, $81] to [$12, $129] in 2020) in the cost-benefit analyses of public projects. Such a rise will have a substantial effect on the results of the analyses of certain projects and could even modify the hierarchy of the strategic options for energy investments on American soil.

This article proposes several possible ways to understand the differences in the results, by reviewing the definitions of carbon value and taking an in-depth look at the construction of SVC, i.e. IAM-type models. It suggests a method for obtaining an operational value range. The question of the instruments that can be used to convert the value into a price signal is outlined in the conclusion.

Five definitions of carbon value

The wide estimation range for SVC is partly explained by the lack of distinction among at least five different definitions of "carbon value".

The **academic definition** presents SVC as being both the discounted sum of the marginal costs of the abatement of one unit of CO_2 and the discounted sum of the marginal damage, calculated throughout an optimised economic trajectory. Ideally, the marginal cost and marginal damage will necessarily even out as efforts to reduce emissions are made, so long as their cost remains below their benefit, i.e. the damage avoided. SVC thus marks the boundary of effective emission reduction efforts.

The **market price**, or rather the market prices – because there is no unified carbon market – are supposed to reflect the price of the climate constraint by imposing a rarity on CO_2 emissions via emission permits. However, these prices are incomplete because the markets, for now, only cover a fraction of emissions, produced primarily by the energy sector and several industrial activities (i.e. less than 50% of the total emissions in Europe) and the low level of the prices currently emerging on the EU-ETS market (around 5 to 6 euros) indicates above all that the quota allocations have been overly generous.

The cost of emissions abatement measures the additional cost generated by any proactive policy of replacing productive capital with capital that produces fewer emissions, in relation to a "business-as-usual" baseline scenario. This notion of cost may seem more tangible than the other definitions of carbon price because it originates from the available abatement technologies. However, defining this cost is not the easiest of tasks. It always depends on an emission reduction target – deemed to be politically desirable – at a given time horizon, and on constraints concerning the speed of deployment of the techniques.

The value of the damage avoided throughout a "business as usual scenario" provides an estimate of the cost of doing nothing. This value increases over time as the concentration of GHG in the atmosphere nears potentially dangerous thresholds. In this sense, it has the value of raising awareness and providing a warning about the dangers of doing nothing. The Stern report (2006), which evaluates the damage at between 5% and 20% of GDP, sparked great controversy due to the intrinsic subjectivity of any attempt to evaluate damage.

The social value of carbon is a politically negotiated value that is supposed to give a monetary weighting to either the constraint imposed by a national emission reduction target (as is the case for France and Great Britain), or to the climate externality in the economic analysis of public projects (as is the case in the US). It allows for the measurement of the internal rate of return of projects by internalising the cost of the established emission reduction target or the social cost of climate change. This value is chosen after comparing expert opinions and the results of models. The work of commissions of experts, brought together by public authorities in France, Great Britain and the United States to define the SVCs to be incorporated into the economic analysis of public projects, clearly shows that the models reflect the diverse range of scientific points of view on this issue and that the chosen values eventually boil down to a political choice.

Creation of the controversial estimates of SCV

Since the start of the 1990s, the scientific literature has posed questions about the dynamics of climate policies: **should we act decisively now or postpone the efforts until later?** In the language of cost-benefit analysis, the costs of significant early action on preventing potentially major future climate damage (Stern, 2006) may be amply justified by the anticipated benefits, i.e. the avoided climate damage. On the contrary, other analyses show that it is more economical to delay the efforts and thus tolerate higher climate risks. Future generations, which will presumably be richer, would possess better technologies, and would be better equipped to confront these challenges than the current generations, which are relatively poorer (Nordhaus, 2008). This controversy directly relates to the arguments about the proper value of SVC because, generally speaking, the level and trajectory of the SCV determine the degree of effort that a society is willing to make in order to reduce its emissions.

To understand why there is so much divergence in estimates of SVC, we need to examine the architecture of the integrated economy and climate models. In their aggregated form, the models discussed in the literature are very often designed as variations of the seminal "DICE" model (Nordhaus, 1994, 2008). This is an inter-temporal optimisation model with a benevolent planner that optimises a social utility function under the constraints of the accumulation of capital and of climate dynamics that generate a rise in

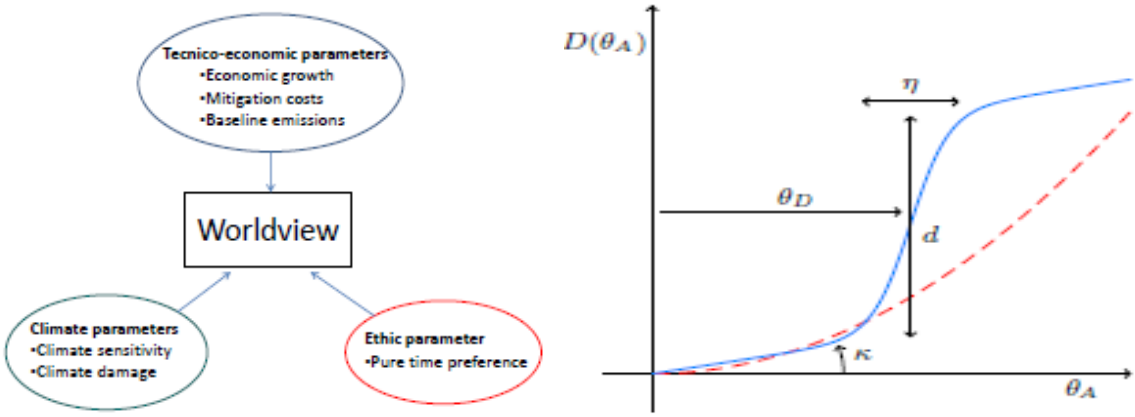
temperatures. This temperature rise retroacts with the capital dynamics through climate damage that drastically reduces a proportion of the wealth produced. Such a model allows for the calculation of an SVC in its academic sense.

Based on the RESPONSE model developed at the French International Research Centre on the Environment and Development (CIRED) and whose specificity is its ability to accommodate different forms of modelling, we have sought to reproduce the differences in results in order to improve our understanding of their origin.

Two main sources of divergence have been identified:

- the parametric **uncertainty** of the models, i.e. the uncertainty over certain key parameters such as the discount rate, climate sensitivity, magnitude of the damage, the rate of technical progress, changes in emissions and the potential growth. As there is no scientific consensus on the value of these parameters, the choice of a value is necessarily a matter of a "belief" or of a subjective choice within an objective range established by the scientific community. A combination of beliefs about these uncertain technical and economic, ethical and climate parameters forms what is referred to in figure 1 as a "world view";
- the **functional forms** of the integrated models, which differ according to the modeller's choices and determine the architecture of the models. The complexity of this architecture varies according to the number of phenomena that it represents. It may or may not integrate phenomena of economic inertia and may or may not model the scientific inertia concerning certain climatic phenomena. With regard to the form of the chosen functions, the example of the damage function, presented in figure 1, speaks volumes. We can expect different impacts on the results according to whether the form of this function is quadratic or sigmoid. The choice of this functional form depends on both technical motives and "beliefs" about the right way to represent the damage.

Figure 1: Components of a world view and representation of two forms of damage functions (quadratic shown by dotted lines and sigmoid by solid lines)



The distinction between these two potential sources of divergence in the results – world views originating from parametric uncertainty and the functional forms chosen by the modeller – is necessarily academic and incorporates a share of arbitrariness. The fact of formulating the debate on climate within the context of a cost-benefit analysis already relates to a certain type of "world view". This term has a narrower meaning in this context. It does not concern the way in which the modeller formulates the problem but rather the differing opinions on socio-economic, technological and climate-related items. The RESPONSE model adheres to the cost-benefit analysis framework and presumes that this approach allows for the performance of experiments on types of thinking that are beneficial to climate policies. **A "world view" is defined as a combination of beliefs about key uncertain parameters of our integrated model**.

The functional forms themselves relate more to the modeller's personal choice. Indeed, it is the modeller that optimises the adjustment of the model's "shell" to his or her interpretation of what is important in the climate debate. For example, to reflect the political target of 2°C adopted at the Copenhagen COP (2009), the modeller may thus decide to represent a threshold effect in the damage function by giving it a sigmoid shape. Therefore, it is the proportion of the modeller's subjectivity that is targeted by the examination of the influence of the choice of functional forms on the results.

What is the influence of world views on SVC?

Since the publication of the Stern report (2006), the debate has focused on the effect of the discount rate. But to understand the differences in the results, we need to assess the impact of all components of a world view.

It clearly appears that the wide ranges of values that are discussed in the literature are consistent with divergent opinions about the key calculation parameters. For some of these parameters such as the rate of pure time preference, the long-term growth and damage, the uncertainty may remain insurmountable because no decisive scientific argument can ever settle the debate. For those parameters that focus on the abatement costs and technical progress, technological discoveries and feedback may, in the future, provide more accurate information about the "true" value of these parameters. The case of climate sensitivity remains somewhat different in that furthering our knowledge of this item only seems to increase the uncertainty surrounding it. The range of "reasonable values" of sensitivity [1.5 – 4.5°C] has changed very little within successive IPCC reports. In a more fundamental manner, this parameter poses questions about the human capacity to comprehend an unobservable phenomenon that will take place in the future, but for which ex ante knowledge is essential if we are to optimally anticipate the impacts of climate change. By definition, this phenomenon relates to a unique experience – climate change – which is currently only sending out low-intensity signals that are difficult to interpret other than via subjective probability distributions.

Espagne et al. (2014) evaluate the relative effects of different parameters on the basis of a sensitivity analysis of the RESPONSE model for the set of parameters that constitute a "world view" (over 2,000 output scenarios) and of an econometric model that explains SVC using the components of a "world view". **They show that the discount rate is important but that other parameters such as climate sensitivity and long-term growth can have as much, or even more, of an impact on the results.**

What is the impact of functional forms on SVC?

To answer this question thoroughly and clearly separate the effects of functional form from the effects of uncertainty on the parameters, we first need to develop a criterion for the equivalence of functional forms (Pottier et al. 2014). Three key lessons emerge from the analyses.

- Models with a quadratic damage function are insensitive to the other choices of functional forms;
- Models with a threshold-effect damage function produce contrasting recommendations according to the other modelling choices (inertia and uncertainty)
- precaution effects, i.e. increases in short-term reductions of emissions only appear when non-linearities are integrated into the model (threshold-effect damage or inertia in the costs).

Our original model for comparing the effects of functional forms makes it possible to eliminate any artificial restriction of the SVC ranges, and to ignore certain climate policy options for the sole reason that the architecture of the model prevents them from being shown. On the other hand, after performing this exercise we remain unable to present an SVC or an abatement trajectory that might be "truer" than those calculated previously. **This method facilitates fundamental interactions among different modelling frameworks and identifies the possible decisive factors for the differences in policy recommendations.** On the other hand, it does not help us to determine which is the best of the possible architectures. This supposes the definition of a criterion for assessing the performance or pertinence of the models.

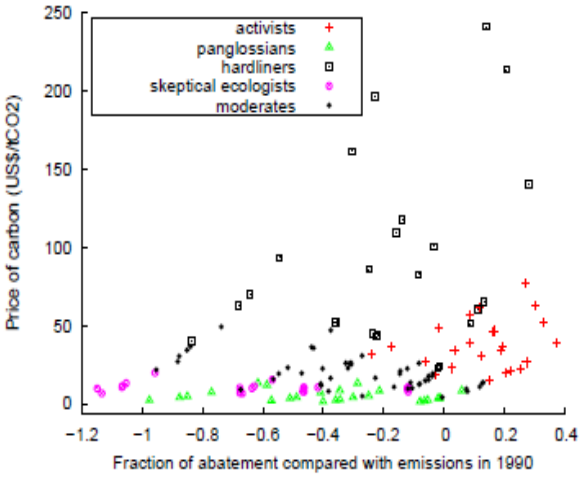
Defining an operational SVC range

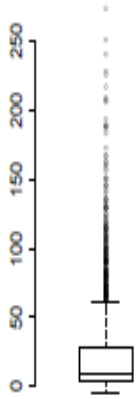
After updating the sources of divergence of the results, it must be recognised that no single SVC value is "truer" than any other. The choice of an SVC is always a question of political compromise. However, there are sound theoretical reasons for thinking that such a compromise is possible. The mapping of the climate debate in 2020 presented in figure 2 organises the results in terms of "tribes" that bring together apparently similar world views and allows for the reproduction of the results found in the literature (Perrissin Fabert et al. 2012). These ranges are, however, more informative, because organising world views into "tribes" provides the key to interpreting the differences in values by associating each of these positions with the type of world view that is likely to generate it. This helps to dispel the impression of "vagueness" or inaccuracy that may be given by a wide crude range and thus to identify the "causes" of these differences.

This mapping also allows for the observation of the mapping of SVC channels that bring together world views which are similar for different reasons because the tribes are not apparently in agreement with one another. This is explained by a game of compensating for the relative effects of the components of a world view.

To go further than this qualitative assessment of the distribution of the results, the box plot in figure 2 shows the distribution of results that arise from a more compact analysis of sensitivity for the key parameters of a world view (2,304 scenarios). The results are highly concentrated in the lower part of the range because the median is worth $16.30, whereas the highest value is $250. The range of the outliers, i.e. of the 90-100 percentiles, is by far the widest – from $65 to $250.

Figure 2: Mapping of the climate debate in 2020





	Social Cost of Carbon in 1990 US$	
	2020	2040
Mean	29	43
Median	16.3	25.6
Highest 50% range	[16.3, 250]	[25.6, 300]
Lowest 50% range	[0, 16.3]	[0, 25.6]
50% range around the mean	[13, 81]	[19, 108]
Narrowest 50% range	[2.3, 17]	[3, 26.5]
25-75 percentiles	[8.5, 36.6]	[11.5, 56]

Interpretation: Each point of this space is identified by a symbol specific to the tribe of the world view from which it originates. The position of members of the same tribe in the climate debate thus appears in the form of a scatter of the same type of points For example, the scatter of red crosses encompasses the tribe of activists. These individuals believe that the damage from climate change will be moderate to very high, and that the abatement costs are low. Their valuation of the present is variable (0.1 or 2%) according to whether they have a moderate or pessimistic opinion of the damage and climate sensitivity. It is probable that given this type of a priori *beliefs, they are in favour of decisive and early action. The majority of the activists do indeed behave as predicted and are shown in the bottom right-hand side of the mapping. The box plot show the distribution of the results of a sensitivity analysis whose main characteristics are shown in the table.*

In order to determine an "operational" SVC range based on this distribution of results, one possibility could be to assign a coefficient of probability to each parameter value and each combination of parameters and in this way to weight the ensuing climate policies. In principle, to this end, it would be necessary to carry out a vast opinion survey for a representative sample on a global scale, or to conduct experimental economics studies in order to update any correlations between beliefs that are "psychologically" inconsistent. Another alternative would be to perform an analysis of expert opinions about the likelihood of particular combinations of beliefs. It is hard to believe that none of these methods is really capable of providing reliable information. This is why, for practical reasons, an equal weighting has been given to each world view.

The results of a descriptive statistical analysis of the distribution are shown in the table in figure 2. **The ranges that cover 50% of the world visions around the mean or the median allow the impacts of the extreme positions to be cancelled out and are thus the ranges that provide the most pertinent information for establishing a compromise range**. Due to the concentration of the results around the low values, other ranges encompassing 50% of world views are likely to give a disproportionate weighting to world views that do not consider climate change to be a credible threat. The ranges of the 25-75 percentiles are [$8.50, $36.60] in 2020 and [$11.50, $55.80] in 2040. Around the mean, these ranges become [$13, $81] in 2020 and [$19, $108] in 2040. These ranges, however, remain very wide. This is partly due to the decision to attribute an equal weighting to each of the world views. The removal of some of the Panglossians – the disciples of Master Pangloss, the eternal optimist in the tales of Voltaire – and of the sceptics would, for example, move the results upwards and reduce the range of the 25-75 percentiles.

Nevertheless, claiming to reveal the "true" SVC would be misleading. The insurmountable uncertainty over the parameters that make up a world view is inevitably reflected in the SVC. The choice of an SVC ultimately relates to the balance of political power and a subjective choice within reasonable ranges. The role of the economist and modeller is thus to make room for such choices.

The link between the value and price of carbon: the choice of instruments

While it is theoretically possible to determine a range of SVC, the traditional remedies of economic analysis for converting value into a price of carbon run into major diplomatic obstacles. After over 20 years of climate negotiations, the introduction of a global carbon tax remains an inaccessible goal, as is the implementation of a major global carbon market. Even at the national level, the examples of attempts to introduce a carbon tax clearly show that the deployment of an ambitious environmental taxation system remains difficult and can only be negotiated in the framework of a broader discussion of the fiscal covenant.

In practice, instruments that introduce a carbon price suffer from a problem of social acceptability. By modifying the profitability of past and future investment choices, these instruments directly affect the installed capital and the existing behaviours. They generate a financial transfer from the holders of CO_2-intensive capital to those that possess or are installing low-carbon capital. The "losers" may refuse to pay the microeconomic costs imposed on them by the low-carbon transition.

Other channels exist for sending a signal about the value of carbon to economic agents: "investment" instruments (subsidies, subsidised loans and feed-in tariffs) which implicitly assign a value to emission reductions. These instruments do not impact the installed capital but reward the emission reductions achieved by new investments. They thus benefit from a higher degree of social acceptability but in theory are less effective than pricing instruments and are potentially costlier for public budgets. In order to adjust the amount of public support, the SVC could provide metrics capable of preventing too great a disparity among the implicit prices of avoided CO_2 included in this type of instrument.

A debate about SVC could also be held within climate negotiations. An agreement on SVC would seem to be more accessible and more stable than an agreement on the price of carbon because it gives an insight into the scope of a low-carbon investment opportunity rather than just the costs of climate policies. In its Decision (paragraph 108), the Paris Agreement *"recognizes the social, economic, and environmental value of mitigation activities and their co-benefits to adaptation, health, and sustainable development"*. Such a value is not the price to pay for emitting CO_2, but rather the agreed value to be incorporated into the analysis of projects and the baseline value to be used for the adjustment of public support and guarantees for low-carbon investments. In a very pragmatic manner, it eliminates the gap between the private and social returns on new investments and safeguards the installed capital. In this way, it significantly reduces the distributive effects of the price signal.

The SVC thus provides the politically acceptable signal of what the price of carbon should be. It could become the cornerstone of different innovative instruments for financing the low-carbon transition (climate obligations, green securitisation and green quantitative easing). The deployment of monetary instruments secured against an SVC that is guaranteed by the public authority is a clever way to "commit" States to a forward contract on the price of carbon (Hourcade et al. 2014; Aglietta et. al. 2015). This contract is attractive to private investors due to the guarantee on SVC, which is economical for the public budget (in the short term, provided that the guarantee is not implemented), and is also potentially very beneficial if carbon pricing instruments eventually cause the price of carbon and the SVC to converge.

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Valuing a natural asset according to the discounted value of ecosystem services

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The valuation of a natural asset according to the discounted value of ecosystem services involves the transposition of a method that is very widely used in asset valuation to ecosystems. This is the net present value of the future cash flows of an activity, commonly referred to as *Discounted Cash Flow* (DCF), which financially reflects that an asset is "worth what it brings in". This approach requires a very clear definition of ecosystem services and their social benefits, and the consideration of the fact that ecosystem services alone cannot express the total value of a natural asset.

In their Strategic Plan for Biodiversity 2011-2020, adopted in Nagoya in October 2010, the 193 signatory countries of the Convention on Biological Diversity (CBD) set targets that include the following: By 2020, at the latest, people are aware of the values of biological diversity (…)"; "By 2020, at the latest, biodiversity values have been integrated into national and local development and poverty reduction strategies and planning processes and are being incorporated into national accounting, as appropriate, and reporting systems". This is a question of attempting to show the proportion of national wealth that is represented by biodiversity and ecosystems.

These targets are repeated in the European Biodiversity Strategy ("Biodiversity, our life insurance and our natural capital"), adopted in 2011. This strategy especially envisages "that with the Commission's support, the Member States shall map ecosystems and their services and evaluate their status within their territory between now and 2014, evaluate the economic value of these services and encourage the integration of these values into accounting and reporting systems between now and 2020".

The French National Biodiversity Strategy, adopted in 2011, also adopts these guidelines in its seventh target entitled "Including biodiversity conservation in economic decision-making".

One of the avenues adopted for promoting the value of biodiversity involves the valuation of the services that humans obtain from healthy ecosystems. Ecosystems thus appear to be natural assets whose value could be assessed as the net present value (NPV) of a time series of present and future flows of ecosystem services (ES_i) over a given period of time (T).

$$V_{natural\_asset.} = NPV(\sum_{i}^{T} ES_i)$$

The use of ecosystem services to value natural assets, or to incorporate their values into national accounting systems, raises a series of conceptual and methodological questions that must be addressed before any operational implementation. This firstly involves clearly defining the concept of ecosystem service by including the aims of the valuation at the stage of the semantic debate, and secondly, it means properly understanding and taking account of the limitations imposed by this approach.

Making the ecosystem service concept operational for the purpose of economic valuation

A need to clarify the ecosystem service concept for economic valuation

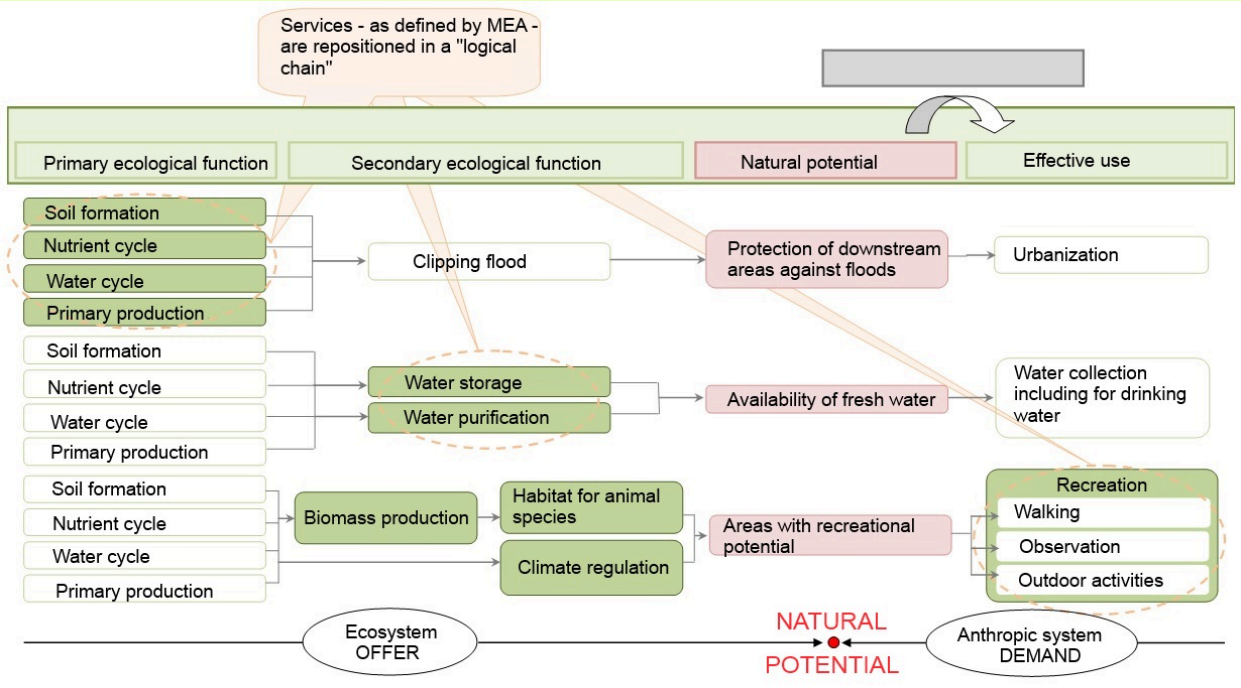
The ecosystem service concept became organised at the international level between 2001 and 2005 with the development of the Millennium Ecosystem Assessment (MEA, 2005), which involved contributions from more than 1,360 experts from nearly 50 countries. The MEA (2005) defined ecosystem services as "the benefits that humans derive from ecosystems. These include provisioning services such as food, water, construction timber and fibre; regulating services that affect the climate, flooding, health, waste and water quality; cultural services that provide recreational, aesthetic and spiritual benefits; and supporting services such as soil formation, photosynthesis and the food cycle".

This very broad definition of the concept of ecosystem services has been adopted by the scientific community and widely disseminated, including within the field of politics. However, as mentioned by Chevassus-au-Louis et al. (2009), the definition and classification of ecosystem services in the MEA remain an open and hotly debated question. In particular, it poses major problems for operational use in the framework of an economic valuation and for the eventual integration of the values into national accounting systems:

– The definition fosters confusion between provisioning services and goods taken from ecosystems. The definition of the MEA clearly mentions goods (water, timber and food) as examples of this category of ecosystem services; their integration into the national accounts is not necessary since these values are already accounted for.

– Habitat or support services do not constitute a direct benefit for human societies. Instead, they characterise the ecological functions of the ecosystem as support for the expression of ecosystem services. Chevassus-au-Louis et al. (2009)[79] specifies that they cannot be the subject of an economic valuation "the support functions are only mentioned as a reminder, since it is a question of maintaining the existing systems, they are valued through the services provided by these systems".

Box 1: From the ecological function to the ecosystem service, in CGDD (2011), Évaluation économique des services rendus par les zones humides – Enseignements méthodologiques de monétarisation, Études et documents no. 49



Note: This logical chain, even when highly simplified, is not linear; several ecological functions may contribute to the same ecosystem service. Similarly, an ecosystem service generally depends on several ecological functions. This logical chain illustrates the absolute need to refrain from accounting for support services in this way and to conceive of them as clearly ecological functions.

– The perception of the benefits provided by ecosystem services can vary considerably according to the types of stakeholders (e.g. a farmer does not derive the same benefits from the agricultural ecosystem as a city dweller or a forester). The identification of the beneficiaries of the services is therefore a prerequisite that is the key to their valuation.

[79] Chevassus-au-Louis et al., 2009, p.211

– Finally, certain cultural services correspond either to immeasurable benefits (e.g. spiritual interactions with ecosystems and the sacred dimension of certain natural components for certain human populations), or to acknowledged benefits due to the simple fact of their existence value (e.g. cultural services associated with the existence value of certain species).

Attempted clarifications with a view to creating ecosystem accounts

Different attempts will be made to clarify the concept of ecosystem services, particularly from the perspectives of valuation and accounting. However, semantic differences will remain, especially due to the complexity of the concept itself, with an ecosystem service being defined as a flow of material, energy or information originating from the ecosystem and contributing to one or more benefits derived by human societies. An ecosystem service can thus be considered a two-dimensional concept: ecological and socio-economic. It can be evaluated in response to two types of questions: (i) what potential for services does an ecosystem offer and (ii) what contribution does an ecosystem make to human societies?

The attempts to clarify the concept of ecosystem services generally focus firstly on the distinction between goods and services and secondly on the difference between ecological functions and ecosystem services. In both cases, there are very slight divergences that can be described as conventions adapted to the aims in question.

The experimental ecosystem account systems developed by the United Nations (SEEA-EEA, 2013) have paid special attention to attempting to resolve these difficulties and have adopted the following conventions.

The definition of ecosystem services implies a distinction among (i) ecosystem services, (ii) the benefits to which they contribute and (iii) the well-being to which they are finally assigned. Ecosystem services must also distinguished from the characteristics of ecosystems and from ecological processes and functions.

Ecosystem services are only defined when their contribution has a clearly established benefit for human societies. Consequently, the definition of an ecosystem service excludes any flows that jointly refer to support services or intermediate services.

Different terms are used to describe ecosystem services as they are defined by the SEEA-EEA: The most common are "ecosystem goods and services" and "final ecosystem services". The first term acknowledges that ecosystem flows include flows of tangible elements (e.g. timber, fish, etc.) and flows of intangible services. The second term acknowledges that only services that contribute to a benefit are included in the field.

The ecosystem services defined by the SEEA-EEA exclude abiotic services. The ecosystem services defined by the SEEA-EEA are divided into the three categories of the Common International Classification for Ecosystem Services (CICES): provisioning services, regulating services and cultural services. This classification has been established in order to avoid double counting of services.

The valuation of an ecosystem service presumes the definition of a boundary between the ecosystem service and the benefit that results from its use. As an illustration, the SEEA-EEA adopts the following convention for the production of timber: the benefit results from the felling of timber in forests for different uses (construction and energy, etc.), whereas the ecosystem service is expressed in terms of the available standing timber. For the SEEA-EEA, the ecosystem service (in this case provisioning) corresponds to the standing timber just before felling and the benefit corresponds to the timber just after felling.

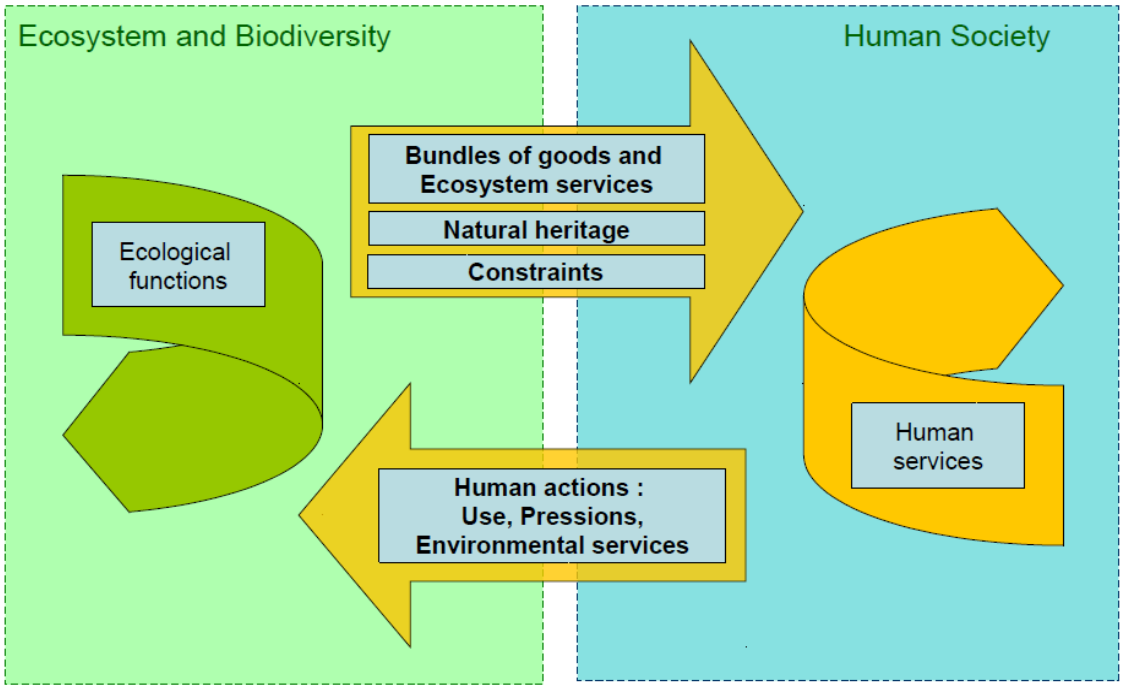
The distinction between an ecological function and an ecosystem service is also the result of a convention. An ecological function or a combination of ecological functions may contribute to a benefit for an individual or a social group, or indeed for the whole of human society. In all of these cases, the SEEA-EEA refers to ecosystem services.

The notion of a provisioning service is also limited to situations in which goods are taken from the natural environment for use in sectors such as food, pharmacopoeia and energy, but whose production has not required the active management of the environment. If the production of such goods has required the active management of the ecosystem (as is generally the case in agriculture for example), then the SEEA-EEA considers the services in question to be anthropic rather than ecosystem services.

The conventions adopted for the French assessment of ecosystems and ecosystem services (EFESE)

The French project for the national assessment of ecosystems and ecosystem services (EFESE) has clearly identified these difficulties, and because it aims *to produce* values for national accounting systems in particular, conceptual choices or conventions have been adopted at the earliest possible stage in order to avoid the pitfalls of double counting and immeasurability.

Fig. 1: Simplified conceptual framework for the EFESE



In the framework of the EFESE, it has been agreed to make clear distinctions among the following types of major benefits:

– ecological functions
– goods taken from ecosystems
– ecosystem services taken from ecosystems by human societies
– natural assets
– environmental services carried out by humankind for the benefit of ecosystems.

This typology is based on identifying the compartment that directly benefits (ecosystem or socio-economic system) and the supplying compartment, in addition to the possible type of measurement of the benefit in question (table 1).

Table. 1: Typology of services adopted for EFESE

Supplying compartment	Compartment that directly benefits	Type of benefit	Type of measurement of the benefit
Ecosystem	Ecosystem	Ecological functions (supporting)	Biophysical indicators
	Socio-economic system (individual, social group or society)	Goods taken from ecosystems	Biophysical quantities and economic valuation
		Regulating and cultural ecosystem services	Biophysical quantities and economic valuation
		Natural heritage : immeasurable services (spiritual, identity-related and symbolic interactions)	Identification and geo-referencing
		Natural assets: protected species and areas, sites and landscapes awarded environmental quality labels	Identification and geo-referencing
Socio-economic system	Ecosystem	Environmental services	Cost-based approach
	Socio-economic system	*Services (outside scope of the EFESE)*	*Economic indicators*

Ecological functions

Ecological functions correspond to phenomena specific to the ecosystem, which result from a combination of structures and ecological processes and which occur with or without a human presence. In particular, these are basic functions and functions concerned with maintaining the functionality of ecosystems (nutrient cycle, soil formation and primary production, etc.). The notion of ecological function corresponds to the dynamics that support the production of ecosystem services and which ensure the maintenance of the good ecological, physical and chemical state of environments. Certain publications refer to them as "support services" (MEA, 2005) or "intermediate ecosystem services" (CICES, 2013).

Table 2: Table of correlations among the MEA (2005) and EFESE typologies

MEA (2005) typology	EFESE typology
Supporting services	Ecological functions
Provisioning or extraction services	Goods
Regulating or control services	Regulating services
Cultural and spiritual services	Cultural services (measurable benefits; use value)
	Natural heritage (immeasurable benefits; non-use value)

For the EFESE, it has been decided to make a clear distinction between "ecological functions" and "ecosystem services" (CGDD, 2010; CGDD-MNHN, 2010). Therefore, ecological functions are valued for themselves and not as services. The aim is thus to measure the dependency of bundles of ecosystem goods and services with regard to ecological functions.

The distinction between ecological functions and ecosystem services arises, in particular, from the definition of a notional boundary between ecosystems and human societies. This boundary may therefore vary according to the perception of the extent of human intervention in ecosystems. This means that certain ecological functions (e.g. soil fertility) are considered to be regulating ecosystem services provided that they underlie the production of goods taken from ecosystems which are predominantly managed by humans (e.g. agriculture

and aquaculture). In this case, the goods obtained are considered to be derived from anthropic services, and the functions constitute regulating services (pollination and soil fertility, etc.). When the goods are procured directly from ecosystems whose operation is not significantly affected by human actions (e.g. gathering and fishing), the ecosystem service is defined by the production of these goods, and the ecological services presented are therefore considered to be ecological functions rather than services.

Ecosystem goods and services

For the EFESE, ecosystem services are described as the use by man of the ecological functions of certain ecosystems, via uses and regulations that manage this use (SNB 2011-2020). They can be described via the benefits obtained by humans from their current or future use of miscellaneous ecosystem functions, while guaranteeing the long-term maintenance of these benefits.

The goods taken from ecosystems are of an indisputably tangible nature (e.g. water, food, and materials) and their market value clearly reflects a degree of dependency of the economy on the ecosystems in question.

The services obtained from ecosystems are of an intangible nature (e.g. water purification and sequestration of atmospheric carbon), and when their monetary value can be measured, it also reflects a degree of dependency of the economy on the ecosystems being studied. The economic valuation of the services only relates to their use value, and if applicable to their option value in the framework of prospective analyses. The concept of total economic value (TEV) is therefore not used in the EFESE for measuring the economic value of the services provided by a type of ecosystem.

Instead, it is a question of assessing the changes in the value of a service over a specific time interval in order to measure the evolution trends. The valuation also endeavours to focus on groups or bundles of ecosystem goods and services.

Bundles of ecosystem goods and services

In the framework of the EFESE, a "bundle of ecosystem goods and services" is described as being a group of several ecosystem goods and services that are regularly observed together in time and/or space (Raudsepp-Hearne et al. 2010). These goods and services co-vary in time and space.

Natural heritage

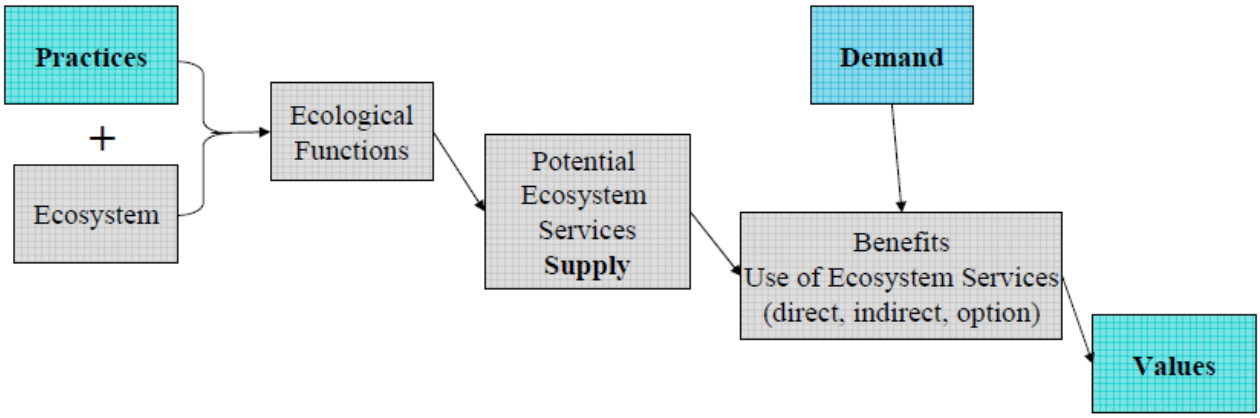
Certain cultural services focus on major identity-related, or even spiritual, interactions with an immeasurable dimension. They are documented in the EFESE, as their mere existence may prove to be decisive in the decision-making process. However, their monetary value is not systematically sought.

Elements to be considered in the economic valuation of an ecosystem service

The value of an ecosystem service measures a benefit and the level of society's dependency on the operation of an ecosystem. By definition, this is an anthropocentric approach. If there is no demand, the value of the benefit is zero. Consequently, as the ecosystem service is the ecosystem's contribution to the production of this benefit, it is also devoid of value. In a different socioeconomic context, of course, the demand may be positive and the value of the service may also be positive. In both scenarios, the potential for an ecosystem service or the supply of a service may prove to be positive.

The value of an ecosystem service is partly dependent on the characteristics of the ecosystem, which determine its ability to meet the demand and satisfy the characteristics of the social ecosystem at the time of the assessment (lack of demand or variable demand; different demand according to categories of stakeholders). Moreover, the value of an ecosystem service depends on the ecosystem management procedures (Fig. 2). For example, the pollination service value of a field of alfalfa that has been mown before flowering will be nil, whereas the same service will have a positive value if mowing takes place after flowering. It is thus crucial to calculate the value of a service, and to take account of the range of possibilities in terms of the management of an ecosystem (traditional agriculture, organic agriculture, conservation agriculture, etc.)

Figure 2: Logical chain of valuation of ecosystem services incorporating land managemen in the ecosystem being studied



Source: CGDD, 2013 – adapted from TEEB, 2008

These elements can be condensed into the following formula:

$$VALUE_{Ecosystem\ Service} = f(time, space, land\ management)$$

The limitations imposed by assessments of ecosystem services

In addition to the difficulties already mentioned, the ecosystem service concept has major limitations regarding an approach to the national wealth derived from nature. According to Chevassus-au-Louis et al. (2009), the difficulties include the characteristics of mixed (public-private) goods; problems of comprehending spatial and temporal dynamics and the nature of the "joint production" of several services by a single ecosystem; the complexity of the interactions among structures, ecological functions and services; finally, the fact that agents only define the items from which they benefit as services.

Dealing with interlocking scales

The very high dispersion of the monetary values proposed for ecosystem services is a result of the diversity of the ecosystem services in question, at both ecological and socio-economic levels. This dispersion is higher when the valuation is carried out on a local scale and lower at the national and international levels simply due to the smoothing of the values produced. This characteristic of the services must be taken into account so that the scale of the valuation is chosen according to the aims that have been established. Moreover, Chevassus-au-Louis et al. (2009) recommends performing the valuation of services according to major "social ecosystems" characterised by (i) their geographical area, (ii) the type of ecosystem, (iii) the degree of anthropication and (iv) the country's level of wealth.

The consideration of the diversity of the beneficiaries, their perception and their weight in the valuation

Ecosystem services reflect the benefits derived by certain users from natural environments that have been anthropised to varying extents. It is therefore obvious that the services do not concern everyone in the same way – everything depends on the motivations, interests and practices of the different stakeholders and, of course, of the time. This prompted Zhang et al. (2007) and Swinton et al. (2007) to propose the concept of "disservice", or negative service. Indeed, for certain stakeholders, the ecosystem may impose constraints on the development of their activities (e.g. crop-destroying pests for farmers). However, for other stakeholders, the same constraint may constitute a genuine value. The EFESE has not adopted the concept of disservice and favours an integrative approach to services that constitute nature-based solutions to any natural constraints (e.g. regulating service for crop-destroying pests).

To be totally comprehensive, an assessment of ecosystem services must therefore document the values of the services for each category of associated beneficiary. Finally, the demographic weight of certain users of these services may also increase their value very significantly, and at the same time, this use may prove to be unsustainable (e.g. overexploitation or excessive tourist pressure). This comment needs to be put into perspective with the existence of irreversibility thresholds and requires a certain amount of care in the use of this concept for the measurement of natural capital. In this perspective, the EFESE favours a multidimensional approach combining the measurement of the supply and the valuation of the demand for the service.

Consideration of the interactions among services and the problem of the summation of values

Interactions may exist among certain ecosystem services in the form of compromises or synergies. For the former, the value of one service changes inversely to the value of another service. For the latter, the value of both services increases or decreases simultaneously.

The existence of such interactions among ecosystem services is greater when these services are similar to ecological functions. As an illustration, a farmer relies on a range of ecosystem services (pollination, soil fertility, natural regulation of crop-destroying pests, etc.) which, when combined, constitute a benefit that is likely to be valued economically (proportion of the value of agricultural production). However, the benefit for the farmer is the result of a combination of ecosystem services and not of a sum of services.

The calculation of the value of a natural asset on the basis of the net present value of a sum of ecosystem services may thus prove to be inaccurate, particularly when some of these services are highly interdependent.

The tricky question of establishing the discount rate

The calculation of a net present value requires the choice or establishment of a discount rate. This question is the subject of a debate with many differences of opinion regarding the preference for the present. Much of the criticism stems from the depreciation of future issues which tends to prevail over the long term. In a sustainable development-based approach and from the perspective of equity vis-à-vis future generations, environmental economists tend to recommend "hyperbolic discounting", i.e. a discount rate that decreases over time. Some of them also recommend the use of a zero or even a negative discount rate (Ehrlich, 2008).

For the time being, the EFESE is following the Chevassus-au-Louis et al. (2009) recommendation "to apply to questions of biodiversity and ecosystem services the discounting factor that is generally used for public choices, while endeavouring to choose the relative price trends in a transparent and pertinent manner".

What is not expressed by the value of ecosystem services

The concept of ecosystem services constitutes one of the possible representations of the relationships between humans and nature, but other representations do exist, and ecosystem services alone cannot reflect the entire value of an ecosystem. Indeed, their valuation only embodies the value associated with the use of the ecosystem that provides benefits for human societies. In this approach, a lack of use (no current use, no user and no known use) produces a null value for the service in question. In this case, the natural asset may have an option value which, to be measured, presumes the development of scenarios in which a use will be defined for this asset. This measurement is essential and is one of the focuses of study in the EFESE. Moreover, the non-use value (existence value, bequest value and altruistic value) of a natural asset is not taken into account in an ecosystem service-based approach.

In many examples of valuations, the required data are incomplete and the ecosystem services are only partially valued. Therefore the values produced are exclusively lower bound.

Finally, the valuation of ecosystem services provides information about the quantity rather than the quality of the ecosystem. Chevassus-au-Louis et al. (2009) wisely includes this warning: "it is doubtful whether the quantity or quality of services are very sensitive to the biodiversity of environments". We must therefore be wary of attaching too much importance to the net present value of a time series of ecosystem services and refrain from reading too much into what this value tells us.

Conclusion

The ecosystem service concept is complex and remains open to semantic debate. The recent attempts to clarify this concept must allow for its operational use and the integration of the values into decision-making processes and accounting systems. The work carried out in the framework of the SEEA-EEA (2013) has already allowed for remarkable progress in this field.

Chevassus-au-Louis et al. (2009) cites Kinzig, Peerings and Scholes (2007) who argue in favour of the "use of ecosystem services as a mechanism to optimise all investments in conservation by focusing them on the areas in which they will be the most socially useful". This approach would undoubtedly be an appropriate first step for defining baseline values for ecosystems with a view to rationalising the public choices for investment projects. However, although these values can help to shed light on the valuation of natural capital, they only come close to a part of it. What remains to be measured – if deemed to be really necessary – is the so-called "intrinsic" value of ecosystems, which is illustrated by the words of Saint-Exupéry's "Little Prince" (1943): "*If someone likes a flower which is the only one that exists in millions and millions of stars, that's enough for him to be happy when he looks at them. He'll tell himself 'My flower's somewhere out there...' But if a sheep eats the flower, to him it's as if all of the stars suddenly went out! And that's not important!*"

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Part III: Integration into economic choices

In this third part, natural capital is assessed from the perspective of economic stakeholders: Governments, investors, banks, companies. What are the missing values required in order to integrate environmental quality into their long-term strategies? If nature lays the foundation for the wealth of nations, how can we ensure that it is integrated in economic valuation systems? Through which instruments? What are the institutional and regulatory changes required?

While the methodological controversies about the "best" measurement of nature are potentially insoluble, the needs expressed by stakeholders and the urgency to act may create strong social demand, and hence the conditions for speeding up the stabilisation of measurement conventions. The key issue is to favour the ramping-up of investments in natural assets. How can responsible investors be encouraged to embark on the financing of alternative assets? Different public instruments can be used for the promotion of positive externalities. Others still need to be invented in order to activate the financial and monetary vectors that are directly "plugged into" the investments and can have a rapid impact on the mobilisation of private funds for nature.

How can we remedy the failings of the "invisible hand"?

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An economic approach is essential to meet the challenges associated with the protection of nature and biodiversity.

As biodiversity is a requirement for the preservation of life on Earth, biodiversity conservation policies, which are generally presented as being an end in themselves, remain a necessity that should prevail over economic and social considerations.

However, we now have references for analysing the economic and social issues associated with biodiversity policies, taking account of the fact that many economic activities – and thus many jobs – depend on biodiversity, and identifying the social impacts of choices concerning the management of ecosystems. These analyses, even if they remain partial, tend to reconcile different agendas which cannot, in fact, be addressed separately.

This article provides an overview of the available instruments. These instruments vary in their nature: economic incentive instruments, specific ecological pricing mechanisms for the protection of nature and biodiversity and voluntary instruments – especially of an informative nature.

The key issues and challenges associated with the protection of nature and biodiversity are now recognised. On the one hand, biodiversity provides us with precious goods and services, because natural environments contribute to water purification, flood prevention and the structuring of landscapes and our living environment. On the other, natural landscapes are subjected to acute pressures due to human activities, land take and the acceleration of the rate of extinction of living species.

The OECD thus estimates that between now and 2050, terrestrial biodiversity could decrease (again) by 10%, and the surface area of forests by 13%. Fresh water bodies, which have already lost one third of their biodiversity, could suffer new losses. The collapse of fisheries due to overfishing could continue. Finally, 40% of the global population could be living in basins under severe water stress that jeopardises agricultural uses.

An economic approach is essential if we are to rise to these challenges. Indeed, nature protection policies can no longer confine themselves to a strictly "conservationist" approach that only takes account of remarkable species and areas of total protection.

All regions are concerned in one way or another. Species require networks of ecosystems and ecological continuities in which they can operate and evolve, or adapt to pressures – especially climate change. The role of agri-ecological infrastructures has also become an important topic of agri-environmental policies. These mainly consist of hedges, copses, trees – singly and in rows, buffer strips, extensively managed grasslands, low walls, berms, ponds, mature orchards and any environments and areas that are given no inputs of pesticides or fertilisers. They play a major role in protecting the soil and water, form favourable biotopes for numerous species and contribute to the maintenance and restoration of ecological continuities.

In addition, within the production system, they play an essential role at the agronomic, functional, energy and landscape quality levels. These infrastructures are essential to the environment, contributing to the conservation of biodiversity, the water cycle, water quality and carbon storage. As habitats for pollinators and other species defined as crop auxiliaries, they are also highly beneficial to agriculture and allow for a reduction in the use of pesticides.

However, as biodiversity is a requirement for the preservation of life on Earth, biodiversity conservation policies, which are generally presented as being an end in themselves, remain a necessity that should prevail over economic and social considerations. However, we now have references for analysing the economic and social issues associated with biodiversity policies, taking account of the fact that many economic activities – and thus many jobs – depend on biodiversity, and identifying the social impacts of choices concerning the management of ecosystems. These analyses, even if they remain partial, tend to reconcile different agendas which cannot, in fact, be addressed separately.

Examples include the proposals for marine protected areas (MPAs) and for the economic management of fishing, which are often presented as alternative, or even contradictory, approaches, with the former relating to a conservation policy that seeks to protect habitats and biodiversity, and the latter seeking to prevent the overfishing of stocks due to their free access. However, the analysis of the interactions between any MPAs and the fishing efforts in unprotected areas means that this contradiction needs to be overcome, first of all by showing the need to choose the location of MPAs with care. In addition, it allows for the analysis of how these marine protected areas provide benefits for fishing activities, while also stressing that the management conducted outside the MPAs has a crucial influence on their impact in terms of conservation.

More generally speaking, it should be emphasised that the refusal to integrate the ecological and economic dimensions has serious consequences. The refusal to price water at a level that reflects its scarcity leads to it being wasted, and ill-conceived protection policies increase the pressure on the species we want to protect, as the increase in the demand or their price encourages poaching, for example. Therefore, seeking to use economic instruments to protect nature is not a component of an all-out monetisation policy, but – on the contrary – reflects the concern to employ a wide range of instruments capable of protecting the resources required for human development.

Economic incentive instruments

Without proper regulation, a common, freely accessible resource will inevitably be overexploited. From an economic standpoint, the underlying economic issue is a problem of "externality": the party that draws on this resource at a given moment (or develops an activity that affects its status) does not take account of its impacts on other users or on the status of the resource for the development of future generations. With this economic qualification of the problem to be resolved established, environmental economics and natural resources provide a framework for designing the public policies required to remedy this "tragedy of the commons".

How can we reconcile the protection of nature and economic efficiency?

To reconcile environmental, economic and social requirements, public intervention must be conceived of as an "incentive" or as a means of promoting "responsibility", and exerting leverage on private stakeholders. *A contrario*, an approach that only seeks to strike a balance in sectoral decisions (transport, agriculture, urban planning, development and energy, etc.) on a case-by-case basis, among the contradictory interests which are expressed at a given moment, generates added costs and inflexibility. It often perpetuates deadlocks, attaches excessive importance to certain short-term interests and creates "regulatory" uncertainty for investors, making public policies completely ineffective.

More specifically, the cost required to attain an environmental objective may be substantially reduced if a price signal is adopted which clearly and durably reflects the scarcity of the environmental resources. By not providing such a signal, our economy and our society in general are failing to make proper preparations for the future. Moreover, by mainly resorting to uniform and inflexible standards, we are failing to acknowledge the disparities in situations regarding the opportunities to reduce the use of these resources, which generates additional costs and eventually leads to the reduction of environmental ambitions. By exclusively counting on voluntary approaches, we ignore the fact that economic agents are, above all, guided by their private interests, and that we must therefore bring these personal interests into line with the public interest.

The introduction of ecological prices is consistent with this principle – a policy of cost pricing that aims to increase the total wealth – by making the polluters responsible for the socially harmful consequences of their behaviours. The range of instruments that can be used for this purpose, and the support policies that may need to be implemented in order to ensure their acceptability, have been firmly established since the early 1970s. The Pigovian approach to the internalisation of environmental costs through incentive taxation has existed since 1920, while the contributions of Coase (1960) followed by Dales (1968), have allowed for the creation of systems of environmental access rights that can be negotiated on a market.

"Cap-and-trade" permit markets

Consequently, rights markets were introduced into the fishery sector in the early 1980s, well before their use for the regulation of atmospheric pollution. Many fisheries were confronted with a triple threat: overexploitation of the resource, over-investment, and subsidies, reflecting the fundamental economic problem encountered by the exploitation of fishery resources, which is once again the issue of free access to a common resource.

In fact, when a company – rationally from its individual standpoint – increases its fishing effort, it does not "internalise" the fact that the fishing conditions of other operators will subsequently deteriorate, along with the resource that will be available in the future. Overall, the fishing effort increases in this way until it absorbs all of the remuneration that it was likely to obtain from the exploitation of this resource. Moreover, the measures implemented in order to reduce this overexploitation, without addressing this problem of access, generally aggravate the situation, with the increased power of the fleets circumventing the different restrictions imposed on the fishing conditions. Declining incomes, the increasing scarcity of the resource and over-investment thus lead to the need for subsidies that further aggravate these phenomena and which are likely to remain in place until improvements are made to the regulation of access to the resource.

The benefits of "cap-and-trade quota markets" are twofold in this context. Firstly, they allow for the regulation of the overall amount of captures, which is not the case for the usual regulatory intervention instruments which have the additional effect of generating "races for fish". Furthermore, the transferability of quotas is a flexible way to promote their effective use, by restoring the margins for manoeuvre required to ensure that the captures are made in the most profitable manner, at the lowest cost and at the right time, e.g. by extending the fishing times, and to help improve the quality of products.

In relation to the objectives that were set for them, their implementation has generally had a positive impact, especially by breaking the cycles of over-investment, and has reduced the incomes earned due to the scarcity of the resource. The opinions concerning the reconstitution of stocks are less conclusive, primarily because it remains very difficult to evaluate their status. Furthermore, these schemes have not escaped the pressures of "initial over-allocation" which often condition their acceptability, at least at the outset.

On the other hand, some of the different criticisms levelled at this type of scheme are unfounded. For example, the Icelandic experiment is often presented as off-putting, given the magnitude of the restructuring that it required. But this was actually its aim, in the framework of a reform that did not set specific environmental and social objectives, with the good status of stocks being just a way of restoring the profitability of the industry. In other cases, the specificities of the sector have been taken into account, as in Denmark, where miscellaneous provisions (concerning the authorised transfers and the allocation of rights, and through well-managed reserves) have allowed for the successful integration of other objectives, ensuring that overcapacities are eliminated under what are considered to be acceptable conditions.

Nevertheless, their success requires a comprehensive institutional framework. In fact, the implementation of transferable quotas is merely an instrument dedicated to ensuring efficient and sustainable regulation.

Its success depends on the ability to define and ensure the implementation of a multi-annual stock management system and, before then, to guarantee the effectiveness of the regulations. Indeed, the question of monitoring (of captures as well as transfers, in both territorial and extra-territorial waters) is critical, as is shown by the attention paid to these subjects in the Canadian and New Zealand reforms, and the stated goal of monitoring the fishing efforts of "informal" fleets in Chile and Peru. Different studies of the success factors for fishery management even suggest that leadership, the common perceptions of stakeholders, the capacity for self-regulation and monitoring, and the existence of protected areas could be the most important conditions for their sustainability.

Specific ecological pricing mechanisms for the protection of nature and biodiversity

As emphasised by Trommetter and Leriche, the services derived from the operation of ecosystems are often used free of charge, i.e. they have no price and are therefore used at zero cost to the user. This raises the question (cf. Perrings et al., 2009) of how to ensure their inclusion in the management of ecosystems: can we define and implement remuneration for the maintenance of ecosystem services ("beneficiary pays" principle) or a penalty if the service is damaged ("polluter pays" principle)? The attention paid to pollution problems has traditionally led to most of the attention being devoted to the latter problem. However, the former seems just as important in our context. We must also look beyond use values when considering ecosystem services.

Remuneration for ecosystem services

Different management options can often be envisaged, which require a decision to be made: e.g. between developing a site and compensating for it; or not developing a site and benefiting from remuneration for the maintenance of a service. From this perspective, environmental service payments (ESPs) seek to internalise the services rendered by ecosystems in their managers' choices of decisions by providing remuneration for them. They form part of an economic approach, with the managers participating voluntarily and being free to decide whether or not to benefit from the payment mechanisms. However, one of the parties may be public and the demand may also result from public regulations.

In accordance with the above-mentioned approach, ESPs form part of an incentive-based approach, as opposed to regulations which are inflexible and do not encourage the parties to go beyond the norm. They are different from purely voluntary approaches without explicit remuneration and also from other subsidy schemes. They do not have such a clear link to the verified supply of identified services. In this respect, ESPs are a direct component of an approach based on "internalisation" – in this case of the benefits of the ecosystem service provided.

Payment systems for environmental services have several potential sources of financing, which are sometimes combined:

- payment by users of the ecosystem service (e.g. the Vittel mineral water company pays farmers to make sure that their agricultural practices do not affect the quality of the water resource);
- payment by the public authority (e.g. agri-environmental measures);
- payment by operators which are required to offset their impacts (e.g. the Clean Water Act in the United States and the "Bush Tender" programme in Australia).

The rapid development of ESPs usually occurs in the framework of public regulations, with the implementation of a "no net loss" type of obligation and "credit" markets. This is typically the case for schemes implemented in the United States, in the framework of the Clean Water Act and the Endangered Species Act.

The trading of biodiversity credits has thus been possible in the United States since the end of the 1980s, following a provision of the "Clean Water Act" which is intended to protect wetlands, according to which developers or planners that destroy a wetland area are obliged to "create, improve or restore" another wetland area "with similar functions and values", situated in the same basin area. To this end, they often use the services of "compensation banks" which sell credits. These compensation banks are generally private companies that have generated biodiversity credits by restoring damaged ecosystems.

In the 1990s, this mechanism was extended to the conservation of the habitats of endangered species. Investors then created "conservation banks" which obtain their credits by restoring appropriate ecosystems for endangered species or by creating them from scratch. They then sell the credits thus created to developers or planners subject to the requirements of the Endangered Species Act.

The key implementation issues to be resolved are the definition of the services and the possible amalgamation of some of them, the additionality of the services provided that justify the allocation of credits, the valuation of the benefits in order to determine the number of credits allocated, and the scope of use and transferability of the credits, etc.

"Asset management": ecosystem maintenance and resilience services

To implement the "ESPs" and set their amount, we must be able to evaluate the value of the service provided. The development of methodologies for this purpose has been an essential component of research in environmental economics over the last twenty years.

In this way, the services we derive from biodiversity have been more clearly identified, namely: provisioning services (gathering, timber, hunting), regulating services (quality of the land, water, air), and cultural services (beauty of a species or landscape) or links with spirituality. The economic value of these services and the size of the sectors concerned have also appeared to be much higher than we could have imagined. Different summaries of this work, with a view to its implementation, have also been carried out: MEA (Millennium Ecosystem Assessment, 2005), which included a typology of ecosystem services; TEEB (The Economics of Ecosystems and Biodiversity, 2010), which listed the initiatives undertaken on evaluating the cost of biodiversity losses due to current practices; and obviously, Bernard Chevassus-au-Louis' report (2009) on "the economics of biodiversity and of services relating to ecosystems".

The capacity of ecosystems to provide these different services is fragile, however. Under these conditions, biodiversity first of all appears to be useful "for its own sake". This is what is referred to as the "supporting" service: nutrient cycle, soil maintenance and primary production. The efficient operation of the ecosystem depends on the ecological efficiency of this supporting service, on which the standard and quality of the services that can be obtained from biodiversity will depend, or simply the feasibility of the "option" of being able to use its services.

Another particularly important element concerns the resilience of ecosystems. These stability problems and risks of collapse have been studied for around forty years, with the majority of ecosystems having several possible operating regimes: dynamic, chaotic and uncertain for the renewal of species below a certain level of stock (cf. fishery resources); appearance of "blooms" of cyanobacteria in lakes due to phosphorous pollution, with hysteresis phenomena making it difficult to return to oligotrophic status. In particular, one of the topical questions regarding climate change is to assess whether the speeds of adaptation are insufficient in relation to the risks of passing the tipping point (cf. corals, Sahalian-Saharan system, pollinators, etc.).

In this type of context, the instrumentation to be implemented is not limited to the introduction of a single scheme that is deemed to be the most suitable for establishing the price signal; combinations of instruments may be required. This is illustrated by the deliberations concerning environmental responsibility mechanisms, which in the first place concern accidental damage to ecosystems such as oil spills.

In fact, the prevention of accidental pollution events and environmental disasters requires the development of specific regulating instruments, with judicial redress being the instrument that adheres most closely to the requirement of favouring incentive instruments that allow economic agents to choose the most effective measures – except for cases in which complete prohibition would be justified – and to evenly distribute the efforts among these measures.

Environmental responsibility is therefore also an incentive instrument that disciplines high-risk behaviours due to the deterrent effect of legal proceedings when an accident occurs. Indeed, the risk of having to make good any damage and pay compensation encourages prevention, while allowing the agent concerned to choose how this is carried out. Moreover, in relation to the traditional approaches based on regulations and administrative policing, the cost of remediation in the event of an accident is therefore borne by the "polluter" and not by the "community".

For all that, both types of instruments – traditional *ex ante* regulation through standards and inspections, and *ex post* liability through the courts – seem to be complementary in this case, because in the context of environmental damage, legal liability mechanisms must come to terms with several difficulties that reduce their potential effectiveness: the insolvency of polluters in cases of serious accidents; dispersion of damage that does not prompt victims to go to trial; problems in establishing the causes, etc. Under these conditions, each instrument has its pros and cons and it is beneficial to combine them.

In 1980, this led the United States to adopt a specific liability programme for contamination by hazardous substances: CERCLA (Comprehensive Environmental response, Compensation And Liability Act). This establishes no-fault, personal, joint and several liability. In the event of an accident, the principle consists of trying to come to an amicable settlement with the federal Environmental Protection Agency (EPA) rather than go to court. The EPA also manages a fund (Hazardous Substance Superfund) for the decontamination of orphan sites, financed in particular by the civil fines paid by CERCLA offenders.

Voluntary instruments: a stopgap additional measure in response to the insufficient development of ecological prices?

Instruments for differentiating among products and meeting expectations not satisfied by the markets

For many reasons, ecological prices cannot be established on all markets in an optimal manner, especially with regard to nature and biodiversity:

- Rights markets cannot be established everywhere, especially when their monitoring costs are too high. A rights market as for fishing quotas requires the keeping of centralised logs for recording the trading with the maximum security. This condition is a requirement for guaranteeing the integrity of the market and the trust of stakeholders. This type of infrastructure has a fixed cost that cannot be reasonably borne by small markets. Likewise, it must be possible to collect incentive taxation without excessive additional costs for the calculation of the tax bases and collection procedures. However, the tax bases that apply to biodiversity are very often hard to observe.
- Another stumbling block is due to the fact that there may need to be precise distinctions among ecological prices throughout a given territory, because damage to nature depends on the context: a

pollution event does not have the same environmental impact if it occurs far away from areas that are sensitive in terms of their biodiversity. Therefore, ecological taxation, when it actually exists, tends to be implemented at the lowest level, as it covers the general situation, with a reliance on the introduction of standards to address problematic situations.

The stumbling blocks facing ecological prices are partly associated with a lack of information, both for regulators that are seeking to implement them on an intangible basis and for consumers that cannot exercise their powers of discrimination according to preferences for products that have less environmental impact. The implementation of an informative price signal is a possible solution in response to a demand from consumers, by leading to a segmentation of markets.

The method commonly that producers of goods and services commonly use to inform consumers about the quality of a product is quality labelling, in addition to the reputation of a brand. In fact, a high price in itself gives the consumer no guarantee that the product is of higher quality. To gain the consumer's trust and willingness to pay a higher price for a quality product, private or public quality labels are implemented. They give producers an opportunity to segment the market by offering products whose characteristics differ in a recognised manner.

The forms of these types of informative instruments may vary significantly according to particular products and contexts.

Specificities in terms of nature and biodiversity

With regard to biodiversity – as for other environmental characteristics – there are multiple instruments based on information signals:

- labels associated with voluntary commitments: for biodiversity, France has developed these types of labels in line with the National Biodiversity Strategy. They provide recognition for companies and other economic stakeholders that make the effort to conform to the recommendations made in the strategy. This is a voluntary approach that may be rewarded if the commitments are credible and verifiable within the monitoring system established by the public authorities;

- the environmental information displayed on products could include a biodiversity dimension, even if it is currently difficult to evaluate impacts on biodiversity within a life cycle-based approach. This would involve willing producers displaying information about the impact of their products in terms of environmental pressures: greenhouse gas emissions, water consumption, land use, etc. An experiment was conducted in France in 2011 and certain companies have shown that such a scheme is possible at reasonable cost. For all, that the biodiversity dimension is the hardest to gauge for a product. Land use (surface area) can be envisaged as a criterion but it is easy to understand that this is just one aspect – albeit an important one – of the pressures exerted by the production process on nature. This type of issue is therefore still developing, and the European experimentation that is still in progress could provide new information that will help us to make progress in this direction;

- the labelling of financial portfolios and assets is another potential information tool that can help distinguish the environmental quality of different financial products. A green label has recently been created by Novethic (a subsidiary of the French Consignments and Loans Fund). However, there are currently only seven labelled funds. After the Banking and Financial Conference's recommendation in 2014 to work on a new energy and ecological transition label, the Green Economy Committee (Comité de l'économie verte), established in early 2015, will be asked to give its opinion on a labelling project. The nature and biodiversity dimension is, however, still developing, while the climate and greenhouse gas emission dimension is at a more advanced stage.

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Appendix

Instruments	Benefits	Drawbacks	Examples
Standards			
Standards	- easy to understand for economic stakeholders	- threshold effect - static - particularly economically inefficient: does not fully exploit the most economical margins for manoeuvre in order to attain an objective	- prohibition of genetically modified organisms
Ecological prices			
Quota markets	- environmental efficiency - economic efficiency	- pressures on public decision-makers to define a minor constraint	- fishery resource
Environmental service payments	- remuneration of positive externalities associated with agricultural practices that favour the preservation of ecosystem services	- generally high transaction costs	- Vittel contract - agri-environmental measures in the common agricultural policy
Compensation obligation	- encourages stakeholders to find a value for biodiversity		- Crau plain range
Informative signals			
Voluntary commitment label	- differentiate among companies and brands		- National Biodiversity Strategy
Information displayed on products	- differentiate among consumer products	- hard to implement for biodiversity	- European experimentation in progress
Label on financial portfolios	- differentiate among savings products	- hard to implement for biodiversity	- Novethic green label - energy and ecological transition label currently being developed

Institutional and organisational innovations for increasing investment in natural capital

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The investment in the natural capital that biodiversity represents is reflected by actions to protect, improve, restore or create ecosystems. To achieve these investments, it is necessary to overcome high transaction costs induced by the strong *site specificity* and strong *physical specificity* of that capital; it often allows for the production of *non-rival* and *non-exclusive* ecosystem services; it requires the mobilisation of a *high level of human capital* and the consideration of *complex ecological dynamics.*

These are therefore high-risk investments, likely to produce benefits that are difficult to exploit on markets, and for which it is virtually impossible to reallocate the capital in which the investments have been made. Consequently, it seems unlikely that this type of investment will be seen as highly beneficial to the economy. However, several interesting possibilities do exist.

The aim of this chapter is to describe situations in which transaction costs have led to the disappearance of forms of investment in natural capital (ornithological economy), and also to define recent organisational and institutional innovations that have allowed for significant reductions in the transaction costs associated with the implementation of environmental compensation policies and for the initiation of major investments in the restoration of wetlands, with a view to obtaining knowledge and formulating recommendations.

Renewable natural capital[80] (NC) corresponds to all living resources with endogenous reproduction capacities. These capacities may be expressed over long cycles (*e.g.* certain broadleaf tree species and certain coral species) or short cycles (*e.g.* small pelagic fish stocks).
Investments in NC by humans may be interpreted as any actions that aim to maintain or increase the capacities of this resource. Four possible actions are usually defined:

- *protection*, which aims to prohibit or restrict uses of the NC in question (e.g. nature reserves and quotas);
- *improvement*, which aims to increase the quality of the environment in which the NC is situated (reduction of the level of water pollution by installing a waste-water treatment plant, adoption of more selective fishing techniques);
- *restoration*, which corresponds to the process of re-establishing an ecosystem or a population that has been degraded, damaged or destroyed (restoration of formerly canalised river banks);
- *creation* which aims to manufacture or intentionally replace an ecosystem or a population with another ecosystem or population that is considered to have a greater value (creation of artificial reefs at sea that create a hard substrate on which specific fauna and flora can become established, in places where there was formerly a soft substrate and a different animal and plant community).

At the tenth Conference of the Parties to the Convention on Biological Diversity (CDB), held in Nagoya in 2010, one of the strategic targets adopted was the restoration of 15% of the degraded ecosystems on Earth by 2020. Attaining this target requires investments in these ecosystems that public stakeholders will not be able to deliver alone. There is a need to be able to stimulate private investment in the restoration of degraded ecosystems. Consequently, understanding the constraints currently facing these potential investors is important. This chapter examines these constraints and discusses ways of overcoming them.

[80] Conceiving of the ecosystem as a form of renewable natural capital leads us to consider that physical and biological components, of natural origin, generate flows of environmental goods and services (Millennium Ecosystem Assessment, 2005).

We have decided to divide the chapter into three sections:
- The first section is dedicated to describing constraints on investment in NC while highlighting the key role played by transaction costs[81] in guiding investment strategies.
- In the second section, a neo-institutional interpretation of organisational and institutional innovation strategies in the field of agronomy will help us understand the green revolution measured against the yardstick of transaction cost reduction strategies, which in reality have resulted in a great reduction in the diversity of the living world.
- The third section of this chapter covers the example of the development of offsetting measures for wetlands (WL) in the United States with a view to illustrating how it is possible to take account of the characteristics of biodiversity on the basis of organisational and institutional innovations that have been "designed" according to ecological principles.

Constraints on investments in NC

An initial constraint to overcome: the characteristics of renewable natural capital

The first constraint that affects investment in NC, which is well known to environmental economists and extensively covered in the literature, is the public or common nature of goods that will be produced by this NC (conserved landscapes, abundant flora and fauna, quality of coastal waters, etc.) (The Economics of Ecosystem and Biodiversity, 2010). There is also a dual problem of non-exclusivity and non-transferability of the goods produced, which leads to the inability to trade the majority of environmental goods on the market. This makes it impossible for the total amount of investments to be covered at market price. The consequence – if we adopt an individualistic economic form of reasoning – is that everyone wishes to consume public or common goods but no-one has an interest in investing in their maintenance. Indeed, the risk is in being the only party to make this effort and in seeing the other users derive a benefit from an investment in which they have not participated.
There are three types of organisational innovations that can be implemented to overcome the problems associated with the public or common nature of NCs:

- creation of new private rights markets (individual, transferable quotas such as those developed in certain fisheries) so that the producer can benefit from its investments in the NC;
- replacement of the public and planned management of NC by private and commercial management (e.g. creation of natural parks with the adoption of a management plan) in order to mobilise public investment which will allow for the maintenance of a public NC offering goods and services to the entire population;
- facilitation of coordination among stakeholders interested maintaining or increasing CN with a view to promoting common property management and rules of use and access which aim to guarantee that any individuals that benefit from goods and services generated by NC shall make specific investment efforts to ensure its renewal (common property management of forests).

At this point, it is important to emphasise that the returns on investment will not necessarily be evaluated in terms of commercial benefits. The investments made by public stakeholders or local communities may thus lead to non-commercial benefits that can be valued against the yardstick of quality of life improvement criteria such as health indicators or indicators of access to recreational and nature-oriented activities, for example.
Potential solutions do therefore exist in response to the common or public nature of NC.

A second constraint to be overcome: transaction costs concerning investment in natural renewable capital.

The second constraint identified by economists in order to highlight the difficulties relating to investment in NC is the high transaction costs that act as an obstacle to the implementation of the organisational innovations aforementioned. Transaction costs correspond to the costs of gathering information, analysis, time for negotiations involving stakeholders in the transaction, the development of contractual guarantees, and the coordination or monitoring of the performance of the commitments entered into. This second constraint has received less coverage in the economic literature, but we believe it to be essential for explaining much of the lack of investment in NC during the last century and still today.

[81] Transaction costs correspond to the costs of gathering information, analysis, time for negotiations involving stakeholders in the transaction, the development of contractual guarantees, and the coordination or monitoring of the performance of the commitments entered into.

Indeed, creating rights markets, establishing a planned public management system and creating forms of community coordination cannot be ordered from above. These measures require organisational and institutional innovations which give rise to numerous transaction costs. Organisational innovations that are intended to create rights markets, public management or community coordination, can be compared in light of the characteristics of the transaction that they are seeking to implement (in our case, an investment in NC) and of their capacity to reduce the associated transaction costs (Ménard, 2012).

For transactions relating to CN, there are six transaction characteristics to be considered (Scemama et Levrel, 2014).

1) Biophysical specificity

The more complex and diversified the components of the biodiversity represented by the NC, driven by the dynamics of interactions among the different levels of the living world, the more specific this capital can be considered: it would be difficult to redeploy it for any use other than that for which it was originally created. The more specific the NC, the higher the transaction costs to be met. However, it is the highly specific nature of natural ecosystems that allows for the production of a highly diverse range of ecosystem services for the population.

2) Site specificity

This reflects the extremely strong links that exist among the components of biodiversity that form the NC and the natural habitat in which these components are found.

3) Environmental uncertainty

This corresponds to the uncertainty relating to the complex ecological dynamics and the hazard associated with global changes such as climate warming. Environmental uncertainty generates high transaction costs. For example, it is hard to anticipate the expected results of an ecological restoration action in a contract. This requires knowledge and expertise as well as monitoring and demonstration tools that are difficult to mobilise.

4) Institutional uncertainty

This corresponds to the relatively vague, unstable or uncontrolled characteristics of the rules of the game relating to investment in NC. Levels of risks of penalty are a significant component of this uncertainty. Institutional uncertainty generates several major risks: of seeing the rules of the game change over time, which may make the business model associated with the investment made in NC totally obsolete; of observing that the State is unable to enforce compliance with a law that created a business opportunity; of seeing the benefits of certain investment efforts being fraudulently seized by agents that do not run the risk of sanctions.

5) Frequency of exchanges

The more frequently a transaction is repeated, the greater the potential influence on reputation and trust, which will reduce the transaction costs because informal coordination rules can be replaced by more complex formal rules.

6) Specificity of human capital (knowledge and expertise)

A substantial proportion of investment actions in NC require knowledge of the operation of ecosystems and their responses to restoration, protection or improvement actions. They require specific skills in ecological engineering methods that will differ according to the types of ecosystems in question and the contexts in which they are situated. Having to mobilise highly specific knowledge and skills for the investment process once again generates very high transaction costs because human resources that are highly specialised in a certain type of investment will be difficult to redeploy on alternative investments. In order to obtain an increase in private investment in NCs, it is important to bear in mind that creating favourable conditions for these types of investments requires the adoption of innovations that will manipulate one or more of the six characteristics with a view to reducing the transaction costs that potential investors will have to meet.

An illustration of the role of investment costs for investment in NC: history of economic ornithology Transaction costs generated by the complexity of ecological dynamics and by the site and biophysical specificities of this capital caused agricultural science to favour approaches that involve controlling natural variability and reducing the specificity of the assets with which it was concerned. The use of inputs and mechanisation aims to transform complex, non-linear ecological dynamics into linear, controlled dynamics. And the selection of cultivated species reflects the desire to simplify the specificity of NC by focusing on species that are the most productive in the short term. Taking a moment to examine the history of "economic ornithology"[82] allows us to

[82] Economic ornithology: "*The study of birds from the standpoint of dollars and cents. It deals with birds and their relation to agriculture, horticulture, trade and sports; it treats of species important to the farmer, the fruit grower, the game dealer, the milliner, and the sportsman*" (Palmer, 1900, p.259). This discipline can be considered a forerunner of disciplines that focus on the notion of "*ecosystem services*" that is so popular today.

show the potential for the investment choices made in the field of agricultural science to be interpreted from the perspective of transaction costs.

Ornithological economics was very successful between 1870 and 1930 (Kronenberg, 2014). It allowed for the analysis of how birds could be useful for crops through their functions as pest regulators, pollinators and seed transporters, etc. This discipline was so successful that there was an "Ornithological Economics Division" at the *US Department of Agriculture* at the end of the 19th century, which was responsible for encouraging farmers to invest in the protection or restoration of habitats favourable to the proliferation of "useful" bird species with a view to combating pests and increasing crop yields.

Ornithological economics, however, soon ran into implementation problems due to the recommendations made by the American Department of Agriculture. The main problem was that such investment strategies required farmers to possess specific knowledge and expertise in the understanding of ecological dynamics, agricultural practices and developments favourable to the proliferation of these species on their land. This also required the ability to monitor the impacts of restoration, protection or improvement actions on the proliferation of useful birds and on the resulting productivity increases in order to be able to make the necessary adjustment to agricultural practices. All these factors generated numerous transaction costs for farmers. Consequently, although it was technically possible to develop forms of conservation agriculture at the end of the 19th century, transaction costs to be met for their operational implementation seemed enormous to farmers. After the First World War, the use of chemicals in agriculture and the emergence of what would become the "green revolution" in the United States, led to the gradual disappearance of economic ornithology. Indeed, the use of inputs very soon came to be regarded as a much more certain and effective alternative to birds (at least in the short term), as it did not require farmers to have specialised knowledge.

This explains why, between 1915 and 1946, the ratio of scientific publications by the *US Department of agriculture* concerning the use of birds to those concerning the use of pesticides increased from 1:1 to 1:20 (Kronenberg, 2014). The idea of "manipulating" certain natural variabilities – in a spirit of complicity between ecological and agronomic dynamics – in order to improve levels of agricultural productivity, disappeared in favour of a strategy of controlling all agricultural variabilities.

Agronomic approaches did not change throughout the twentieth century. NC was increasingly likened to a stock that needed to be managed at an optimum level and the institutional, organisational and technical innovations designed to guide farmers' investment strategies were created in response to this goal: subsidies encouraging measures to reduce the specificity of the NC, development of public and private bodies dedicated to this task, establishment of a social division of labour specific to the industrial system and an increasing reliance on physico-chemical capital.

In recent years, however, we have been witnessing numerous initiatives that reflect a change of paradigm in the field of agricultural science, both for ecological and economic reasons. However, at a time when conservation agriculture is being mentioned as an alternative to conventional agriculture – through measures such as biological pest control – it seems clear that farmers will be facing the same transaction costs as their 19th century counterparts, when farmers were seeking to optimise their yields through the protection afforded by "useful birds"[83]. Not taking account of these transaction costs means running the risk of increasing the number of "one-off case studies" that will demonstrate the full agronomic potential of these new practical measures but with limited operational scope when it is necessary to transmit these measures to agricultural "practitioners".

An example of organisational and institutional innovations that have allowed for increased investments in NC while taking account of its specificity: compensatory measures for wetlands in the United States

For a long time, wetlands (WL) were perceived as being a useless habitat (compared to forests, for example), and at worst were considered to be a source of negative impacts for the population (e.g. diseases transmitted by mosquitoes).

In the United States, the recognition of WL as NC coincided with the creation of regulatory frameworks that were designed to protect them: the *Rivers and Harbors Act* of 1899, the *Fish and Wildlife Coordination Act* of 1939, the *Federal Water Pollution Control Act* (1972) and the *Clean Water Act* (CWA) (1977). Through this series of institutional innovations, WL were given the status of public goods by the federal State, which justified the investment actions in this NC.

[83] However, we can count on the fact that the number of techniques available for collecting and processing information about ecological interactions has significantly increased over the last century and this could consequently reduce a substantial proportion of the transaction costs.

Section 404 of the CWA clearly mentions which types of investments must be made in this NC by stipulating that any impact on a WL generated by a development project must be avoided, reduced and offset (ARO sequence)[84]. This section thus creates an obligation for private investment in protection, conservation, improvement and creation actions, which will be beneficial to the maintenance of an NC of a public nature. The only return on investment for a private investor is to obtain planning permission to build on a wetland area. The developer's entire strategy will obviously be guided by the aim of obtaining this authorisation at the lowest cost, and all the more so as the risk of penalty will be low.

However, there is a low risk of penalty due to the characteristics of the transaction: the Act is written in terms that leave great freedom of interpretation to the agents responsible for its implementation (high level of institutional uncertainty), the ecological objectives and equivalence criteria for the compensatory measure are not clearly mentioned (low biophysical specificity) and the only reasonably stable criterion seems to be the proximity of the compensatory measure and the area of impact (high level of site specificity). Finally, the frequency of the transaction between the regulator and the developer usually boils down to an exchange between the regulator – a member of the *US Army Corps of Engineers* (USACE) – and the "developer".

This situation generates high transaction costs for the user, because institutional uncertainty and the low transaction frequency create an information imbalance that favours the developer which can easily use it in a strategic manner. In this context, it would be logical for the regulator to refuse the transaction on grounds of certainly having more to lose than to gain. But the regulator is clearly not like any other economic stakeholder. It is a public stakeholder that must make decisions to ensure that the transaction is in the public interest. Yet the transaction that the USACE enters into with the developer includes both the compensation project and the development project. It must therefore take account of the benefit of the development project for the population.

In such a context, it seems counter-productive to place the regulator in a situation in which it has only two options: accept or refuse a transaction that relates to an economic issue and an environmental objective at the same time. In this situation, stubbornly resisting projects that generate wealth and employment for the region would appear to be difficult, especially in times of economic crisis. This is especially true when there are gaps in the information required to make this decision, when the rules for justifying this choice are incomplete and when there is no opportunity to learn from the repetition of the transaction with the developer. That is why whenever investments – even moderate ones – have been made in the form of compensatory measures close to the affected sites, the regulator has rarely been in a position to be able to refuse an application for planning permission. Developers have thus had complete freedom to adopt investment strategies guided by the minimisation of costs.

Transactions concerning compensatory measures have increased very significantly but to the detriment of the biophysical specificity of WL. Between 1974 and 1984, average losses of 135,000 ha of WL per year were still being observed in the United States despite the legal protection that theoretically covered this type of ecosystem (Dahl, 2011). The failure of this public policy was acknowledged firstly by scientists and then by the American audit authority with the publication of a report whose title left no doubt as to the origin of the problem (Government Accountability Office, 2005): *"Wetlands Protection. Corps of Engineers Does Not Have an Effective Oversight Approach to Ensure That Compensatory Mitigation Is Occurring"*.

This prompted USACE to propose organisational and institutional innovations that aim at developing a hybrid regulatory system, combining commercial and hierarchical characteristics for WL compensation in the United States.

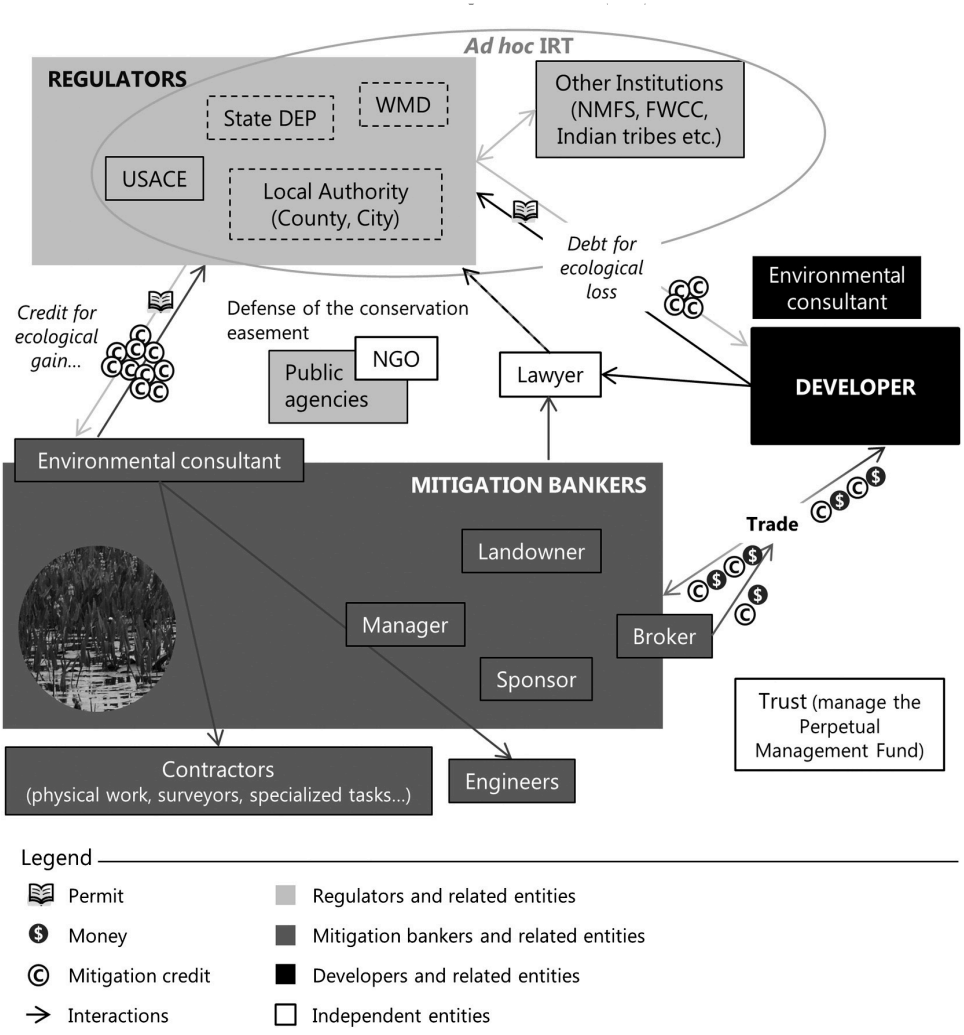
Organisational innovations for creating a transaction specifically dedicated to investment in NC

The system of mitigation banking

One of the recommendations of the report of the US court of auditors was to rethink the system of compensation for WL based on an organisational form that already existed but was seldom used at the time of the report's publication: the system of "mitigation banks"). This consists in incorporating a third party into the regulatory system that will allow for the separation of transactions relating to development projects, on the one hand, and transactions relating to investment projects in the restoration of WL, on the other (figure 1).

[84] The principle is that once the avoidance and reduction stages have been completed, there will still be what are referred to as "*residual*" losses of WL that will need to be offset through investments in WL near the affected sites. The aim is to obtain gains that are equal to these losses through these compensatory actions.

Figure 1: Interactions between stakeholders in the MB system (Vaissière and Levrel, 2015, p.83)



The mitigation bank (MB) corresponds to a system involving the pooling of compensatory actions for the purpose of investing in major reserves of NC, with the responsibility for the implemented actions being concentrated in a small group of stakeholders. It is used to designate both the place in which the ecological restoration is carried out, and the organisational form that implements the investment.

MBs must justify the effectiveness of investment actions to the authorities in order to be eligible to receive mitigation credits[85]. These credits are then sold by MBs to developers that have caused damage or destruction through development projects. The sales take place on a market whose geographical extent is dictated by boundaries corresponding to an ecosystem unit (sub-basin area covering an average area of 1,500 km^2).

The first positive point of this system is to allow for a change in the regulator's position.

With this system, there is indeed a transaction between the regulator and the MB that is specifically dedicated to investment in WL restoration. This is a much more comfortable position for the regulator as the MB will derive profits from its restoration actions. The regulator can therefore easily refuse the transaction if it considers that the project is not strong enough with regard to the anticipated ecological gains. Furthermore, in contrast to the standard permit system, the regulator does not have to take account of the development and mitigation project simultaneously, in which the ecological investment amounts to nothing more than a constraint and any refusal of a transaction corresponds to the stoppage of a development project that will create revenues and jobs.

[85] By granting mitigation credits on the basis of the observed ecological gains, it is agreed that the restoration will come into effect prior to the occurrence of the impacts, which will prevent cases of temporary ecological losses. It should, however be noted that the credits are "*released*" in stages, and that a proportion of them can be sold provided that certain legal guarantees have been adopted: application of a conservation easement, adoption of a long-term management fund and of an insurance fund (Robertson and Hayden, 2008).

The transaction with the developer corresponds to an ecological debt that can only be paid off by acquiring credits from BCs. If the developer lacks the means to purchase credits, it can resort to avoidance or reduction actions, or must abandon its project. If the regulator can adopt a firm stance vis-à-vis the developers it is because, in contrast to the standard permit system, authorising development projects accompanied by low-quality compensatory measures amounts to reducing the sales opportunities for MBs. Indeed, there is a strong correlation between the transaction carried out with the MB and the transaction carried out with the developer. The levels of ecological debts that the developer must settle before being able to obtain its permit are the source of the level of the demand for credits on the mitigation market. If the regulator is too flexible, the quantity and/or the price of the credits fall on the market and the MBs logically see a drop in profits. However, this new economic sector represented by the MBs is also a source of wealth and employment. The strict application of the environmental policy in terms of compensation for WL is no longer just a constraint for the economic development of a region, it is also a source of development for a new business sector. And this is what has led the MB lobby (the *National Mitigation Banking Association*) to launch several legal proceedings against US government in recent years for its failure to apply the law on compensatory measures.

In such a context, the regulator is operating in a less hostile socio-political and economic environment, removing the accusation of hindering economic growth in a region. The regulator may also be more demanding in terms of environmental compensation, as this requirement is a source of development for a new economic sector.

The second positive point associated with the MB system is that the pooling of mitigation actions leads to the concentration of responsibilities for investments in WL and thus facilitates the regulator's control over them. This also leads to an increase in the frequency of transactions, which has impacts (good and bad) on the reputation of MBs, and has learning effects for the regulator which has to cope with far fewer situations in which it is hampered by information imbalances. Finally, by increasing the size of the restored areas and their connectivity with other WL, an improvement in ecological efficiency can be observed. It has indeed been shown that the success rate for WL restoration actions increases very significantly for larger areas (100% above 100 hectares) (Moreno-Mateos et al. 2012), hence a decrease in environmental uncertainty.

A hybrid rather than commercial system

The MB system immediately brings to mind an approach based on market regulation, with the externalisation of compensation tasks. However, this conception can be tempered to a significant extent.

From the perspective of investors in NC, the creation of MBs corresponds to an organisational innovation underpinned by a strategy of both externalising and internalising ecological restoration tasks. The externalisation strategy is linked to the fact that a new channel for investment in NC is being created. The internalisation approach is linked to the replacement of a multitude of small investment projects – carried out by applicants for permits – with large WL restoration projects (figure 1).

For the regulator, this regulatory system has been accompanied by innovation that tends to be based on the externalisation and specialisation of tasks.

The assessment of the ecological gains generated by compensation actions is now carried out by an independent body, the *Interagency Review Team* (IRT). This is a group of assessors whose role, in the general interest, is to defend the ecological equivalence associated with compensatory measures. It consists of members of State and federal environmental agencies, local authorities and representatives of special interest groups such as tribes. The IRT assesses applications for the creation of an MB and the amount of credits that can be granted to this bank in view of the estimated ecological gains. It finally defines the sequence for issuing these credits in view of ecological performance indicators that will demonstrate the gains obtained. USACE no longer has to make a decision to accept or refuse a development project (with the associated compensation), on the basis of its own assessment. It now only has to mention a quantitative conditionality subject to the permit being granted, based on the recommendations made by an independent body. Once again, this is a more comfortable position for the regulator in relation to the standard organisational form.

The long-term management of the compensated sites will be guaranteed by the adoption of conservation easements[86] on the land used and by handing over this management to a local environmental NGO once the management plan associated with the compensation project is finished and the ecological gains mentioned in this project have been demonstrated. Moreover, this NGO will benefit from financial resources for the long-term management of the site through the creation of a management fund and being allowed to collect interest on the latter.

[86] A conservation easement is a legal tool that assigns a perpetual environmental function to the beneficiary site, including in the event of a change of ownership. The owner thus definitively relinquishes any right of use that would have a negative impact on the land, or indeed any use whatsoever.

It consequently seems to us that the MB system cannot be considered to be a market instrument in the strict sense of the term. It rather appears to be a hybrid form (figure 1) that combines commercial, hierarchical and community characteristics (Scemama and Levrel, 2014; Vaissière and Levrel, 2015). There is therefore a mixture of commercial management (concerning the trading of credits), public management (based in particular on spatial planning with a view to ecological consistency) and a collaborative approach involving public stakeholders (USACE and IRT), economic stakeholders (MBs) and citizens (environmental NGOs).

Institutional innovations to reduce the uncertainty surrounding transactions and increase levels of human capital while maintaining the specificity of the natural capital

Following the criticisms made by the US Court of audit, the administrations in charge of the ARO sequence published a document in 2008 that set out to stabilise the rules concerning compensatory measures for WL, entitled "*Final rule on compensation for WL losses*" (USACE and *US Environmental Protection Agency*, 2008). The Final Rule is a 113-page document explaining the entire process leading to the creation of an MB for WL in perpetuity. It is mainly based on the *mitigation bank instrument* – a contract that governs the life of each American MB – in which each stage of compensation is described in order to optimise the regulation of this activity (Hassan, 2015).

At the same time as the creation of new rules, information systems were also developed by the State with a view to organising and facilitating access to knowledge for the stakeholders. These innovations can be summarised in the form of three new information systems.

- The first innovation concerns efforts to standardise the ecological equivalence calculation system[87], which can be used to compare projects on the basis of functional indicators (hydrological and ecological dynamics) and structural indicators (composition and abundance of species).
- The second innovation is the adoption of standardised monitoring protocols for the results of ecological restoration that will justify the granting of compensatory credits. The results must be demonstrated on the basis of specific indicators as mentioned in table 1.
- The third innovation is the creation of an online database named RIBITS (*Regulatory In-Lieu Fee and Bank Information Tracking System*[88]), which contains all of the information about MBs on US territory: location, available compensatory credits and service areas corresponding to the limits of the credit markets.

These three new information systems have helped reducing institutional uncertainty by limiting situations with information imbalances. This has also led to the pooling of knowledge about biophysical and site specificities with a view to increasing the levels of human capital dedicated to investment in WL restoration.

All these elements have reduced the levels of transaction costs and thus facilitated the development of transactions associated with the MB system. An increase in the number of BCs and in the production of compensatory credits corresponding to investments in the ecological restoration of WL can thus be observed (figure 2).

The turnover of the WL compensation market in the United States today currently amounts to around €2 billion for 10,000 hectares of WL restored per year (in compensation for 7,500 ha. destroyed) (Madsen et al. (2010, 2011).

But what particularly interests us in this chapter is to find out whether these institutional innovations have been designed to conform to the biophysical and site specificities of the NC, and whether the uncertainties (environmental and institutional) associated with the key long-term issues have been taken into account.

In view of the information mentioned in table 1, it seems that the institutional innovations do not detract from the specificity of the WL. Although this regulation system has certainly not resolved the entire question of the implementation of WL compensation, it seems to have nonetheless helped improving the effectiveness of this public policy (Van Teeffelen et al. 2014). An indication that MBs for WL may be more ecologically efficient is that 69% of investment in the NC is based on restoration actions, whereas this percentage drops to 42% if we consider all compensatory measures (thus including the investments made on the basis of standard public permits) (Scemama et al. 2015; Madsen et al. 2011). And restoration is considered to be the best form of investment in natural capital by far, compared to improvement, conservation or creation actions (NRC, 2001; GAO, 2005).

[87] For example UMAM (*Unified Mitigation Assessment Method*) is the name of the method that was implemented in Florida.
[88] https://ribits.usace.army.mil/ribits_apex/f?p=107:2

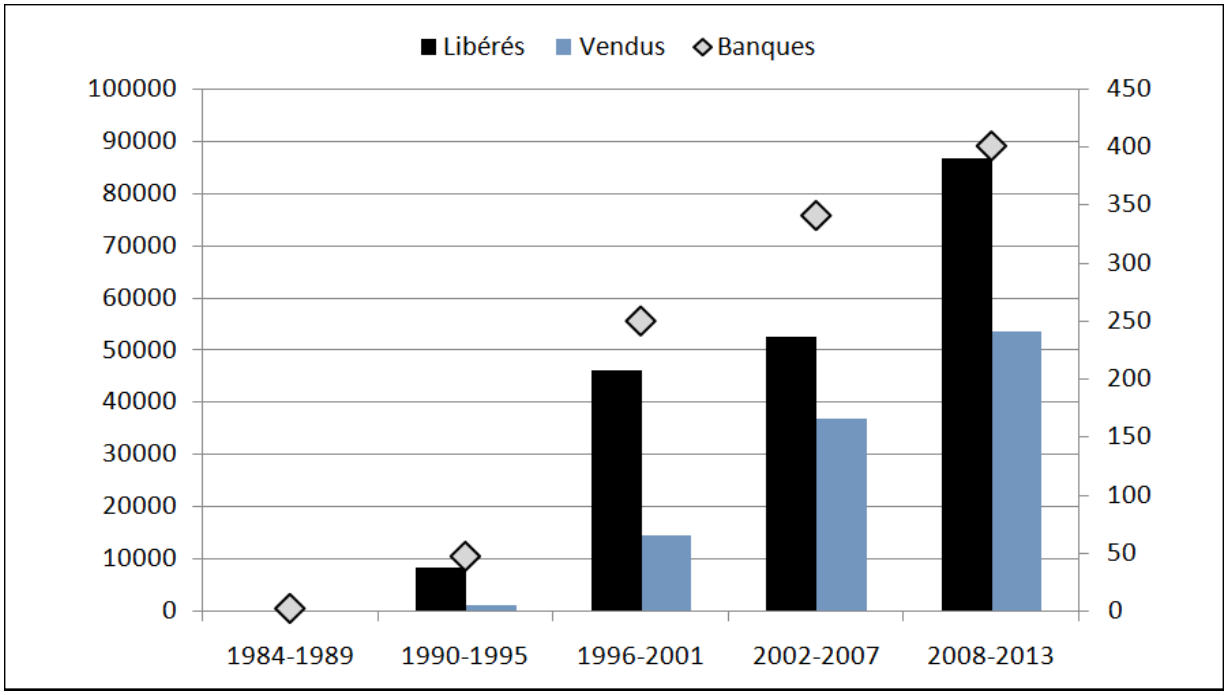
Table 1: Description of how institutional rules conform to the characteristics of transactions

Characteristics of transactions that are sources of transaction costs	Nature of the risks relating to the quest for lower transaction costs	Institutional innovations of the MB system for limiting these risks
Site specificity	Risk of ecological restoration zones being situated a long way from the impacted areas	The credits granted to MBs can only be sold within a service area whose boundaries correspond to the hydrological limits of the zone (average of 1,500 km^2 in the United States). The credits assigned to investment actions in NC will be higher when they take place in close proximity to areas of urban sprawl and on sites that have suffered from significant ecological damage (e.g. urban wasteland).
Biophysical specificity	Risk of reducing biological diversity by being too flexible in considering the ecological equivalences between impacted areas and restored areas	There are as many mitigation credit markets as there are types of WL (there are thirty or so different credits for WL) and the size of the markets is restricted to the service area. The districts recommend the use of standardised tools for calculating equivalences, with the adoption of an increasingly functional approach to equivalence (example of UMAM in Florida).Credits are procured on the basis of clear performance criteria (e.g. hydrological conditions, floristic value index, multi-annual growth of native species, plant cover index, abundance of invasive species, etc.).
Environmental uncertainties	Biodiversity pays the cost of the failure of an NC investment project	The ecological effects must be demonstrated before credits are granted (except those given for compliance with legal guarantees). The risks of failing to achieve the targets must be covered by a guarantee fund that will be released in favour of the State for the management of the ecosystem in which the investment was initiated. In the event of the collapse of an MB, credits that have not already been released will not be made available but the perpetual environmental easement will be maintained.
Institutional uncertainties	Lack of long-term management Lack of legal guarantee for the transfer of property rights	Obligation to apply a perpetual environmental easement to the acquired sites. Obligation to create a management fund which will generate an annual interest rate that must cover the budgets for the long-term management of the site that is transferred to a local environmental NGO. The bankruptcy risks of investors must be covered by a guarantee fund that will be released in favour of the State for the management of the ecosystem in which the investment was initiated.

An argument that seems to partly undermine the credibility of the investment bank system is that it could facilitate compensation and thus lead to an increase in the number of authorisations to destroy wetlands. The USACE's rejection of applications to destroy wetlands did indeed seem to drop slightly between 2009 and 2013 but these rates are in any case very low, fluctuating between 2.6% in 2009, 1.2% in 2011 and 1.6% in 2013 (figure 3). Therefore, there would not appear to have been a change from a regulation system in which destruction permits were refused, to a system in which permits are granted in favour of an increase in the number of compensation banks.

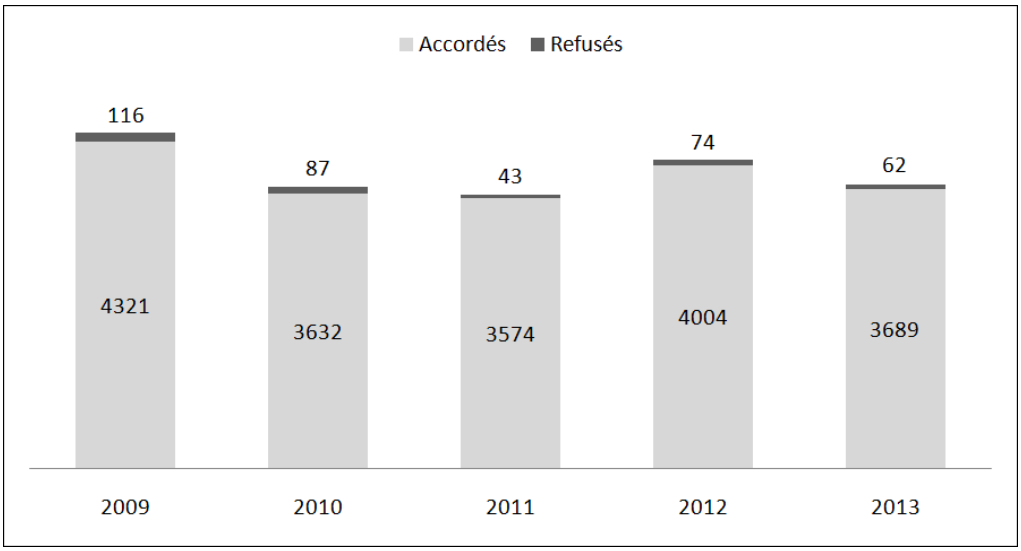
Other factors point towards an improvement in the situation. Today, the rate of wetland losses is only 5,000 ha/year in the United States (Dahl, 2011) and 98.7% of the mitigation banks are said to conform to the ecological performance criteria stipulated by the administration (Denisoff and Urban, 2012). Moreover, it has been observed that the rising prices of mitigation credits have clearly led to changes in the opportunity costs associated with land uses, especially in Florida. The distances between the mitigation site and the impacted site have been estimated at around twenty kilometres, on average.

Figure 2: Changes in the number of MBs and in the total quantity of credits released and sold over time



Source: Scemama et al. 2015).

Figure 3: Number of permits to destroy wetlands granted and refused



Conclusion

This history of the last 100 years of institutional and organisational innovations, whose aim has been to reduce the transaction costs to be met by investors in NC, is based on reducing the specificity of natural assets with a view to facilitating commercial exchanges.

One of the questions arising today is to find out how it is possible to create organisational and institutional innovations that provide incentives to invest in NC under the constraint of maintaining the specificity of the living world and taking into account environmental uncertainties. Indeed, there is a fundamental incompatibility between the desire to increase the number of transactions concerning investment in NC and the aim of maintaining the specificity of this NC. Consequently, the more specific the NC, the higher the transaction costs

and the more difficult it will be to increase the number of transactions. However, the main aim of this chapter was to highlight the fact that the transaction costs are not solely related to the specificity of the NC and that it thus seems possible to increase the level of the transactions corresponding to investment in the NC without sacrificing its specificity.

Our analysis thus allows us to emphasise that it seems possible to make institutional innovations – which are intended to increase investment in NC – conform to the biophysical and site specificity of the NC. However, this is not possible unless the "additional transaction costs" generated by the consideration of this dual specificity are offset by the reduction of the transaction costs associated with the other specificities of the transaction, i.e. the frequency of transactions, the institutional uncertainty and the level of human capital to be mobilised. The institutional innovations could thus have the following objectives:

- increase the frequency of transactions between the regulator and the investor in the NC;
- reduce the institutional uncertainty by strengthening the rules of the game and monitoring them;
- reduce the levels of human capital to be mobilised in the regulation system by implementing standardised and free-access information systems.

The example of the MB system for WL in the United States has allowed us to illustrate how such innovations can be expressed in concrete terms:

- the concentration of responsibilities for the implementation of compensation for WL in a smaller number of stakeholders facilitates the monitoring and increases the *frequency* of the transactions while pooling investment actions in ecological restoration – a source of greater environmental efficiency for projects;
- the stabilisation of the rules through the Final Rule scheme allows for the mobilisation of legal (environmental easements), insurance (insurance fund), financial (long-term management fund) and technical (monitoring and calculation of equivalence) tools that will eventually allow the *rules of the game* to conform to the *specificities of the NC* and the *environmental uncertainty* while reducing the *institutional uncertainty* for potential investors;
- the creation of easily accessible information tools has made the regulation system more transparent and the expected ecological objectives more standardised, which has led to a further reduction of the *institutional uncertainties*, as well as reducing the need for investment in *human capital* for private operators.

One factor that explains the relative success of mitigation banks thus seems to be that institutional innovations introduced in response to the criticisms of the American audit authority have been "designed" on the basis of hydrological constraints: the market boundaries are defined according to hydrological constraints, the private property rights on natural assets are transferred into the public domain according to the environmental easement principle, and the long-term management dynamic and adaptation processes inherent to this dynamic are budgeted for. To our knowledge, this is the only example in the field of unexploited natural, which makes it a completely original case study.

However, it very soon becomes apparent that this mitigation bank system is only applicable to NC with a relatively limited degree of specificity. The thirty or so types of credits for ZH thus need to be put into perspective with the thousand or so types of credits that exist for the MB system for endangered species in the United States in the framework of the *Endangered Species Act*. The mitigation "market" for endangered species, which was created at approximately the same time as the WL market, is therefore much smaller (turnover of approximately €200 million per year and protected areas equivalent to 1,800 ha/year), reflecting the high transaction costs relating to the specificity of the asset concerned.

It should also be emphasised that the economic and ecological performance of a regulation system in no way guarantees its social legitimacy. The example of the mitigation bank system for WL in the USA is a perfect illustration of this. This regulation system, which is seemingly more ecologically and economically efficient that the standard permit system, may appear to be inappropriate for questions relating to territorial (spatial redistribution of the NC through the MB system) and ethical dynamics (are the compensation and the project that gave rise to it socially acceptable?) or distributive fairness (who wins and who loses in these spatial dynamics?).

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Businesses and natural capital: risks, opportunities and driving forces of action

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The degradation of biodiversity – the concept underlying our natural capital – covers a series of questions relating to the disappearance of species, the destruction and deterioration of natural areas, the rationalisation of ecosystems for productive purposes, the interruption of ecological continuities and the reduction of genetic diversity. Evaluating the cause-effect relationships is not a simple matter. However, the consequences of this degradation have clearly discernible impacts on human well-being. As key stakeholders in the economy and society, companies are at the forefront of these issues, in terms of the impacts and also in view of their dependencies on ecosystems, which are recent considerations. The rationale for their operation requires a demonstration of the possible bases for the action with a view to managing the risks and seizing opportunities relating to markets, costs, regulations and the financing conditions. Nevertheless, only approaches that combine regulation and innovation in companies can take the wide range of values of biodiversity into consideration.

Although the principles of corporate and social responsibility are now officially incorporated into French law and standardised at the international level, the corporate world still varies in the importance it attaches to biodiversity-related issues. Certain companies have been actively engaged in this field for decades, while others still have little understanding of the issues, which are sometimes perceived as being just another constraint in a difficult economic context. However, due to their central role in economic development, their financing and innovation capacity and the size of the pressures they exert on ecosystems, either directly or indirectly, the private sector is a key player in ecological transition, which must establish a new development model that takes into account all of the impacts and dependencies of economic activities in relation to ecosystems. The complexity of biodiversity and ecosystem concepts, whose definitions convey a language and way of thinking that sometimes bear no relation to corporate issues, does not seem to facilitate dialogue or pedagogy. In this case, dynamics of the living world, territories and interactions are the watchwords. Contrary to the climate issue in which a single accounting unit is available, biodiversity can only be measured by a range of diversified biophysical and socio-economic indicators, which are necessarily adaptable. But this should not overshadow the benefits of actions carried out by companies or prevent them from implementing concrete projects. Firstly because this is consistent: biodiversity is not just any ordinary environmental consideration. Quite the contrary, this living fabric of the planet (Barbault, 1997) is at the crossroads of the most essential economic and environmental issues for companies, such as coping with the growing scarcity of natural resources, managing water, combating and adapting to climate change, overcoming energy dependence and managing supply chains. And secondly because it is possible. Even if the complexity of living systems make the idea of being able to control everything completely unrealistic, means of action do exist. The idea of companies having to come to terms with nature rather than damage it is gradually taking form.

Indeed, the recent notions of natural capital and ecosystem services allow for the establishment of a conceptual and semantic link between the two worlds of economics and ecology. They form the basis of the thinking about the biophysical and economic evaluation of ecosystems, which allows the stakeholders – including private operators – to measure their interdependencies with biodiversity. This is a first although insufficient step towards taking action. These evaluations must therefore be covered by socially accepted standards and be oriented towards operational objectives in order to make them truly pertinent and usable by private stakeholders in space and time. The notion of natural capital and its appropriation by companies are also central to the debates concerning innovative instruments for biodiversity conservation, such as environmental conservationbiodiversity offsets and payments for environmental services. These instruments, which are crudely considered to be market-based instruments, allow for the financing and implementation of actions that take account of the values of biodiversity (economic or otherwise), and can provide genuine added ecological value in the field, while being sources of both risks and opportunities for companies. However, their mobilisation requires clear, sustainable and applicable public policies, which are both coercive

and incentive measures, acknowledging the potential role of private stakeholders in the conservation of biodiversity while guiding and regulating their approach. As biodiversity is hard to reconcile with simple ideas, only a combination of public and private actions and the creation of natural capital governance regimes that combine regulation, public policies and corporate innovation are capable of achieving sustainable solutions focusing on the quest for genuinely green growth.

I. Context and key issues

– Companies and biodiversity: from the identification of impacts to the management of interdependencies

For many years, companies viewed the environment from the perspective of its role as a supplier of raw materials, water and energy – resources once considered to be cheap and abundant – or in terms of the regulatory constraints relating to certain environmental impacts. In this context, the link between natural resources and the ecosystems from which they are derived was never clearly apparent. It was only in the early 1990s that the premises of a change in the private sector's position on the environment began to emerge, in the wake of international environmental agreements and the widespread implementation of corporate social responsibility, followed by corporate social responsibility. A real turning point in private stakeholders' perceptions of biodiversity occurred with the publication of the results of the Millennium Ecosystem Assessment in 2005 and the TEEB in 2008. These projects – each adopting specific approaches – proposed a common framework of analysis and action regarding ecosystems and the services humans obtain from nature. While the subject still remains complex and quite poorly understood by many company directors, the dependency of the majority of economic activities on ecosystems is now explicitly acknowledged by the use of the notion of ecosystem services. This notion makes it possible to take account of the social value of ecological functions. In addition to revealing the environmental impacts of economic sectors and the associated externalities which are covered by numerous studies[1], dependency on ecosystem services is becoming a strategic issue with tangible commercial and financial consequences for companies. Methodologies are emerging for identifying, evaluating, managing and reporting on companies' relationships with biodiversity and ecosystem services. These initiatives are institutional (CBD Global Platform on Business and Biodiversity, EU Business and Biodiversity Platform, etc.), introduced by civil society (WBSCD, WRI, BSR, Cambridge Natural Capital Leaders Platform, etc.) or involve multiple partners (Natural Capital Coalition, etc.). Their aims may include sharing the lessons learned from the best practices for measuring and integrating natural capital into decision-making, as well as campaigning for a certain standardisation of the associated tools and methods for companies. Similar work has also been carried out in the WRI and WBCSD greenhouse gas protocol, which defines internationally recognised standards for public and private organisations (Carbon Balance in France). These diverse initiatives aim to arouse the corporate sector's interest in taking account of natural capital by increasing the relevance and strength of approaches based on the valuation of ecosystem services, in such a way as to improve the perception of their added value from the corporate standpoint in relation to the tools and strategies that are traditionally used for environmental management and for managing the value chain, such as Life-Cycle Analysis.

– A growing social demand

This change in the understanding of private stakeholders' relationships with ecosystems coincides with a change in consumers' and citizens' preferences regarding nature. According to a CREDOC (French research centre for the analysis and observation of living conditions) study in 2013, 93% of French people stated that they were at least quite sensitive to the environment in general (second-highest level of sensitivity attained in the past 10 years). 62% declared that they knew what biodiversity is (+3 points compared to 2010), whereas 35% stated that damage to biodiversity has already had an impact on their daily lives (a 7-point increase since 2010). Originating from the general public's increasingly acute awareness of environmental issues and also helping to develop it, eco-labelling and environmental certification schemes are proliferating in many sectors, from agriculture, forestry and fishing to tourism and construction. The associated markets are growing fast. In the fishing sector, MSC (Marine Stewardship Council)-certified seafood products accounted for 10% of the total wild catches in 2014. "Chain of Custody" certification, which is mandatory for companies in each link of the value chain of MSC products in order to ensure their traceability, is held by companies based in 64 countries, and the labelled products are available in 102 countries (compared to 41 and 79 respectively in 2010) (MSC, 2014). In organic agriculture, the labelled utilised agricultural areas have now exceeded one million acres in France (Agence Bio, 2013). They have increased nine-fold in 20 years. There are now twenty

times more organically certified processing and distribution companies than there were 10 years ago. The total expenditure on organic products for consumption in 2012 amounted to €2 billion, with French products accounting for 3/4 of this total, on a market that has quadrupled in value since 1999.

These changes in production and consumption modes, which develop and strengthen one another, prompt us to rethink the ways in which private stakeholders, by seeking to satisfy their own interests and in response to this new social demand, can participate in the conservation of natural capital and in its financing.

– **Innovative biodiversity conservation funding mechanisms**

Coinciding with this growing appropriation of the key natural capital-related issues by companies, the rise in innovative financing schemes for the conservation of biodiversity, which was initially an international phenomenon, is now developing at all levels of governance and research. This phenomenon is occurring in a context of shortfalls in the available budgets derived from traditional tax revenues in response to the financing needs for international strategies and action plans for the conservation of biodiversity and the sustainable use of the associated resources. Consequently, a number of schemes or instruments, whether designed to mobilise additional financial resources or reduce the future conservation needs through changes in stakeholders' behaviours (Fetiveau et al. 2014), place the private sector at the heart of the deliberations concerning their creation, implementation or, quite simply, their financing. But the heterogeneity of instruments generally described as being innovative prevents any generalisation, as the majority of them are implemented via governance and financing schemes involving both the public and private sectors. Economic instruments are considered to be innovative if they allow for:

- the allocation of a cost or a benefit to the destruction or enhancement of biodiversity and/or ecosystem services respectively, thus prompting stakeholders to internalise their externalities that were previously not accounted for. In short, these instruments seek to create a price signal that will generate changes in the stakeholders' behaviours. This is the incentive principle that underlies biodiversity offsetsenvironmental compensation ("polluter pays" principle) and environmental service paymentspayments for environmental services ("beneficiary pays" principle). For all that, this price signal is not intended to reflect the economic value of biodiversity or of ecosystem services.

- or the introduction of a principle of eco-conditionality into the existing policies or projects. In this category, we find certification/labelling mechanisms, co-benefits in terms of biodiversity for climate finance (introduction of "biodiversity" performance criteria into the REDD mechanism, taxation of CO_2 emissions and implementation of adjustment mechanisms at borders), and the earmarking of financial sector investments for economic activities in favour of biodiversity.

II. From awareness to measuring the impact of natural capital on the business of companies

1 Why take action?

On the basis of the observation that the majority of economic sectors affect and depend on ecosystems, the interrelationships between companies and biodiversity generate risks and opportunities which, in the stakeholders' own interest, need to be identified, measured and then accordingly managed/exploited. The risks, regardless of their nature, mainly concern the failure to take account of biodiversity in corporate strategies, projects and production methods. The opportunities relating to biodiversity, however, cannot be reduced to a simple risk-reduction policy, but assume the implementation of more proactive approaches based on the adoption of natural solutions to provide the impetus for the creation of value, or in response to the social demand for nature expressed by consumers. Several distinct but intrinsically interrelated categories of risks and opportunities, may be revealed for companies, such as:

– Market risks and opportunities. A company's failure to take account of biodiversity may lead to a drop in earnings, a loss of market shares and/or of access to certain markets and vice versa. Taking the cosmetic industry as an example, the French market for natural and organic cosmetics increased at an annual rate of approximately 25% between 2005 and 2011, compared to growth of 4% for conventional cosmetics (Deloitte, 2012). Although this growth slowed down somewhat thereafter, the market still amounted to €395 million in 2013 (COSMEBIO, 2014), even if the total share of the organic segment of the cosmetic market remained small (approximately 3%);

- Cost-related risks and opportunities. The failure to take account of biodiversity may lead to higher production costs, losses of productivity or breaks in the supply chain, thus jeopardising the competitiveness of companies. In France, for example, the sector covering the protection of drinking water abstraction points and the distribution of water incurs substantial costs relating to diffuse pollution sources (nitrates and pesticides). In reality, even beyond the source of the pressures generated by anthropic inputs, the increase in treatment costs may be due to factors such as the destruction of upstream buffer zones (grass strips and green ditches, etc.) which normally help to reduce runoff containing agricultural inputs, and/or to the deterioration of the hydromorphological conditions of rivers, which reduce the self-purification capacities of environments. Indeed, the diversification of flow facies, meanders and the presence of riparian vegetation are essential factors which increase the self-purification capacity of rivers, and thus eventually reduce the downstream treatment costs required. Conversely, the integration of biodiversity considerations into corporate production modes may secure supplies of high-quality raw materials and reduce costs. In agriculture, while the economic impact of conservation agriculture approaches and techniques, based on natural processes and biodiversity, varies according to farming systems – in large-scale arable farming for example – the drop in operating expenses due to the reduced use of fertilisers and crop protection products can, in certain cases, offset, or more than offset, the drop in yields, thus maintaining or improving the gross margins of farms in comparison to conventional systems (INRA, 2013);
- Risks/opportunities in relation to image and reputation. The failure of companies to incorporate biodiversity-related issues is likely to generate risks of impacting their image and reputation as perceived by different stakeholders such as clients and suppliers but also financiers, public bodies and civil society in the broadest sense (associations, etc.). In a world in which information is accessible from anywhere and at any time, particularly via social networks, there are abundant examples of companies being subjected to denunciation campaigns conducted by civil society, as is the case for the Lego and Shell groups targeted by Greenpeace in 2014, and the giant IKEA, which was criticised for the shortcomings of its CSR policy by Oxfam in 2006. Another case in point concerns the global paper group Asia Pulp and Paper, a supplier of paper and packaging that, according to certain NGOs such as Greenpeace, is partly produced using illegal timber, to and were bought by companies including Kraft, Nestlé, Adidas, Mattel and Danone, which, since the revelations, have stopped their procurements from this operator and promised to implement policies to combat deforestation in their supply chains;
- Risks/opportunities in relation to the regulations. The regulations on biodiversity conservation have gradually become stricter in France over recent years, due, in particular, to the emergence of corporate environmental responsibility (LRE – Environmental Responsibility Act) which introduces an obligation to make good any environmental harm, the reform of environmental impact assessments and the strengthening of the "Avoid-Reduce-Offset" process (Grenelle II Act), in addition to the obligation to carry out extra-financial reporting on biodiversity. The failure of companies to properly anticipate and implement these obligations may incur their legal liability and result in damage to their image, an increase in costs and a loss of financial profits. Conversely, the implementation of proactive approaches that go beyond the regulatory obligations can allow companies to anticipate future changes in the regulations, reduce future conformity upgrading costs and promote the political and social acceptability of projects.

2 Driving forces

By definition, the links that companies maintain with biodiversity vary enormously according to the economic sector concerned. A construction and public works company will clearly not have the same impacts, needs or expectations in this field as a logging or energy company. To provide guidance for actions, depending on companies' relationships with nature and the main solutions to be implemented, three types of economic activities can be identified: those whose core business is based on the exploitation of renewable natural resources, activities that need to damage or destroy nature, and those that neither exploit nor destroy it but that can come to terms with it.

The first category encompasses sectors that directly exploit renewable natural resources such as agriculture, forestry and fishing, and sectors that indirectly exploit them via their supply chains, such as the paper, agri-food and cosmetic industries. The overexploitation of natural resources is one of the major causes of the degradation of biodiversity. The key issue here relates to the preservation of the environment's capacity to

produce this resource and to its sustainable exploitation, by considering it not as a fixed stock with a linear biological productivity, but rather as a component of a complex entity – the ecosystem – whose dynamics respond to the interactions between the multiple species that it accommodates. For these activities, the solution is to ensure the sustainable exploitation of the resource and the conservation of the ecosystem that produced it. The commercial expression of this sustainable exploitation consists of ensuring the environmental certification or labelling of production modes, procuring certified products throughout the value chain, and of providing information about these actions. These certification or labelling schemes may allow access to niche markets, and all the more so because the labels are based on standards with stringent requirements. Labels with more flexible requirements and with a lower additional cost may attract a broader customer base. In 2015, for example, the French forestry and timber sector covered over 8 million hectares of PEFC (Pan European Forest Certification)-certified forests, amounting to around 35% of the total French forest area (PEFC, 2015). Today, more than 3,000 companies are operating in 14 business sectors (pulp and paper, printing and graphics chain, furniture and construction, etc.). They now have a PEFC-certified monitoring chain which requires a clear distinction between certified and non-certified timber throughout the transformation and marketing chain. Their number has tripled in a five-year period.

The second category of activities covers the land-use planning and infrastructure sectors, as well as the extraction of non-renewable resources. In a world in which any development requires an irreducible number of planning measures that lead to land take use changes and from natural environments destruction, the first step towards a necessary reconciliation consists of moderating the underlying needs of these activities (e.g. energy savings), or and of applying the "Avoid-Reduce-Offset" (ARO) sequence. The ARO sequence firstly involves avoiding as many of the impacts of projects on natural environments as possible, and then reducing the inevitable impacts, before finally offsetting the "residual" impacts. The environmental offsetting of residual impacts clearly corresponds to the final stage of this three-part process and is only meaningful if it is carried out as a very last resort. The cost of ecological biodiversity offsetting, as borne by public or private project owners and if it is anticipated far enough in advance of the project cycle, thus becomes an incentive in itself to avoid and reduce impacts. Although the complexity of the living world clearly prevents any possibility of replaceability between destroyed environments and restored environments, it is sometimes possible to take action – in the form of conservation, restoration and even recovery – through ecological engineering, subject to whether the measurement of ecological equivalence is based on species, habitats, ecological functionalities and/or ecosystem services. For example, after impact avoidance and reduction, the building of the A65 motorway between Pau and Langon in south-western France on a 1,600 ha site with including 450 ha of natural environments, generated compensation obligations for 1,372 ha of habitats concerning ten or so wildlife species (European mink, otter, bat, European pond turtle, white-clawed crayfish, etc.) requiring restoration and maintenance over a 60-year period. Another example on a much smaller scale is the building of a retirement home for elderly dependent people (EHPAD) in Etampes in the Ile-de-France region. Occupying a 1.6 ha site with 0.83 ha to be developed, this project entailed compensation obligations providing for the restoration and management of at least 1.3 ha of wetlands, in addition to the maintenance of an existing wetland area covering 0.53 ha, all for a period of 5 years. Practically non-existent in the national regulations at the beginning of the 1970s, environmental compensationbiodiversity offsets is now, at the global level, enshrined in the regulatory obligations of 28 countries, with legislation being developed in 31 others (MEB, 2014a).

The third category of activities encompasses all of the other economic sectors whose core business activities have links with nature, but which are more complex and subtle than its destruction or the exploitation of natural resources. Here, the responses are found by looking for synergies in the interrelationships and interactions of the activity with natural processes. The tourism, water production and distribution, energy and waste management sectors are examples of such activities. The diversity of the sectors concerned mitigates against ready-made solutions, but there are numerous examples of synergies: from the production of drinking water which can use ecological infrastructures such as upstream wetlands to reduce treatment costs, and coastal tourism activities that depend on the existence of beaches and coral reefs, to the stakeholders responsible for managing hydroelectric dams or port infrastructures which, to prevent sedimentation and silting phenomena – which are sources of dredging costs – can invest in combating soil erosion or removing sediments through environmental engineering techniques, etc. More specifically, from 2012 to 2015, a consortium of partners (companies and universities, etc.) in the waste water treatment sector, coordinated by the Suez Environnement group, worked on the development and industrialisation of green discharge areas at the outlets of waste water treatment plants. The ZHART (artificial wetland zones) project follows on from the "Zone Libellule" pilot project (from the French acronym meaning "Area of Biological Freedom and to Combat Emerging Pollution"), launched in 2009 by the Lyonnaise Des Eaux company in the French *département* of the Hérault. It aims to combat micropollutants (endocrine disruptors, medication residues and pesticides, etc.),

discharged downstream from water treatment plants, whose concentrations are often below the detection thresholds. These artificial wetland areas, consisting of different but consecutive areas of vegetation with complementary treatment capacities, allow for the natural purification of waste water, act as buffer zones between the waste water treatment plant and the natural environment, and provide habitats for local biodiversity. This project eventually aims to create 35 artificial wetland zones in France, with an average area of 5 ha. In short, there are multiple opportunities, in terms of actions and interactions, for companies to avoid quite substantial additional costs, stand out from their competitors and become real stakeholders in change.

3 Specificities of the financial sector

The financial sector occupies a special position in this landscape of economic activities. At first sight, its direct links with biodiversity and natural environments appear to be quite limited. But this point of view, which still prevails today within the financial, insurance and investment community, is starting to change. As the interdependencies of companies and natural environments become ever-more tangible, environmental regulations become stricter and liability schemes are established, the operational risks associated with the failure of financial institutions to take account of natural capital in their investment and financing choices become increasingly tangible. Environmental, social and governance factors already play increasingly important, although still insufficient, roles alongside yield and risk considerations, in the decision-making of analysts, rating agencies and portfolio managers. But the situation is changing. At present, 80 financial establishments in 34 countries which have signed the Equator principles have made a commitment to apply the sixth performance standard (PS6) of the International Finance Corporation concerning biodiversity and ecosystem services to the funding of projects. In addition, the Natural Capital Declaration (NCD), signed by 41 banks, investment funds and insurance groups at the Rio+20 conference in 2012, formalised the recognition of the importance – for the financial professions – of natural capital as a producer of ecosystem services in the creation of a sustainable global economy. Since then, work on understanding and integrating natural capital into financial services and products has been gradually progressing according to the categories of assets in question. For example, with regard to the public debt market which represents 40% of global bond markets, a recent study (UNEP FI-GFN, 2012) shows that environmental damage, the growing scarcity of natural resources and vulnerability to the impacts of climate change may have direct consequences for the economic growth of countries, and thus on their loan repayment capacities. In particular, it is estimated that a 10% variation in the production capacity of a country in terms of biological resources causes a decline in the trade balance amounting to between 1% and more than 4% of GDP *(Ibid).* It is therefore in the best interests of financial institutions, which generally consider bonds to be relatively risk-free assets, to incorporate this environmental dimension into the analysis of sovereign credit risks. The decision made in June 2015 by the Norwegian national sovereign fund – which controlled 1.3% of the entire global market capitalisation at the end of 2014 – to withdraw its holdings from mining companies and energy groups in which coal accounts for more than 30% of the business or turnover, also merits consideration. Although it concerns a closely related field – climate – this type of commitment regarding biodiversity is likely to become more common in many sectors in the future. Another example concerns corporate bond issues, which have become an increasingly popular form of financing as opposed to bank credit. The growing scarcity of water resources may generate additional operating costs or capital expenditure for certain business sectors, and therefore ultimately affect the risk of companies defaulting on payment. But inIn the context of the work carried out for the NCD, tools are being created with a view to assessing – from the bond-holder's perspective – the risks pertaining to this increasing scarcity of resources and incorporating them into the dividends paid by companies, in order to ensure the an optimal risk coverage.

The complex link between environmental damage and corporate financial performance is thus gradually becoming apparent. These varied initiatives are promising and the financial sector can potentially make a substantial contribution to funding ecological transition. Nevertheless, regarding the consideration of biodiversity and ecosystem services in all their complexity, there is currently a shortage of operational tools backed by existing risk analysis methodologies that stakeholders in the financial sector can use to measure all of the environmental impacts of their financing and investment decisions and to quantify their retroactive effects on the yields of different assets. However, as for the carbon problem, work has now begun on creating ways of measuring the contribution that can be made by an asset portfolio to the funding of biodiversity conservation.

The aforementioned developments illustrate the innovative idea that companies can now be perceived as being not only part of the problem but also a key part of the solution. But biodiversity conservation, by its very nature as a public good, and indeed as a merit good, must do more than meet a set of private needs.

III. The need for combined approaches associating regulations, markets and corporate innovation for natural capital conservation

The challenge is to overcome the obstacles associated with voluntary and market approaches on the one hand, and exclusively public intervention – as the guarantor of the public interest – on the other. To do this, we firstly need to demystify the idea of the commodification of nature that is associated with certain economic instruments on the one hand, and then take account of the limitations of the economic analysis of biodiversity, on the other, before outlining several possible ways to create institutional organisation schemes combining the public and private actions that are essential for the effective conservation of natural capital.

1 The myth of the commodification of nature

There is a great deal of controversy surrounding innovative financing mechanisms for biodiversity conservation, most of which aim to mobilise funds that supplement the traditional public budgets, and thus involve the private sector in some way. One of the main points of contention concerns the idea that certain instruments, and sometimes even economic analysis in general, by seeking to take account of the values of ecosystem services and incorporate them into the decision-making of private stakeholders, could lead to the inevitable commodification of the living world. This would then be subject to trade-offs agreed by companies and financial institutions in the constant quest for profits. It is true that terms such as "biodiversity market" and "ecosystem service markets", as used with reference to the carbon and water markets, are commonly found in the scientific and grey literature, which by definition causes confusion. But the very idea of commodification denotes a lack of understanding of the underlying principles of economic evaluation and of the mobilisation of economic instruments. Firstly with regard to economic evaluation, a certain number of techniques have been developed in environmental economics in order to break away from the market model and cover all ecosystem values (Salles, 2010). By its very nature, the market is inefficient in the presence of externalities and in terms of the management of public goods. These characteristics are intrinsically related to the nature of many ecosystem services. Therefore, the adopted view of biodiversity is certainly anthropocentric and primarily instrumental, but under no circumstances is the estimation of the economic value of biodiversity actually reflected by the idea of allocating a price to it on any type of market that involves a confrontation between supply and demand. The reasoning concerning innovative economic instruments, which are often considered to be "market instruments", is also erroneous. In the cases of both environmental compensationbiodiversity offsets and payments for environmental services (PES) environmental service payments (ESP), it is not species, habitats or ecosystem services – which by their nature are not appropriable – that are bought or sold, but rather conservation or restoration actions which, in the field, result in remunerated changes of practices in areas in which the stakeholders possess rights of useuser rights (MEB, 2014b). Conversely, when the implementation of ESPs PESs or compensatory biodiversity offset measures measures is associated with the use of legal tools such as environmental easements, in reality it is the constituent rights of private property that are placed in the public domain. Moreover, as the compensatory measuresbiodiversity offsets concerning geographical areas are limited by the specificity of the impacted habitats, and ESPs PESs are associated with changes in practices that often have a local impact, it is not markets – in essence multilateral – that are created, but rather a series of bilateral contractual relationships between stakeholders involving extremely varied trading items. It should be borne in mind that these agreements between stakeholders are strictly defined and controlled by the regulations. Consequently, in these two specific cases, the myth of commodification does not hold true. More broadly speaking, regardless of the degree of involvement of private stakeholders, there are currently no biodiversity or ecosystem service markets and they will probably never exist.

2 Limitations of economic analysis for the conservation of natural capital

Economic analysis, and the evaluation of ecosystem services in particular, in addition to some of the associated instruments, cannot be simply reduced to a means of commodifying the living world. And But it is also true that biodiversity cannot be limited to purely economic considerations. The instrumental view of biodiversity, in which it is seen as a source of ecosystem services, constitutes just one of several possible justifications for its conservation, such as the recognition of the intrinsic values of nature for example. This is also the reason why ecological compensationbiodiversity offsets, in France and many other countries, is are not based on a principle of equivalence in terms of ecosystem services, but rather on a measurement system based on variables such as protected species, community habitats and certain ecological functionalities.

Moreover, the appropriation of the notion of ecosystem services by private stakeholders via a primarily economic approach poses the risk of grossly oversimplifying the ecological dynamics. Ecosystems are

characterised by threshold effects, amplifying feedback loops and delayed effects that lead to "tipping points", or sudden changes (collapses) of the status of biodiversity. In this way, the disappearance of certain "cornerstone species" or a change in the distribution of species may generate a series of impacts throughout the entire trophic chain, altering the operation of entire ecosystems and therefore the availability of ecosystem services. However,E economic analysis, and the marginalist approach in particular, struggle to comprehend non-linear dynamics. In general, the complexity of the interrelationships within ecosystems encourages stakeholders to adopt a simplified view that sometimes proves to be too simplistic to be pertinent.

3 Conditions for action: towards combined public-private approaches

Biodiversity, as a public good, is characterised by property rights and a distribution of the associated costs and benefits requiring a collective governance of the action that presumes a certain amount of coordination among the agents. The empirical results do indeed tend to show that in general, private stakeholders, whose property rights may facilitate the efficient regulation of environmental problems by the market, are no better or worse at managing natural resources than, whose property rights facilitate the efficient regulation of environmental problems by the market, or by the State, as the guarantor of the public interest. The effectiveness of the management is dependent on the rules established within the institutional arrangements created by individuals in order to protect and maintain the resources for which they are collectively responsible (Ostrom and Basurto, 2011).

The implementation of environmental compensationbiodiversity offsets crystallises the key issues relating to the combined public-private approach that is required. Based on the application of the "polluter pays" principle, this mechanism is based on a regulatory obligation to offset the residual impacts of projects, which actually creates a demand from project owners that are ultimately responsible for the implementation of the compensatory measures concerning them. Each stakeholder (project owners, instructing departmentspublic authorities, compensation biodiversity offset operators, etc.) has a role, obligations, rights and needs, and the effectiveness – both environmental and economic – of the mechanism depends on it. As the guarantor of the public interest, the State is responsible for ensuring the scientific reliability of the dimensioning of the compensatory measures, their geographical consistency and the effectiveness of their implementation over time. Project owners, which are subject to regulatory obligations, must incorporate their financial and operational consequences into the design of the project at the earliest possible stage, while maintaining the profitability of their business. Finally, compensation biodiversity offset operators, which can manage the implementation of compensation offsets on behalf of the project owners, must ensure the profitability of operations, the ecological effectiveness of the actions undertaken and the maintenance of commercial and operational risks at an acceptable level... over a long period and in a very uncertain context. This consequently requires stable, predictable and applicable regulatory frameworks, in addition to the use of tools and rules that facilitate long-term action while favouring adaptive strategies.

Conclusion

The aims and means of combating the degradation of natural capital are much more difficult to express than those used for tackling climate change, which has nevertheless been the subject of intensive debate. However, the associated challenges are just as critical for all stakeholders, both public and private. Today, there have been significant improvements in companies' awareness of environmental issues. The degradation of biodiversity and the collapse of ecosystems, crises relating to the management of water and the failure to adapt to climate change are just some of the 10 biggest global risks in terms of impacts recorded over the last decade by the World Economic Forum at the global level.

It should however be noted that the voluntary approaches carried out by companies also have limitations and that they alone are insufficient to combat the degradation of biodiversity. They will necessarily be focused on certain ecosystems from which their resources are obtained, or on the preservation of certain ecosystem services that are considered to be essential. Just like innovative financing mechanisms for biodiversity conservation that cannot be reduced to instruments for the commodification of nature, only combined public-private approaches to governance can produce efficient and acceptable solutions for the management of natural capital.

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Renewable natural resources and the accounting systems of organisations

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Responses to environmental challenges – climate change and the degradation of biodiversity – do not necessarily require us to call into question the capitalist system, but rather to reform it in order to ensure that the maintenance or indeed the creation of natural capital creates value. For an organisation, the creation of value must now involve an internationally recognised accounting system. In this paper, we shall therefore be proposing potential solutions to be considered for the creation of new accounting rules, e.g. in terms of capital increase or depreciation, which will help to improve the integration of biodiversity issues into the strategies of organisations.

The question of accounting for the management of natural resources in the economic world was ignored for a long time, although as far back as 1908, Theodore Roosevelt proposed forging closer links between economic development and environmental protection in the following declaration: "We have become great because of the lavish use of our natural resources and we have just reason to be proud of our growth. But the time has come to inquire seriously what will happen when our forests are gone, when the coal, the iron, the oil and the gas are exhausted, when the soils have been still further impoverished and washed into the streams, polluting the rivers, denuding the fields and obstructing navigation." While adhering to this view of development, it should be noted that despite a certain number of obstacles, some progress has been made in recent years. Our aim is to present and analyse them. This is not a question of challenging the capitalist model, but proposals for reforming the system are required in order to take better account of natural capital because, as Jacques Weber declared in 2008: "In the capitalist system, the creation of profit is the driving force for action. Let us keep this basic rule. And develop incentive rules that change the conditions for the creation of profits: we will still have a capitalist market system, but now, first and foremost, it will help to maintain the viability of the planet and of the societies that inhabit it." This is the framework of analysis in which we shall endeavour to propose some general answers to the question: how can we take better account of natural resources in the strategies of organisations? To this end, we shall be presenting the specificities relating to the management of renewable natural resources and analysing the consequences of different approaches for the accounting systems of organisations.

1. Renewable natural resources and biodiversity: What are the specificities?

Before attempting to answer this question, let's remind ourselves of what biodiversity means: It refers to the *variability of living organisms of any origin, including, among others, terrestrial, marine and other aquatic ecosystems and the ecological complexes to which they belong: this includes diversity within species, between species and of ecosystems* (article 2 of the Convention on biological diversity). Biodiversity is the *"living fabric of the plant"* (Barbault, 2006, Barbault and Weber, 2010) and humans are obviously part of it.

1.1 The context and key issues

Society as a whole uses services derived from the ecosystems functioning, and these services are often used free of charge, i.e. they have no price and are therefore have no value on the balance sheets and income statements of organisations. The following question arises: To improve the management of ecosystems and natural resources, do these services need to be included in companies' balance sheets? In other words, does the fact that there are no prices attached to these services which are procured by organisations imply that they have no value? In attempting to answer this question, it seems appropriate to refer to the work carried out on the costs of inaction[89]. There may be two categories of costs of inaction:

– firstly, the substitution costs for these services, i.e. if a stakeholder benefits from a service for free and if this service is destroyed, it will have to pay a substitution cost for the service if there is an existing

[89] In this article, we shall not be going back over the work of Sir Nicholas Stern (2007) on the cost of inaction vis-à-vis climate change or of Pavan Sukhdev (2009) on the cost of inaction regarding biodiversity. We shall simply be using their work, which tends to be aimed at the macroeconomic level, to create tools at the microeconomic level, mainly by means of financial accounting.

technology that performs the same service. There may also be a service restoration or re-creation cost, bearing in mind that in this case, it will be necessary to take account of the time frames required for the restoration to take effect. In this way, restoring polluted soils by excavation will be more costly but quicker than by phytoremediation;

– secondly, the costs associated with the relocation of production if the organisation is obliged to look for this service elsewhere, or indeed the cost associated with the stoppage of production (if the service is destroyed and there is no replacement).

One of the questions is to know whether remuneration can be defined and implemented for the maintenance of ecosystem services ("beneficiary pays" principle) or a penalty in the event of the destruction of a service ("polluter pays" principle).

In the framework of biodiversity and ecosystem services in the strategy of organisations, we need to bear several elements in mind: Organisations have impacts on biodiversity that need to be taken into account; organisations use biodiversity and ecosystem services, which help to create value for both profit-making and non-profit-making organisations.

An important point to be considered when dealing with renewable resources is that in principle, they are indeed renewable. As emphasised by Trommetter and Leriche (2014): "The capacity of ecosystems to provide these different services is fragile. Under these conditions, biodiversity firstly appears to be useful "for its own sake". This is what is referred to as the "supporting" service: nutrient cycle, soil maintenance and primary production. In fact, the ecological efficiency of this supporting service determines how efficiently the ecosystem will operate, and this in turn dictates the standard and quality of the services that humans will be able to obtain from biodiversity. Furthermore, the standard and quality of the supporting service at a given moment depend on the services that have been used by humans previously, and constrain (positively or negatively) the standard and quality of the services that humans will be able to obtain subsequently."

In attempting to explain the relationships between humans and biodiversity in detail, several points can be raised: Taking the example of an organisation: in its uses, it may require a certain number of ecosystem services, but in addition to this quantity, it may also need a certain quality of service. We presume that it will initially have no problem in accessing and using these services. There may be impacts when the organisation uses these services: on the future services that the organisation itself will want to use and on the uses that the other stakeholders will want to carry out. This requires the consideration of the effects of the current uses on the resilience of ecosystems and the associated services that are procured by the different stakeholders[90]. The key issues in terms of the resilience and operation of ecosystems are therefore essential. The resilience must be analysed: in relation to the future needs[91] of the organisation under the constraints of its current uses; in relation to its future uses under the constraints of other stakeholders' current uses; in relation to other stakeholders' future uses under the constraints of its current uses.

It is at this level of analysis that the approach based on the costs of inaction is particularly relevant, because inaction may jeopardise the resilience and future operation of ecosystems: the inaction of one organisation may have impacts on the others and on the organisation itself; the inaction of others may have impacts on the organisation. This means that thought needs to be given to defining what actually constitutes inaction. Inaction by whom? Inaction in relation to what?

It is in this context of dynamic interactions in which the supporting service is at the heart of economic, social and, of course, ecological development that we need to striving to maintain an adaptive potential. But who are the different stakeholders and what do they have in common? The stakeholders to be considered are companies, public authorities and inhabitants. They all share the characteristic of using accounting tools of variable sophistication in terms of assets and liabilities. An accounting system is therefore a tool that allows us to compare and extend the analysis to all interested parties, including those that are not situated within a given region but that will have an influence on the strategy of organisations (e.g. shareholders). But are they individually aware of their dependency on biodiversity?

1.2. The Business and Biodiversity Interdependence indicator (BBII)

This tool has been created to provide guidance for organisations – from a broader perspective than the corporate standpoint – in their analyses of their interdependencies on biodiversity and ecosystem services. There may be multiple and diverse fields of application for the indicator, as is the case for multinationals and regional authorities. The framework of analysis is based on five categories (taken from Fromageot, Leriche and Trommetter, 2014).

[90] It should be borne in mind that the fact of maintaining an ecosystem for a service does not necessarily guarantee its resilience. Certain services may be favoured to the detriment of the operation of the ecosystem as a whole.
[91] It cannot be excluded that future uses may be different from the current uses, which further complicates the analysis.

Criteria directly linked to the living world: This type of criterion includes questions concerning the organisation's dependency on raw materials through its activity, with these resources originating from the present or past living world (e.g. fossil energy sources). It also includes dependency on technologies and services of the living world, through the ecosystem-services based approach...

- Criteria linked to current markets: this type of criterion is based on an analysis of turnover and its dependency vis-à-vis biodiversity: proportion of the cost of the use of raw materials derived from biodiversity in the total manufacturing cost; proportion of the company's turnover depending directly or indirectly on biodiversity in relation to global turnover.

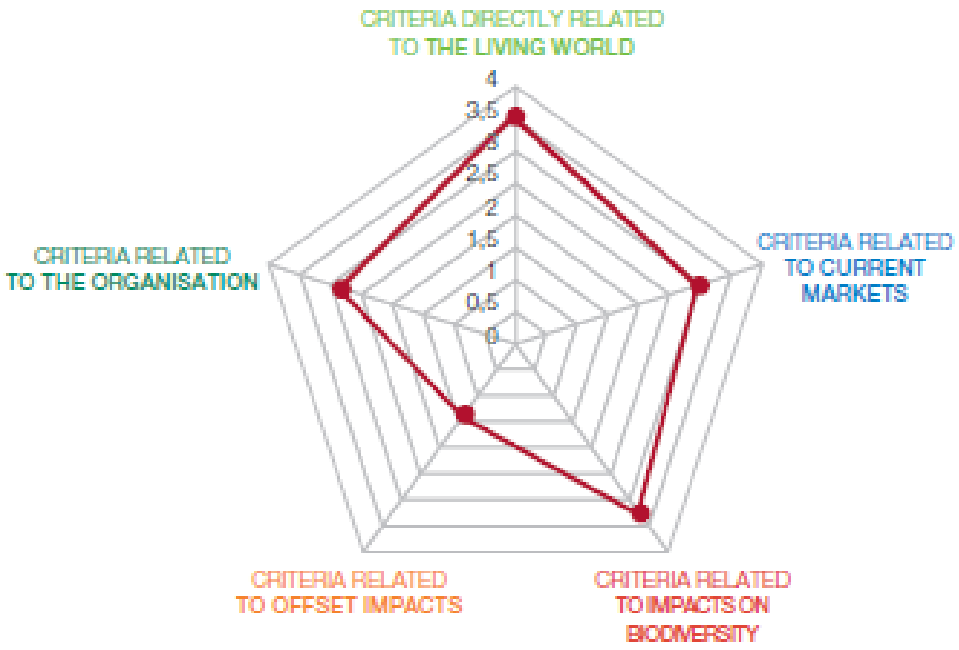
- Criteria relating to impacts on biodiversity: this type of criterion, which is more common, allows the organisation to investigate the impacts of its activity on the living world and, more specifically, whether or not these impacts are reversible.

- Criteria relating to compensation for the impacts: this type of criterion places the emphasis on the implementation of compensation – whether compulsory or voluntary – for the impacts of the activity.

- Criteria relating to the organisation's strategies: this type of criterion poses the question of the position occupied by biodiversity in the company's strategy. Is biodiversity a key factor for ensuring the sustainability of the stakeholder's activities? Is the consideration of biodiversity the source of a competitive advantage? What are the challenges and prospects for innovation and access to new markets for the stakeholder in relation to biodiversity?

On the basis of these five criteria, organisations can create a pentagram that can help them to analyse their positioning in relation to other organisations.

Figure: Pentagram for two organisations



Source: Houdet, 2008; Fromageot, Leriche and Trommetter, 2014

The BBII was developed as a tool for internal consultation within an organisation. The BBII is an analytical phase prior to the development of an action plan, or the use of other tools. Since its creation, more formalised voluntary approaches have been developed[92]. Biodiversity is thus no longer perceived as just a simple

[92] The Ecosystem Services Review (ESR) is the fruit of a collaboration mainly involving the World Business Council for Sustainable Development and the World Resource Institute. The ESR is a methodology designed to help decision-makers organise strategies for considering the risks and opportunities relating to their impacts on ecosystems. The publication "Guide to Corporate Ecosystem Valuation" (WBCSD, 2011) is intended to become one of the key tools of the WBCSD. The CEV should allow the company: "to explain, in concrete

environmental issue for which it is sufficient to minimise costs to attain an imposed reduction target. Biodiversity becomes a strategic factor for stakeholders due to the fact that new issues emerge (Trommetter and Leriche, 2014):

- Can minimising costs in order to achieve an anticipated reduction of impacts today be the source of additional costs that will allow us to benefit from services tomorrow?

- Could financing restoration costs today be a requirement in order to allow us to benefit from services tomorrow?

Beyond individual perceptions, the BBII promotes awareness of the interdependency among organisations on the subject of biodiversity and ecosystem services. How can we take account of these interdependencies?

2. Biodiversity and accounting systems of organisations: initial possibilities

We are seeking avenues of research in order to integrate natural resources into the financial accounting of organisations, by taking account of both the interactions among stakeholders on the subject of biodiversity and the negative and positive impacts of stakeholders' strategies on natural capital.

The aim of the accounting system is to improve the consideration of changes in natural capital in the strategies of organisations (be it in terms of amortisation, provisions, depreciation, investment or creation). The accounting system provides a snapshot of the interactions between stakeholders in which the interactions associated with natural capital are under-represented today. Nevertheless, we believe that an accounting system is an appropriate tool for improving how this resource is accounted for, because this capital is not a corporate asset but rather a liability (a resource), which is a debt that the organisation has towards the party that placed the capital at its disposal. This point justifies amortisations (of assets) and provisions (for liabilities) in association with the organisation's activity and with the maintenance of the capital. Financial capital, which is a resource in the liabilities, can be used to purchase machines, for example – a use of resources in the assets – whose uses must be amortised, as it is unacceptable for the company to solicit the shareholders again when the machine is obsolete. The same must apply to the consumption of natural capital.

2.1. An accounting framework adapted to the renewal of the environment (Comptabilité Adaptée au Renouvellement de l'Environnement – CARE)

Management accounting starts with the consideration that a manager must maintain (and in a certain manner renew) its ecosystem (natural capital) in the same way that a company maintains and renews its financial capital (through the amortisation of its machines, for example). This approach forms the basis of the CARE method (Richard, 2012, Rambaud and Richard, 2015)

The simplest situation that can be modelled is one in which the company is required to manage natural capital for the sake of its own economic viability. In this context, the natural capital that the company uses is only profitable for itself. It is therefore in the company's interest to ensure its maintenance. It bears the costs of maintaining this capital and the anticipated future costs in each financial year (amortisations): in a compulsory manner or as a precautionary measure. The aim is to avoid harmful behaviours. These amortisations are a form of savings, amassing amounts that are available once the thresholds of irreversibility are reached. The sums "saved" and then "invested" remain within the company. This model is based on the principle that the maintenance of natural capital is compulsory (as for financial capital) and cannot be replaced. This model is based on a strong view of sustainability. We are considered to be too close to the thresholds of irreversibility in the theory of viability (Aubin, 1991) to ignore the risks that are posed.

Matters are a little more complicated when the manager is required to maintain natural capital in order to ensure the sustainability of the supplies of goods and services that human societies obtain at the local and/or global level. This is because the amounts allocated to the maintenance of this capital by the manager will not be savings, insofar as the manager cannot benefit financially from its own "investments"[93]. On the contrary, compliance with the limitations that lead to a resilient ecosystem may be achieved to the detriment of the manager. This approach is fully compatible with the "polluter pays" principle. In this type of situation, a negotiation between managers and beneficiaries might lead to the provision of a financial contribution by the beneficiary. In theory, this could be envisaged and be economically efficient enough to ensure the economic viability of the manager. We shall examine this point in detail, because one question that arises is: how do you find the right balance between the "polluter pays" principle and the "beneficiary pays" principle?

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terms, the way in which it evaluates, exploits, manages and reports on its impacts on ecosystems and biodiversity". (Fromageot, Leriche and Trommetter, 2014).

[93] In fact, the manager compensates for a deterioration of natural capital through its own fault and in its own interest even if the most serious consequences might appear on other stakeholders' sites.

The CARE model focuses on the consumption of natural capital and therefore on the company's impacts on its environment. Jacques Richard insists on the notion of a maximum threshold for the use of nature in the same way as there are maximum "thresholds" of use for a machine in a company (a certain number of hours per year, for example). These maximum thresholds of use are then associated with the amortisable life of the machine. We can indeed over-exploit nature and prevent it from being resilient. Irreversibilities must be avoided. The CARE model thus adopts an approach involving the "amortisation of natural capital consumption". The notion of amortisation in accounting takes account of the notion of uncertainty about the reality of the effect. Therefore, there are amortisation charges, extraordinary amortisation charges and provisions. In the case of provisions for future charges, there may be a reversal of a provision if the charge is ultimately lower than predicted. Jacques Richard (2012) thus specifies that:

- If the depreciation of the environmental function is certain and systematic, it is an ordinary amortisation charge;

- If it is certain but episodic, it is an extraordinary amortisation charge

  E.g. loss of nutrients from soil;

- If it is a possibility, it is a provision.

According to Jacques Richard: "Natural, non-renewable resources should be entered as liabilities at their replacement cost in terms of renewable energy. They would then be amortised as assets as the natural, non-renewable resources are extracted. The amortisation funds would then be used for investing in renewable energy sources."

This model takes account of amortisation issues in relation to the consumption of nature. This model also works in the case of the management of renewable resources. Taking the example of a farm that pollutes a river (green algae):

- A farmer carries out an assessment that reveals nitrate levels which are above the acceptable standards for maintaining soil functions;

- The cost of repairing the environmental functions by using a different method of farming (under-cropping) is €100,000;

- This cost of replacement (of one method by another) will be entered under liabilities (as natural capital to be conserved) and under assets (as a soil resource);

- It will lead to amortisation over the period during which balance is expected to be restored;

- In principle, no dividends will be distributed before the situation has been rectified.

Jacques Richard points out that this approach differs from the internalisation of externalities, as the aim is to ensure the *ex ante* consideration of the costs for the "avoidance" of damage. This is a preventive rather than curative approach. It allows for the consideration of the effects of nature conservation on the company's future activities and possibly on the other stakeholders' activities. However, this approach has certain limitations. We shall present three of them:

- It is difficult to incorporate the need to have a quantity but also a certain quality of inputs in order to produce and thus create added value. To incorporate this into the CARE method, we would need to redefine the characteristics of natural capital in quantitative and qualitative terms;

- There is no consideration of the positive and negative interactions among stakeholders, as the CARE model focuses on the relationship between a company and natural capital;

- There is no taking account of incentives to invest in biodiversity, which would amount to increasing the natural capital available for all stakeholders.

The CARE model remains highly instructive on the issue of damage prevention because it "does not wait for disasters or even a rise in temperatures to occur before recording a charge: it does so at the occurrence of an event that casts doubt on the subsequent capacity of the capital to operate". J. Richard, 2011.

2.2. Possible new accounting solutions

One of the questions that arises is: who pays for the maintenance of a service? Another is: should we continue to adopt a stock-oriented approach? It is indeed important to encourage companies to invest in biodiversity in order to create "natural potential". But who will finance it? And how is the value of this investment accounted for on the company's balance sheet and income statement? In an attempt to provide answers to these questions, we propose to investigate new approaches to the criteria of provisions, amortisation and investment.

2.2.1. Maintaining an ecosystem service

The situation that interests us here concerns an organisation that can now no longer benefit from an ecosystem service when it used to benefit from such a service free of charge. As long as the upstream stakeholders have uses that remain within the legal standards, the impacted organisation must compare the cost of inaction (replacement of the service) with the cost of helping the upstream stakeholders change their practices in order to maintain or restore the service from which the downstream organisation benefits. The following question arises: must we now pay for a service that used to be obtained free of charge, before its disappearance? Should we be compensated for a service from which we no longer benefit?

This is the example of the Vittel company, which witnessed a deterioration in the services that it was using to sell its mineral water, in terms of the nitrate and pesticide levels in its catchment basin. The levels remained compliant with the potability standard but their rate of increase raised fears that it would become impossible to maintain the company's mineral water bottling operations. Vittel thus needed to provide incentives for farmers and other interested parties (golf courses, regional authorities and the French state railway company – SNCF) to modify their practices in order to restore the services required by Vittel. The restoration option chosen by Vittel has local impacts on its business and that of the other stakeholders, in addition to global impacts (not currently accounted for). Vittel has purchased a large proportion of the farm lands, which have become company assets and helped the other parties to modify their practices.

The Vittel example is not an isolated case, as organisations often face uncertainties regarding the availability of a service that is used as an input. In accountancy, there are "coverage accounting systems to cover the risk components of inputs and outputs" (IFRS9). Consequently, there are provisions for the depreciation of raw materials that are in stock. This means that in the event of having to purchase a raw material of the same quality as one that is in stock, and which would cost less, the value of the stock would have to be depreciated. But how can this conception of provisions be adapted to provisions for losses of flows of free services?

An organisation can invest on its own behalf, so that it can benefit from a service in the future. This is a simple situation in which the company just needs to be aware of its own dependency. It can invest to make sure that other parties change practices (or in certain cases do not change practices) so that[94] it can continue to use services. We are not dealing with an "amortisation" approach, because it is possible for an organisation to be deprived of a service without the resilience of an ecosystem necessarily being affected. Likewise, machines used by others are rarely amortised. Organisations thus adopt a "risk management" approach, with the mobilisation of provisions for risks, which are quite numerous in accountancy. Companies need to be aware that the price of renewable natural resources does not reflect their value for organisations and the Earth's ecosystem as a whole. So what is the value of a resource that is used free of charge? First of all, the organisation must evaluate the cost of replacing the service, and then take account of the cost for the upstream company of adapting its development and practices to the downstream service needs. Finally, the downstream organisation must compare these miscellaneous costs with the participation of the service in the creation of added value for the organisation. In certain cases, however, a single service may be used downstream by several stakeholders. How can we manage a service that is used collectively and dependent on collective upstream use? This is the challenge for the future.

2.2.2. Investing in Biodiversity

At present, organisations have at least two reasons to invest in biodiversity: investing in response to a legal obligation, and investing in a voluntary manner in anticipation of future returns.

Investment in response to legal obligations.

The organisations studied here are developers that have to compensate (in a compulsory manner) for their development operations (e.g. land take and development of transport corridors: roads and railway lines). This compulsory compensation can be carried out directly by project managers, or by purchasing biodiversity units from suppliers (equivalent to "*mitigation banking*" in the USA). Developers can therefore apply to suppliers of compensation options (such as the French Caisse des Dépôt et Consignations Biodiversité [Biodiversity consignment and loan fund]). They can then implement compensation according to supply or demand. Compensation according to supply may prove to be more ecologically efficient as it will generally be carried out within an ecological continuity (green and blue belt networks), but it may also prove to be riskier if the supplier cannot sell all of its biodiversity units. Indeed, the existence of competition in the supply of compensation puts us in a competitive context, and if there are too many suppliers, there is a risk of a drop in the prices of biodiversity units. If they drop sufficiently, it will be detrimental to companies proposing a compensation offering based on the re-creation of ecosystems (more costly than simply purchasing and

[94] "*Today, in financial and fiscal law, a company is not entitled make risk provisions without proof of a probable legal obligation or of a probable quasi-obligation to a third party.*" Jacques Richard, personal paper.

possibly restoring land). The compensation market according to supply then turns out to be less attractive than anticipated. On the other hand, if there are too many applicants, this could raise the prices of compensation units or biodiversity units, which might encourage certain firms to implement ex post impact avoidance or reduction activities whose cost could then prove to be prohibitive in relation to the anticipated benefits of the project. This raises the question of the definition of a biodiversity unit: does one hectare purchased to prevent its future destruction yield as many biodiversity units as one hectare purchased for the re-creation of a habitat, and whose cost is much higher. This is all the more important because these biodiversity credits are assets of the company (but at what "value" – price per unit on the market? Amount invested by the company to obtain a biodiversity unit?), and because selling at a lower price than the value of the biodiversity units on the asset side of the balance sheet would be damaging to the company, as would be the depreciation of financial assets[95]. This reflects all the importance of the definition by the regulatory authorities of the meaning of a compensation obligation and a biodiversity unit. A definition leaving room for a wide range of interpretations can be given to the detriment of an ecologically effective compensation offering, in relation to the *no net loss* issues that have been recently imposed.

Investment in a voluntary supply of biodiversity units.

By restoring, rehabilitating or recreating ecosystems, whether ordinary or polluted ecosystems (industrial or urban wastelands). This raises questions such as investment in biodiversity, e.g. in phytoremediation. This tool is used for the prevention or removal of pollution. How can corporate financial accounting take account of these different options in order to make them more attractive, both for companies and for shareholders that have contributed a resource – financial capital – and on which they can expect a return, including in the form of an increase in the available natural capital thanks to the company's actions? Companies may invest in biodiversity for different purposes: to improve their image, for reasons associated with the ecosystem services that the company obtains from the ecosystems it wishes to develop, or for the services that others will obtain from its investment in biodiversity. In this last case, development and the subsequent compensation are directly incorporated into the strategy of the company which, on the liability side of its balance sheet, accounts for the fact that the destruction of an ecosystem and its associated services procured by humans may be harmful to the company itself in the future. This means that there is greater consideration of the dynamic interactions between the company and Nature. For example, biodiversity and climate change are related, because apart from the simple fact that humans speed up change (greenhouse gas emissions) through their actions, allowing biodiversity to decline (deforestation and land take) will accelerate the speed of climate change by reducing the planet's capacity to absorb greenhouse gases. This is the *lose-lose* model. Moreover, as emphasised by Trommetter and Leriche (2014): "reforestation for carbon storage will be all the more effective because it will be conducted with the aim of maintaining an adaptive potential for biodiversity".

In conclusion

The CARE approach makes taking account of natural capital a central concern of companies by compelling them to ensure its maintenance, both for their own use and for the uses of others, through its inclusion in their financial accounts. Therefore, there is clearly a conception of the maintenance of a "stock of natural capital" which is under pressure from uses and the capacity of this natural capital to regenerate (notion of resilience). This model suggests taking account of the "polluter pays" principle in company accounts. This approach forms part of a standard view of environmental issues, in which companies aim to minimise costs in order to attain a given environmental objective (Trommetter and Leriche, 2014). It should be remembered that Jacques Richard (2011) proposed amortising the consumption of non-renewable resources in order to finance the development of renewable energy (maintenance of an energy production capacity). The deliberations in progress are based on the concept of "natural capital" envisaged as a stock that must be optimally managed if it is to remain sufficient to meet the needs of future generations. However, as Jacques Weber put it: "We are no more able to predict the needs of future generations than people at the time of the French Revolution could imagine the advent of the computer, the mobile telephone or the Internet."

It is a question of inventing a system that allows for the consideration of these new constraints and gives companies incentives to invest in biodiversity. The idea is to show that a depreciation of natural capital, which is represented here by a depreciation of ecosystem services, accounted for as the assets (amortisations) and liabilities (provisions) of organisations, may be a cost factor in the same way as the depreciation of financial

[95] In accountancy, this corresponds to the question of the valuation of "actions" on company balance sheets: at the purchase price or at the market price? ...

assets. Consequently, as Jacques Weber stated: "It would be a good idea to send an urgent message to companies, reminding them that their business is more reliant on the living world than on finance and that it would be harder to rebuild nature than the financial system." Adopting an accountancy-based approach compels chief financial officers, and more generally, the managers of companies and public authorities, to assimilate the question of biodiversity. If biodiversity is perceived to be a source of both costs and benefits, this will involve the company's entire production chain. We need to set the target of maintaining an adaptive potential, i.e. of leaving the greatest possible choice for future generations. This point had already been made by Theodore Roosevelt (1908), who believed that we must we take account of the fact that given the "constant rise in the population and the even faster increase in consumption, our people will need greater quantities of natural resources. If we, of this generation, destroy the resources (…) we degrade the standard of living or deprive the coming generations of their right to life on this continent".

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The consideration of natural capital by institutional investors

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Although the need for institutional investors to take account of natural capital seems to be acknowledged at the intellectual level, its practical implementation is still in its infancy with numerous legal, technical and political obstacles remaining. Recent years, however, have seen the emergence of many innovative initiatives, instruments and practices that aim to integrate natural capital into investment strategies. While this movement is developing and attempting to consolidate its position, it is incumbent on the public authorities to promote its development, particularly by encouraging research into measurement tools, integrating natural capital into investment and corporate reporting, and by placing these issues at the heart of the public debate in time for the next international deadlines. But for this to happen, there will need to be a genuine revolution in ways of thinking and acceptance of the fact that regulation by public reference prices, while necessary, is far from sufficient. A renewed analysis of the fiduciary duty of institutional investors could trigger this revolution.

It is currently acknowledged that the current rate of exploitation of nature is incompatible with its renewal and, as a consequence, with the well-being of future generations. Because it provides ecosystem services, in addition to the natural resources that it supplies, nature should therefore be considered a resource that promotes growth – in the same way as work and capital – but of a clearly different type. Represented in this manner, this natural *capital* would therefore have a price, if not a cost. Others consider that if nature has a value, it cannot have a price, and that its "financialisation" will only speed up the irreversible degradation of this heritage[96].

Although the first institutional warning signal dates back to nearly 45 years ago in the Convention on international trade in endangered species of wild fauna and flora (CITES), adopted in March 1973, the awareness that damage to natural heritage may have lasting impacts on our socio-economic development is relatively recent (Natural Capital Initiative, 2009, Global Natural Capital Initiative, 2012). Modes of production and consumption, however, have continued to consider certain endangered resources to be inexhaustible or infinitely renewable, which has meant that nothing has been done to ensure their sustainability.

Investors – especially institutional investors – have become aware of these issues even more recently. The United Nations Conference on Sustainable Development in 2012 (Rio +20) marked what can be seen as a historic turning point, with the issuing of the Natural Capital Declaration, which was intended to demonstrate the UN's commitment to "supporting the development of methodologies that can integrate natural capital considerations into financial products and services for the 21st century". Initially signed by 39 financial institutions, it must be acknowledged that, nearly three years after its launch, the number of signatories (40) remains unchanged, although a certain number of organisations, including certain representatives of stakeholders in the asset-management chain, have expressed their support.

The greatest progress in these methodologies has been made in the climate-energy field with the transposition of the concept of "stranded assets", due to the increasing importance of extra-financial risks relating to potential regulations on carbon. In this way, a certain number of studies[97] [98] point to the fact that the bursting of the "carbon bubble"[99] could lead to a 40% to 60% reduction in the market value of oil companies and a 15%

[96] Natural heritage is associated with a notion of intrinsic value and with a need for the conservation, or indeed the restorative management, of nature (living, mineral, fossil, etc.). It is consequently a common good to be managed, conserved and passed on to future generations. This explains the choice of the term "natural **heritage**".
[97] Oil & carbon revisited – Value at risk from 'unburnable' reserves, HSBC Global Research (Climate change), January 2013.
[98] Unburnable Carbon 2013 – Wasted capital and stranded assets, Carbon Tracker Initiative & Grantham Research, 2013.
[99] Limiting global warming to +2°C would entail refraining from exploiting two-thirds of the proven reserves of oil, coal and gas, which would, in practice, mean a spectacular downgrading of any investment in fossil energy sources and, more generally, would lead to a major economic crisis.

reduction for diversified mining companies. There would therefore be a significant drop in the value of investment portfolios given the importance of the fossil energy sector in the major stock price indices[100].

While accounting for the carbon problem in investment policies is the most pressing challenge for investors, it is just the tip of the iceberg regarding natural heritage, to the extent that in 2012, the Oxford University Smith School of Enterprise and the Environment launched a vast research programme to analyse the impacts of these potentially downgraded assets for investors, companies, regulators and public policies.

Natural "capital" is struggling to find its place in the investment strategies of institutional investors

Investing *in* natural capital or investing *for* natural capital?

Natural capital or heritage: an externality or a shared asset?

Broadly speaking, there are currently two opposing schools of thought with regard to the approaches to be implemented for the conservation of natural heritage and ecosystem regulations. The rift between them concerns the financialisation of the living world, with impacts that are harmful to some [3], and beneficial to others. On the one hand, there are supporters of the financial valuation of this "resource" – which is currently free of charge – either by a cost (regulation or a reference price, etc.) or by a "market" price (compensation markets, bio-banks, etc.), and on the other hand, there are advocates of a form of collective governance of this heritage, which is considered to be a "common good"[101] [102]. On the one hand, we have supporters of a heritage legacy – nature – that needs to be conserved so that it can be passed on, and on the other, we have advocates of capital that determines the sustainability of investments and which needs to be protected or indeed developed.

In reality, the application of both of these schools of thought relates to a more general debate between *shareholder* and *stakeholder theories*: does a company aim to satisfy the shareholder by maximising the value for the shareholder as that would maximise the value of the company, which would in itself correspond to maximising social well-being [103], or does it aim to satisfy all of the stakeholders in a long-lasting manner[104]?

Greenwashing or a genuine conviction?

The approach, which consists of investing in companies that have the greatest benefit for the conservation of natural capital, does not pose this ethical problem of financialisation, but is criticised on grounds of the allocation choices of certain investors, which may seem opaque to the saver, and of the presence of oil values in investment portfolios that claim to be responsible. However, it is legitimate to ask ourselves whether the most polluting sectors should also be financed, provided that they make environmental efforts. In principle, all sectors should be concerned by the conservation of natural resources and energy transition.

Why take account of natural capital in investment strategies?

Financing needs that cannot be met by public funds alone

The financing needs for energy and ecological transition alone amount to billions of euros according to the estimates of the International Energy Agency. With specific regard to natural capital, the TEEB study (2009), conducted on a global scale, estimated the annual value of biodiversity losses and damage to ecosystems at between 2,500 and 3,500 billion USD, or 3.3% to 7.5% of global GDP. Measures to stop deforestation and the degradation of the associated ecosystems would require annual investments of US$20 to 45 billion.

In a context of the continuing depletion of public resources, the mobilisation of institutional investors (pension and related funds, insurers and reinsurers, reserve funds and other institutional public investors) becomes necessary for three reasons: firstly, on grounds of their fiduciary duty, secondly due to their role in the long-

[100] Des émissions financées aux indicateurs de performance climatique – Etat de l'art de la comptabilité des émissions de gaz à effet de serre pour le secteur financier, 2° Investing Initiative, September 2013.
[101] Ostrom, E., 1990, Governing the Commons: The Evolution of Institutions for Collective Action, Cambridge University Press.
[102] A broad interpretation of the 1992 Convention on biodiversity, which entered into force in 1993 after ratification by 30 States, led to the belief that the said convention made biodiversity a global public asset.
[103] Weinstein O., 2010, Pouvoir, Finances et Connaissance, les transformations de l'entreprise capitaliste entre 20e et 21e siècle, Editions La Découverte, Paris, page 98.
[104] The major contribution by Elinor Ostrom and Oliver Williamson, Nobel Prizewinners for Economics in 2009, was to bring back into favour the specific form of ownership and governance represented by these "commons" and which places the collective decisions of "communities" at the heart of socio-economic interactions. It is an alternative to the model of the creation of shareholder value, based on the private ownership of means of production and resources, as the sole source of the creation of collective wealth. The "commons" question is central to the history of capitalism and the historical definition of fiduciary responsibility.

term financing of the economy, and thirdly on grounds of their institutional societal responsibility. And the resources are available; the total stock of institutional investors' assets amounted to $93,000 billion in 2013, compared to 37 billion in 2001, which corresponds to annual growth of approximately 8%[105]. The investments required for the conservation of biodiversity would only represent a small fraction of the variation in this stock; the problem is thus found elsewhere, and especially in the fund managers' responsibility to optimise the value of their shareholders' assets and not those of society as a whole.

All else remaining equal, natural capital should be analysed as comprising externalities, which themselves constitute a risk that, if it occurs[106], will have a negative impact on the returns on investments and therefore on the dividends of the entire market. Indeed, the largest institutional investors are "universal owners", which means by virtue of their size, they are bound to be invested in all economic sectors. This theory stipulates that investors, whose portfolios include stock in companies that externalise certain costs, are exposed to the risk of diminished returns throughout their entire portfolios due to the fact that these externalities affect other companies in their portfolios and hence the market in general. Consequently, in theory, these "universal owners" have an objective interest in reducing the negative externalities and increasing the positive externalities of their investment portfolios. In summary, the interests of institutional investors should be aligned with those of the community and the public interest so long as they really behave as long-term investors. In reality, however, their management horizon rarely exceeds eight to ten years.

Natural capital – a "physical" challenge for financial markets

Today, and doubtless because the other risks remain hard to evaluate, the management of greenhouse gas emissions in investment portfolios is the biggest challenge facing institutional investors, followed by the use of water and air pollution.

And many investors have taken notice. According to an annual study by Novethic (2014) of 185 institutional investors in 13 countries representing €6,000 billion of managed assets, 12% of the investors surveyed have calculated the carbon footprint of their portfolios and 23% of investors assess this physical risk. The analysis remains limited to a small number of industries which means that it cannot reveal the total exposure of a portfolio to the carbon risk, as its materiality and extent vary from one sector to another. Finally, the carbon risk (risk of the emergence of carbon legislation and price) can only be evaluated in relation to a reference scenario. This means that there is a real "methodological deficit" that needs to be clearly identified. This task has been undertaken by the 2° Investing Initiative think tank which has used stress tests[107] to ascertain the impact of the carbon risk throughout the entire investment chain: starting with the risk concerning physical assets (*stranded assets*[108]), the risk propagates throughout the corporate and portfolio level and, given the importance of fossil energy sources in the global economy, goes on to become a systemic risk[109]. In addition, another project – Beyond Ratings – specialises in evaluating the energy risk of different countries in the framework of the evaluation of sovereign debts.

Encouraging initiatives that lack ambition

Boosted by the COP21, initiatives on climate change are proliferating

For the past fifteen years or so, investors with the greatest commitment to climate change have joined forces in numerous initiatives: *Carbon Disclosure Project – CDP* (launched in 2000, this is a pioneering initiative in terms of ESG reporting, seeking to obtain transparency regarding the emissions generated by the biggest multinationals), and *Global Investor Coalition On Climate Change* (a group of 250 investors seeking to find points of agreement on climate change-related issues at major events such as the COP21[110]), etc.

However, the undertakings of the last fifteen years took on a new dimension in 2014. Firstly, the United Nations Climate Summit led to the signature by 358 institutional investors of the *Global Investor Statement on Climate Change*, a declaration acknowledging the impact of climate change on their portfolios and the need to

[105] OECD (2014). Pension Markets in Focus, Paris: OECD.
[106] For certain sectors, such as reinsurance, this risk has already had a concrete effect, as seen by the dramatic rise in their costs. Even if the amount is less than the average annual economic losses observed over the last ten years ($188 B), natural and man-made disasters generated a cost of $113 B (approximately €90.5 B) in 2014, compared to $135 B (approximately €108 B) in 2013 [L'Argus de l'assurance website, published at 3:09 p.m. on 17 December 2014].
[107] Carbon Risk for Financial Institutions.
[108] Fossil energy resources that become obsolete due to a change in the market or regulations associated with the transition towards a low-carbon economy.
[109] A risk that can jeopardise the survival of the financial system.
[110] http://globalinvestorcoalition.org/worlds-leading-institutional-investors-managing-20-trillion-call-for-carbon-pricing-ambitious-global-climate-deal/

act. Following this summit, two major complementary initiatives were launched: the *Portfolio Decarbonization Coalition,* involving investors committed to the decarbonisation of their portfolios, and the *Montreal Carbon Pledge,* bringing together investors committed to measuring and publishing the carbon footprints of their portfolios.

However, it should be noted that investors are highly dependent on the information provided upstream by issuers, which poses a potential obstacle to any financial initiative.

The recent boom in coalitions on natural capital

Recent years have also seen the emergence of declarations and coalitions that are no longer confined to climate change but to natural capital as a whole.

Firstly, UNEP-FI (United Nations Environment Programme Finance Initiative), in addition to the Global Canopy programme, has instigated the *Natural Capital Declaration* (NCD). This initiative targets the financial sector and brings together 44 chief executives of financial institutions with the aim of integrating the key natural capital issues into the different types of assets and financial vehicles (loans, bonds and insurance products) and also into evaluation and reporting[111]. In addition to the declaration, a coalition of stakeholders: the *Natural Capital Coalition (NCC),* created in 2012 by The Economics of Ecosystems and Biodiversity (TEEB) study group, is the most recent initiative on natural capital. It involves all stakeholders (institutional investors, research, civil society and governments) in biodiversity and aims to standardise the methods used for evaluating natural capital. The coalition is planning on conducting a case study to prove that the integration of natural capital leads to better decision-making by improving the resilience of portfolios, reducing costs, securing supplies and finally creating a more sustainable business model.

Finally, a series of initiatives in 2015 could create closer links between the reform agendas for financial systems and key natural capital issues: the Disaster Risk Reduction Conference (Sendai, March), the Conference on Financing for Development (Addis-Ababa, July), the finalisation of the new Sustainable Development Goals (New York, September) and the achievement of an agreement on climate change (Paris, December).

Practices focusing primarily on taking account of the Carbon issue

These practices encompass the investment strategies that have been developed, the new instruments used and their measurement and reporting methods. However, institutional investors that set themselves natural capital conservation targets – even unquantified goals – are rare.

SRI funds

Certain natural heritage issues are incorporated into the asset allocation strategies of SRI (socially responsible investment) investors. These include three categories of approaches: Best-In-Class selection, the thematic or exclusion approach and shareholder commitment. Most of the time, these approaches (apart from the thematic approach) use ESG (environment, social and governance) criteria, either for deselecting or for weighting stock in a portfolio. However, the environmental component of this reporting consists primarily of GHG emissions. Two other indicators are also used, but to a much lesser extent: the energy consumption of companies in the portfolio and the consumption of water and the volumes of materials used[112].

These approaches are criticised for different reasons, but what they all have in common, thus far, is their inability to provide positive proof of their contribution to energy transition targets and, even more importantly, to the conservation of natural capital. Other instruments, on the other hand, earmark investments for mitigation projects (clean energy sources, energy efficiency, etc.) given that adaptation measures are more difficult to finance due to their low return on investment.

Unlisted funds

In 2014, according to the Cleantech AFIC (French association of investors for growth), a total amount of €470 million was invested in 86 "cleantech" companies (renewable energy, energy efficiency, energy efficiency, water treatment, etc.) in France – a record, but still falling far short of the levels required to meet the challenges. Investment in listed companies is not insubstantial, but in view of their size, these companies are rarely "pure players" in sustainable development or energy transition. Launched in 2015 by the EIB and the

[111] http://www.naturalcapitalforum.com/unep
[112] Etude-Indicateurs-ESG Novethic, 2013

European Commission, the Natural Capital Funding Facility (NCFF) is a financial instrument used for carrying out projects focusing on biodiversity and ecosystem services. These projects will promote the protection, restoration, management and improvement of natural capital (development of soils, land and forests, agriculture, water, waste management, etc.). In addition to investments, this instrument will seek to demonstrate to the market and to potential investors, the attraction – including the financial benefits – of operations relating to biodiversity and adaptation to climate change, in order to encourage the private sector to make sustainable investments.

Green bonds

In theory, these bonds allow for the earmarking of investments for projects that create environmental value (renewable energy sources, energy efficiency, etc.). Despite the existence of the *Green Bond Principles* (published in January 2014), the ratings of these "green" bonds, which have increased dramatically ($66 billion on 10 June 2015 compared to $11 billion in 2013, with between $70 and $100 billion forecast for 2015), do not, for the moment, take account of environmental criteria and they are lacking a global reference standard to ensure their impact and credibility. Nevertheless, ESG rating, verification and certification offerings are starting to appear (Standard & Poor's in particular). Furthermore, UNEP-FI is currently developing "e-risc", a methodology for evaluating and in integrating natural resources into the analysis of sovereign debt.

Low-carbon indexed investment management

Given their size, companies operating in the fossil energy sector figure prominently in the traditional stock market indexes. These indexes play a vital role in guiding the asset investment choices of institutional investors, who invest according to the composition of these indices or compare their performance to the index *benchmark*.

Developed by traditional providers of indexes such as FTSE and MSCI, fossil energy-free indexes in theory exclude coal, oil, gas and mining-sector industries (FTSE Developed ex Fossil fuel, MSCI ex Fossil Fuel, etc.). Nevertheless, in order to avoid excessive variances in relation to the standard indexes, and thus an unreasonable exposure to market risk, certain indexes often, and paradoxically, retain oil companies, which is highly detrimental to their effectiveness and credibility. Allowing for the adoption of a balanced approach between carbon risk reduction and exposure to market risk, low-carbon indexes reduce the weighting of companies exposed to carbon risk and keep a similar level of exposure to other market risks as the standard indexes. In this way, it is possible to reduce the carbon footprint by over 60% in relation to a standard index (e.g. MSCI Europe), and the *stranded asset* exposure by 80%, while maintaining a *tracking error* of only 70 base points[113]. In the long term, an investor can therefore obtain performance levels that are close to the benchmark while benefiting from protection in the event of the materiality of the carbon risk and thus of the loss of value of carbon-intensive companies.

While all of these strategies share the same aim, the debate focuses on their respective effectiveness for all stakeholders. Conveying a strong message and a commitment that corresponds to the urgency of climate concerns, exclusion/disinvestment strategies nevertheless come up against a strong market risk for investors, linked to the exclusion of sectors that have significant importance in the economy, and the lack of incentives for these companies to change their business models.

The role of the public authorities as catalysts for the consideration of natural capital by institutional investors

Speeding up the mobilisation of institutional investors is now at the heart of the political agenda

This is the intention of the initiative launched by the UN Secretary-General in February 2008, in which institutional investors were invited to reorient their investments towards a low-carbon economy offering a wealth of opportunities, followed by the initiative of September 2014 that we have already mentioned.

In the framework of the COP21, the Solutions Agenda is a new initiative which allows stakeholders from civil society to present actions corresponding to GHG reduction. Institutional investors will be able to present initiatives and innovative tools for financing energy transition. Investors' commitments will be consolidated on different platforms, including the Investor Platform on Climate Change for Climate Actions and the general UN platform – NAZCA; but the public authorities must boost the sector because their presence in it is insufficient.

[113] Andersson, M., Bolton, P., Samama, F., 2014. Hedging Climate Risk. Columbia Business School Research Paper No. 14-44.

The different types of public action that might be considered include three thrusts which could help to promote the integration of natural capital by institutional investors: a new governance system, the development of information systems and regulations allowing for the reasoned emergence of environmental asset markets.

Driven by the public authorities and certain investors, research into measurement and reporting tools has been stepped up.

A distinction must be made between two types of investments: investments incorporating an environmental quality criterion and direct investments in nature because ecosystem services generate value for the investor. On the one hand, efforts are made to promote investments that are not harmful to nature, and on the other, nature is considered an asset.

Discovering the impact of investments on natural capital

In order to ensure the efficient management of their portfolios, investors need prior knowledge of the impact of their investments on natural capital. The public authorities, including their financial inistitutions (Additional Retirement Regime Management Institution for the French Civil Service [ERAFP], Reserve Pension Fund [FRR], French Deposit and Consignment Fund [CDC]; pension funds for other countries) must support the development of these evaluations and encourage their international dissemination. This is defined in article 173 of the recently adopted and internationally ground-breaking French Energy Transition for Green Growth Act.

Numerous reporting methodologies that need to be homogenised…

Although the rapid development of GHG reporting (Novethic[114] lists 56 investors involved in measuring the carbon footprint, corresponding to 10% of investors that have made a climate commitment) is encouraging for the measurement of environmental performance, the resulting heterogeneity of the methodologies (their scope, reference period for calculating emissions, transparency, consolidation, etc.) poses problems[115], especially with regard to the distinction between the measurement of emissions (carbon footprint) and the assessment of carbon risk (related to the notion of *stranded assets* mentioned previously).

Nevertheless, the *Greenhouse Gas Protocol* (GHG Protocol) – a multilateral partnership involving companies, NGOs and governments, is currently working towards establishing an accounting standard that could allow for the unification of these methods – especially at the corporate level.

In the framework of the 4th working group of the Natural Capital Declaration, the IIRC (International Integrated Reporting Committee) and other stakeholders have begun analysing how to develop reporting on natural capital. The work will focus in particular on developing recommendations directed at the financial sector. Between now and 2016, the group will be developing a programme that seeks to introduce greater transparency and provide information about the direct impacts of the financial sector via all types of financial products and services (loans, investments and insurance)[116].

… and transparency to be improved

Once these tools have been developed, investors need to publicise their impacts because they have a duty to be transparent vis-à-vis stakeholders and their clients. France clearly leads the way on reporting issues, with article 224 of the act embodying the national commitment to the environment (Loi portant engagement national pour l'environnement) and article 48 of the above-mentioned Energy Transition for Green Growth Act. French stakeholders are not lagging behind. The FRR calculated an initial environmental footprint for its portfolio in 2007 and it measured its carbon footprint in 2013 and 2014. For the second consecutive year, the ERAFP, with the support of Amundi, calculated the carbon footprint of its equity portfolio in 2014. Mirova, in partnership with Carbone 4, has developed an innovative methodology that can be used to measure the carbon footprint of its investments in corporate equities and corporate bonds in tCO_2 equivalents emitted and avoided, following the example of what exists for project financing.

The French Ministry of Ecology, Sustainable Development and Energy is developing two labels that are intended to promote transparency for emitters: the "SRI" label, which includes an environmental component and adopts a best-in-class approach, and the Energy and Ecological Transition fro Green Growth label which rewards the best investors but above all encourages the development and homogenisation of reporting.

[114] Novethic, Les investisseurs mobilisés sur le changement climatique, 2015.
[115] http://2degrees-investing.org/IMG/pdf/2dii_emissionsfinancees_diff.pdf
[116] www.naturalcapitaldeclaration.org/working-group-4/

Can the emergence of environmental assets promote the integration of natural capital into investment policies and strategies?

Apart from transparency and reporting obligations, the public authorities must imperatively facilitate the creation of conditions favourable to the markets when natural capital is substitutable (1 t of CO_2 in France is equivalent to 1 t of CO_2 in China). Moreover, since the mid-2000s, "market instruments" for biodiversity, with varying degrees of regulation by the public authorities, have been strongly developed by the French State. This either involves offsetting damage to biodiversity through payments of financial flows to third-party organisations which will be responsible for implementing compensation in kind, or collecting biodiversity units within an entity called a "bio-bank", which acts as an intermediary between the requesters and suppliers of compensation units. Considering their very mixed results and the increasing, legitimate controversy surrounding them, this attempt to create environmental assets out of "natural capital" can be deemed to be inappropriate.

In addition to ESG criteria, the key natural capital issues should be integrated into the credit policies of specific sectors that have a major impact on natural capital. This capital should also be considered and evaluated in commercial insurance operations and strategies, including risk management, the development of products and services, the management of claims, sales and marketing, and the management of investments.

But for this to happen, there will need to be a true revolution in ways of thinking,[117] and acceptance of the fact that regulation by public reference prices, while necessary, is far from sufficient. Thinking about how to adopt what should be a "back to basics" approach to the fiduciary duty of institutional investors could trigger this revolution, but for this to happen, there will need to be acceptance of the fact that this responsibility is no longer confined to simply maximising the short-term returns on their investment portfolios under constraints. It will also be necessary to change the investment norm[118] and the governance of natural capital – this asset common to us all.

[117] MEDDE, Stratégie nationale de développement durable pour la croissance verte, 2015 (Axe 4 – Inventer de nouveaux modèles économiques et financiers).

[118] Analogous to the concept of standards of consumption or production, which are above all social standards, going beyond the framework of strict economic rationality.

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Nature and money – Reductions of CO_2 emissions as a new eligible asset for central banks

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Money is now largely conceived of in a way that is disconnected from the financing operations for which it is used in the economic circuit, the social interactions that it promotes and the links with the environment that it modifies. This apparent neutrality is in reality more of a very specific institutional construction that conceals the underlying political priorities. Re-incorporating money into environmental and social constraints demands requires us to reveal the mechanics of this neutralisation of money. An application specific to investment in the low-carbon transition can be inferred.

In the following pages, we shall be outlining the bases of a proposal for funding the low-carbon transition using the tools of bank credit and money. We also wish to insert the monetary approach underlying our proposition into the extremely complex landscape of the main schools of thought on monetary issues. Presenting a critical history of monetary theories from the perspective of their interaction with the natural environment and humankind is, however, far beyond the scope and aims of this article.

The current dual financial and climate crisis allows us to re-situate monetary issues by casting light on some of the properties of a medium which, in normal times, defies identification, such is its influence on our daily lives and power to blind us by its omnipresence. Environmental and financial externalities do indeed, seem to bring together, under pressure, such essential components of capitalism as growth and money. The majority of the considerations normally focus on research programmes and separate public policy recommendations that aim to resolve problems relating specifically to either of these externalities. However, the two crises are related and must be addressed and considered together by economic analysis. This heuristic basis underlies the final proposal of this article, which seeks to make a carbon asset eligible for central bank balance sheets.

From neutral money…

As can be seen by the changes in orthodox models of monetary macroeconomics (referred to as "DSGE" models), the 2008 crisis had a relatively marginal impact on ideas relating to money and finance. It is true that the financial sector started to be considered in different ways, and even to be incorporated into the central bank's monetary control function, inaugurating a new "macroprudential" monitoring function by the monetary authorities. But the representation of money that underlies these changes remains identical to its main function before the crisis: acting as a simple neutral intermediary in trade, whose only importance may be due to price adjustment inertia.

Money in this context is considered to be exogenous to the economy. It has a potential to interfere in the political domain and disrupt the power of the economic sphere which, by nature, is presumed to operate in an optimal manner. In such a framework, a "good" monetary policy eliminates these possibilities and thus institutionalises the distancing of money from the economic and political spheres. At best, monetary policy can attempt to compensate for the friction arising from the dynamic evolution of prices, by supporting their relatively lengthy adjustments to the changes in economic conditions.

The success of the exogenous money theory at the political level also signals the failure of any assessment of the qualitative role of money, and especially of a role associated with the environmental externality. Indeed, if money can only reduce transaction costs without playing any particular role in the nature of these transactions or the links developed among individuals in the production and trading processes, then there is absolutely no point in conceiving of the link between the economy and the environment from a monetary perspective. Neutral money is, by essence, blind to the environment as it is blind to the nature of social links.

… to neutralised money

However, this view of money may, in many respects, appear anti-historical and antisocial, since it rejects all of the available historical and anthropological information concerning the origin of money, which point towards it playing an active role in the development of very diverse societies. In this way, the assumption on which the concept of exogenous money is based is that it minimises transaction costs in relation to a barter economy, by

removing the constraint of the "double coincidence of wants"[119]. However, this history is, to a very great extent, completely fictional. There are abundant examples of pre-monetary or non-monetary economies that make no use of the barter system at all. In reality, to date it would seem impossible to mention even one past or present example of a barter economy (from which a monetary economy might have emerged). So how much importance can be attached to such an account? It is probably more helpful in the development of a concept of political philosophy, by allowing a modern institution to be devised on the basis of a mythological reconstruction of economic history: bartering as a logical and therefore necessarily real antecedent of money. Epistemological errors are commonplace. The monetary neutrality of monetarists and neo-Keynesians is thus in itself a purely theoretical construction that has become social only through the institutions that it justifies and helps to consolidate, and not through any type of historical trend. Money, therefore, is not neutral – it is neutralised.

As stated by the economist Milton Friedman when describing the economy of the Pacific island of Yap[120], money as an object that facilitates trade is an ephemeral epiphenomenon: it is the underlying system of credit and compensation that is the essence of money. This indifference to the physical *medium* illustrates the fact that money is not a commodity that would be chosen at random to facilitate exchanges between disparate individuals, but rather a social system of credit and compensation, i.e. a social technology, to use an even more abstract term. We take "social technology" to mean the links that money defines between members of a society and commercial trade links, as well as symbolic links and those relating to power. As soon as these historical and anthropological contributions are accepted, money loses this property of neutrality to take on a political, social and environmental dimension.

Because it renders all types of services to society, the natural environment logically forms part of this complex and abstract system of credit and compensation. It has a full stake in this social technology. Money, in this broader sense, is the tool used to account for the interrelated economic and symbolic debts of members of a society and also with regard to the outside world, be it other societies or natural resources. Through different forms of items that are held to be sacred, a series of credits and compensations encompasses the wide range of natural elements that are useful to societies. This sometimes very sophisticated social technology (e.g. the *potlatch* culture in Amerindian societies) allows so-called "primitive" societies to live in a manner that does not impoverish the environment on which they depend. This environment would only collapse after a major and unprecedented exogenous event, to which the society may respond by making inappropriate decisions. In the framework of capitalist societies, in which commercial value is the main driving force, it becomes necessary to clarify these interrelated debts and give them a monetary value. But the credit and compensation system ultimately operates in the same manner, i.e. as a social technology that defines the links among members of the society, and between the society and its environment.

The fight for control

Accepting the non-neutrality of money immediately raises the question of its control and the extent of its use. In the "chartalist" approach to money, monetary history can cast light on this question of monetary control. Indeed, money always historically appears to be, above all, an instrument *of the* sovereign power or *in opposition* to the sovereign power, but in any case, it always *relates* to this power. On the one hand, it would thus be the *medium* through which the sovereign power raises taxes, and on the other, it would be the medium that allows people to avoid them. In this case, money appears not as a means of simplifying any economic barter-based exchanges that might pre-date it, but as a means of consolidating (or avoiding) the complex logistical management of a budgetary policy that would otherwise be carried out in kind, or not at all. This strong link between fiscal systems and monetary systems could explain the monetary monopoly that is now observed in all countries almost exclusively. By exerting a stranglehold over the circulation of money created in this way, the sovereign power can create markets that will help to develop its power and thus perpetuate its status. If it loses control of this circulation, it will immediately lose its power. Money is thus the perfect vehicle for expressing the tensions of the political power.

Once this historical perspective has been accepted, it can then be used to normatively justify two completely contrasting positions. Supporters of the Austrian school, like Hayek, infer from this that everything must be done to counteract this tendency of the State to exert a stranglehold over private affairs. They go so far as to advocate private monetary systems, which are totally disconnected from any sovereign power. The concrete application of this would be the simultaneous and independent issuance of different types of money by

[119] It is this mythified constraint that prevents trade from happening when person A does not possess the exact goods wanted by person B and vice versa.

[120] In fact, the indigenous people of this particular island used to use a form of money consisting of round stones – the fei. These round stones were so big and heavy that it would be hard to claim they were the best way to facilitate trade. Moreover, trade on the island was limited to a very small number of products, which could have easily led to an economy based on the barter system. It was virtually impossible to transport such stones from one owner to another, at least for everyday transactions. The fei could only be transported for certain cases of compensation that were not simply concluded by an acknowledgement of debt, in which the fei would then remain in situ.

commercial banks, with no "central" money to guarantee any equivalence among them. There were experiments with this *free banking* concept in the United States from the 1838 *Free Banking Act* until the 1863 *National Bank Act*. But the lack of a lender of last resort proved to be prohibitive and the needs of the (civil) war economy soon put an end to the experiment. On the contrary, supporters of neo-chartalism consider that the role of a democratic State is to resolve the political tensions resulting from the changes in money supplies issued by banks when credit is created. Furthermore, this money from commercial banks is not, from this perspective, considered as "real" money but rather as a "sign of credit", reflecting the purely private relationship that it underpins when it is first issued. This "sign of credit" only acquires the status of a general equivalent applicable to real money when it is finally socialised by being incorporated into the productive system.

Money thus permanently reflects the tension between its essentially private creation and its social validation as a public good. In this way, it is the key vehicle for resolving the stresses inherent to any society. It could therefore be logically considered that the environment, in all of its dimensions, corresponds perfectly to one of the possible stress factors that money is responsible for overcoming. However, this logical consideration has not been adopted until today. From the 1980s in particular, the majority of Western countries started implementing monetary policies based on the concept of neutral money that is independent of the political power, even though the issue of climate change increasingly appears to be a global emergency whose resolution will have significant implications for economies. Scientific and political alerts are first sounded in the 1972 Club of Rome report and have intensified since then. At the same time, all kinds of environmental degradations continue at a rate that is unparalleled in human history. The UNEP recently revealed that climate risks are starting to be accounted for in the balance sheets and regulations of central banks in certain Southern countries, which could offer hope of an improvement to this situation. Money, as a vehicle for resolving internal and external societal pressures, has the structural role of integrating the major stress that will predominate in the 21st century – environmental stress.

Limitations and resistance to a single universal equivalent

However, the extension of the monetisation of any form of social link, *i.e.* the use of money as an exclusive social technology, is not unanimously perceived to be a form of absolute social progress. In practice, there is a certain amount of resistance to the reduction of all transaction costs and the increasing fungibility of the world. The main criticism concerns the inadequacy of this tool for summarising all of the links that exist within a society, in addition to the completely specific links between a society and its environment. As we have seen, from a theoretical standpoint, a surreptitious change from a private bond (the "sign of credit") to a social bond (money in its strict sense) without a visible change of medium does indeed justify control of both the quantities and qualities of these "signs of credit", in contrast to the doctrines of the Austrian school. And in one way or another, controlling these quantities and quantities amounts to setting certain limits for the social technology that is money.

These limits may come in different forms. One of them is based on the idea that a single valuation scale cannot take account of the diversity of internal and external societal bonds. The real question then becomes the possibility of the simultaneous existence of different scales of value, without them necessarily being interchangeable due to the incommensurability of the values. The recent emergence of political debates about the pertinence of local currencies, and more generally about monetary plurality within a given social group or geographical area, reflects these doubts. The increasingly overlapping nature of the geographical scales on which the bonds of exchange and solidarity are expressed should tend to intensify these discussions. It is clear that economic theory is quite powerless in response to this trend and is unable to characterise the causes of the phenomenon in a satisfactory manner. One probable reason for much of this situation is the "disembedding" of economic theory from the broader context of social, cultural and historical questions, and from natural sciences. A second possible limit consists of seeking the total or partial elimination of money. Such attempts may have been made in ancient Sparta, without ever managing to completely eliminate the need for minimal monetary flows. Another response could be to circumvent money, as was the case in Soviet Russia, in effect by making it unnecessary, which also deprived the country of money's function as a key economic measurement instrument. These conflicts and resistances become particularly apparent whenever the manifestation of the theoretical neutrality of the instrument is perceived to be a tool that in practice benefits specific and minority interests.

At a more practical level, the monetisation of all forms of value associated with the environment could pose complex technical challenges. While carbon emissions might seem quite simple to measure, the reduction of emissions requires more subjective assumptions. What benchmark should be chosen for evaluating this reduction? How does an emission source, which is necessarily of a microeconomic nature, contribute to the global – macroeconomic – reduction of emissions? Can one reduction of emissions be offset by another? In other terms, do all reductions of emissions possess the properties of fungibility and universal equivalence that are normally attributed to money? The situation becomes even more complicated when we decide tackle the

issue of biodiversity. It is valued in a diverse range of ways according to the geographical scale in question, and often arouses controversy. This valuation is necessary at the global level for conservation reasons but it runs into stronger economic interests at the regional scale and is a source of occasionally violent social conflict at the local level. Therefore, it is particularly difficult come up with a single value that is acceptable to all parties according to a consensual criterion of fairness, which can then be translated into monetary form.

Imaginary capital and coordination of expectations

In effect, money thus emerges, in the context of capitalism, as a universal equivalent of value, which could be compared to physical units of measurement. Just as a metre is an abstract concept of the measurement of distance, a currency such as the dollar does not relate to any physical object. For all that, money cannot be considered to be a scientific measurement in the same way as the physical units of the international system. This is because it measures economic value – a property of the social world – which by transforming it, acts retrospectively on itself. In this section, we shall be focusing on the structural modification of capitalism, which occurred in the last decades of the 20th century, and which gives a key role to the financial sector in the process of accumulating capital and value. Money then becomes representative of a future expected value rather than representing value that has actually been achieved. Since the start of the 1980s and what has been referred to as financial globalisation, an ever-increasing share of the growth of Western countries has originated from the financial sector. Accountancy tends to integrate changes in the value of financial assets, such as the genuine creation/destruction of wealth. The role of the market efficiency hypothesis is to justify this accounting standard from a theoretical perspective and provide a horizon for the deregulation reform policies that need to be carried out. Consequently, any change in the price of assets, *i.e.* of title deeds, will be seen as a change in the underlying value of the capital to which these title deeds relate. The underlying value is thus hypothetically entirely determined by markets that optimise the allocation of the capital at their disposal in order to satisfy a collection of individual interests.

There is, however, another way to conceive of the financial system, which seems much better suited to the observations of the successive financial crises that have arisen since the 1980s. This naturally involves abandoning the market efficiency hypothesis, whose purely utopian conditions of existence are not met in reality, and making the question of the origin of value the central concern. By abandoning this criterion of market efficiency, the evaluation of the prices of financial securities no longer necessarily reflects an increase in the underlying value but simply a form of inflation in the literal sense of the word: a rise in the prices without an increase in value. But whereas the inflation of goods and services reflects their devaluation, the inflation of the prices of assets should be perceived as an enhancement of the capital, insofar as the money placed therein increases for as long as the accumulation of the title deeds continues. This accumulation of title deeds, which are themselves generally secured against other title deeds, and so on, is based on the purely self-referential capitalisation of expectations about the future of economic agents, *i.e* the pre-funding of future value. These expectations about the future allow for the creation of large waves of accumulations of "imaginary" capital, which are based on an actual creation of value that is always comparatively smaller. These expectations inevitably end in disappointment, leading to the destruction of the imaginary capital, which in the meantime has very often changed hands.

These sequences involving the creation/destruction of imaginary capital have three main consequences for the natural environment in the broadest sense of the term. First of all, the fluctuations associated with these financial cycles cause a massive overexploitation of natural resources. The anticipation of the creation of future value often focuses on energy and raw material-intensive sectors, as is the case for information and communication technologies, or land use-intensive sectors such as real estate. In such examples, the accumulation of imaginary capital is reflected by a particularly inefficient but very real use of resources. In recessionary phases of the financial cycle, the complete depreciation of this capital becomes apparent. The non-internalisation of the environmental externality then only further increases the waste of resources associated with these cycles, and prevents the available funds from being channelled into projects with high social returns, such as green investment needs for the adaptation of the productive fabric and the conservation of ecosystems, sustainable cities, etc. Finally, the geographical indifference that coincides with financial globalisation creates the conditions for geographical indifference to the allocation of capital. In this way, even if the environmental externalities have been integrated and the cycles have been relatively controlled, a form of incompatibility may still remain between the notions of the efficient allocation of capital on a global scale and the conservation of a necessarily localised biotope. Consequently, it becomes urgent to "embed" expectations of the future value of economic agents into all aspects of the environmental constraint.

Embedding money into the carbon constraint

The end of the gold standard and then of the Bretton Woods system has thus led to the emergence of a new monetary regime based on the accumulation of imaginary capital relating to the anticipation of future value. At

the same time, capitalist expansion has attained and even sometimes exceeded the limits for the sustenance of all life on Earth. The perpetuation of methods to create private "signs of credit" which are then socially validated in a virtually automatic manner by the central bank in the form of their incorporation into the universal monetary equivalent, will inevitably, through exploitation by people without concern for quality, lead to a continued failure to heed these limits. The proposal formulated and summarised herein amounts to nothing less than establishing a new balance of power within the lender of last resort that is the central bank. This is not just a question of a new balance between the State and Economy, represented in the seminal example of the Bank of England by the monarch and the merchants of London[121], but of a compromise between public power, commercial and productive activities, and the natural environment. A new *grand bargain* must, in one form or another, include the conservation of the environment. And yet prevented carbon emissions are the metrics for a commonly shared wealth, corresponding to a guarantee of the very possibility of continuing the process of capitalistic accumulation. Provided they are valued at a sufficiently high level, in the form of the social value of carbon, for example[122], they could ultimately replace gold as the universally accepted equivalent. Consequently, incentives for the issuance of new "signs of credit" could be automatically associated with the prospect of their potential convertibility into "carbon certificates", issued in a controlled manner by accredited certification bodies. New prospects for low-carbon development are emerging as the future outcomes of such a change[123].

Coordination by the carbon standard

In conclusion, we shall present the balance sheet effects that such a "carbon certificate" accumulation mechanism could have, based on the example of an individual project. Let us consider an imaginary low-carbon project allowing for the reduction of five units of CO_2. The social value of carbon is set at two. This value is the result of a process of political negotiation concerning the value for society of a marginal reduction in CO_2 emissions. This project could be funded with a loan of 100 (to simplify the analysis, interest rates are not taken into account). With the understanding that low-carbon loans can be refinanced by the central bank (BC) for the same amount as the value of the emission reductions achieved, the financial intermediary consequently modifies the assessment of the investment risk for the low-carbon project and grants it a loan of 100.

Balance sheets when the loan is taken out

Financial Intermediary		Low-carbon entrepreneur	
Asset	Liability	Asset	Liability
		100	
100	100		100

When the loan matures, the project holder has repaid 90 with its monetary revenues and has received five carbon certificates (CCs) corresponding to five CO_2 units prevented. These five CCs allow the business person to cancel its remaining debt to the financial intermediary as the latter can refinance the value of the CCs through the central bank (CB).

[121] The central Bank of England was created at the end of the 17th century in response to the social pressures and constraints reflecting the extremely rapid development of the nascent English capitalism. William Paterson's project for a central bank was finally adopted, as it managed to reconcile the interests of major merchants and the royalty – the two most important political forces of this period. A subscription was successfully launched to issue banknotes that were wholly consigned to the State. Subscribers thus entrusted the State with all of their capital, which in return made a commitment to collect new taxes on spirits and shipping tonnage in order to repay the interest on the loans. Acting as both the main lender and the State's cashier, this institution can be considered to be the government's bank. But it is also an independent institution that is totally independent of the governing power, due to the election of its administrators who, at the outset, were chosen from amongst London's foremost merchants. The bank thus issued banknotes mentioning the commitment to pay the bearer a certain number of shillings. This "gold standard" system, which was the fruit of a political compromise between the interests of the British royalty and those of the merchants of London, soon placed immense resources at the Bank of England's disposal, while also compelling it to intervene on the precious metal market in order to influence the prices.

[122] The social value of carbon is defined as the value assigned to a marginal reduction of CO_2 emissions. There are large variations in the values calculated using the existing models due to major uncertainties about physical (climatic sensitivity, etc.), socio-economic (speed of technical progress) and ethical (discount rate) parameters. In this way, the value ultimately chosen is the fruit of a political compromise.

[123] A more technical and exhaustive description of the entire scheme can be downloaded from the following address: http://www.strategie.gouv.fr/publications/une-proposition-financer-linvestissement-bas-carbone-europe.

Balance sheets when the debt is closed

Central Bank		Financial Intermediary		Low-carbon entrepreneur	
Asset	Liability	Asset	Liability	Asset	Liability
5CC	10	~~10~~	~~10~~	100 - 90 ~~5CC~~	~~10~~

The increase in the balance sheet granted by the CB for the purchase of the CCs clearly corresponds to the value accepted by the lender of last resort in a form of low-carbon standard, which is a potential alternative to the gold standard. The public guarantee provided for the value of the CCs purchased by the central bank (CB) is not intended to replace the implementation of a carbon price. Very pragmatically and in accordance with the conception of money as a vehicle for resolving social tensions, it saves the existing capital and sends out a "price signal" to new investments, during the low-carbon transition phase for production equipment. In doing so, it significantly reduces the immediate distributive effects of the carbon price, while sending out a long-term signal concerning the level it must reach. The central bank's balance sheet can then return to its initial size if the State decides to purchase the CCs using its new tax revenues (generated by the gradual implementation of a carbon price, for example). In any case, a certain amount of emissions will have been removed from the economy, which clearly constitutes a creation of wealth in relation to the current trajectory.

In this way, such a scheme to embed the environmental constraint into the economy could steer the incentives for economic stakeholders towards measures to conserve the very lifeblood of their physical existence. It certainly cannot resolve the question of the incommensurability of values and remains within the strict framework of a process of capitalistic accumulation, and even of the accumulation of imaginary capital, in the sense that the low-carbon transition becomes the new "bearer of promises" for the accumulation process. In this respect and as it stands, it cannot convince the advocates of "degrowth" or "enoughness". But from the perspective of deconstructing the existing situation, it seeks to reorient the incentive mechanisms for accumulation in a quite radical manner. This is definitely a change of monetary paradigm which, once validated, may then develop in very different directions in favour of the new balances of social forces.

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Abstract

Although it is common knowledge that GDP is an imperfect indicator and that nature is a key ingredient for growth, there is still no "shared vision" on the appropriate manner to measure and integrate nature into the "wealth of nations". What is at stake is the possibility of an inclusive and sustainable growth.

This edition of the CGDD review aims at presenting the current state of knowledge concerning "natural capital". It first proposes an interdisciplinary reflection about human-nature-society relationships and the economic framing of the role played by nature in economic growth.

This ambition leads to revisit the principle of public and common goods, such as climate and biodiversity which are part and parcel of the wealth of nations.

Attempts to measure the natural capital make it possible to better understand the wealth and frailties of human-nature relationships, by means of (monetary or biophysical) indicators and metrics.

The objective of the second part is to open a dialogue between different methodological proposals in order to point out innovations, but also gaps and needs of knowledge.

Finally, in the third part, natural capital is considered from the perspective of economic agents: States, investors, banks, businesses. What are the missing values they need to integrate the quality of the environment into their long-term strategy? How can we make those values get into business models? By means of which economic and financial instruments? What are the necessary regulatory and institutional changes?

While methodological controversies regarding the "best" way to measure the nature are potentially insoluble, the needs formulated by economic agents and the urgency to act create the condition for a strong social demand to accelerate the stabilization of conventions of measure. The goal is to scale up investments in natural assets.

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