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The Bioeconomy–Biodiversity Nexus: Enhancing or Undermining Nature's Contributions to People?

Mairon G. Bastos Lima [1,2,*] and Ulrika Palme [3,4]

[1] Stockholm Environment Institute, 104 51 Stockholm, Sweden
[2] Physical Resource Theory, Chalmers University of Technology, 412 96 Gothenburg, Sweden
[3] Environmental Systems Analysis, Chalmers University of Technology, 412 96 Gothenburg, Sweden; ulrika.palme@chalmers.se
[4] Gothenburg Global Biodiversity Centre, Carl Skottsbergs Gata 22B, 413 19 Gothenburg, Sweden
* Correspondence: mairon.bastoslima@sei.org

Abstract: Bioeconomy has become fundamental for a post-fossil-resources society, in line with climate change mitigation ambitions. Although it does not have a single, consensual definition, the bioeconomy encompasses various bio-based value chains and economic activities relying on biodiversity. How these burgeoning developments may affect biodiversity, however, still needs further examination. This article explores the bioeconomy–biodiversity nexus through the lens of nature's contributions to people (NCPs). Drawing from the bioeconomy literature and Amazonian experiences, we argue that the bioeconomy may: (i) help conserve or restore habitats, (ii) improve knowledge on biodiversity, (iii) valorize livelihoods and increase social participation, and (iv) aid in moving beyond the commodification of nature. However, none of these achievements can be taken for granted. To date, the bioeconomy has focused mainly on extracting goods from nature (e.g., food, energy, or biochemicals), often at the expense of NCPs that require integral ecosystems and are decisive for a sustainable society in the longer run. Moreover, we assert that it is critical to discern the beneficiaries of various contributions, as "people", in reality, are composed of distinct groups that relate differently to nature and have different preferences regarding trade-offs. The NCPs framework can help broaden synergies in the bioeconomy–biodiversity nexus, but inclusive governance remains critical.

Keywords: ecosystem services; biofuels; Brazil; sustainable development; political ecology; biomass; landscape governance; bio-based value webs; indigenous peoples; forest policy

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1. Introduction

Most scenarios for avoiding a global temperature increase beyond 1.5–2 °C, as stipulated by the Paris Agreement, require substantial increases in bioenergy use [1]. Moreover, the ongoing transition towards a bioeconomy is making biomass production from forests and agriculture increasingly multipurpose and expanding its economic uses [2]. Increased industrial use of biomass, however, if relying on area expansion and plantations of a selected few species, could spell doom for the conservation of natural habitats and biodiversity [3]. The UN Food and Agriculture Organization (FAO) already notes that agri-food systems have been significantly undermining the biodiversity that is the basis of genetic resources and ecosystem-regulating contributions from nature [4]. As bio-based production systems expand, reconciling bioeconomy with ecosystem conservation and multifunctional landscapes becomes even more vital.

Bioeconomy includes both bulk, low-value and high-volume products (e.g., construction materials, biomass for fuels) and finer, low-volume and high-value goods (e.g., biochemical resources for the cosmetic or pharmaceutical industries), as well as services such as experiential tourism [5,6]. How to deliver on that sustainably, however, remains a challenge. There are risks not only to nature but also to the people who depend on it. Critics

have raised concerns about the increasing "commodification of life" and ask who is to benefit—or to lose—from these growing nature-based business opportunities [7–9].

Therefore, this article aims to flesh out the nexus between bioeconomy on the one hand and biodiversity and the closely linked issue of ecosystem health and its importance to people on the other. It investigates how the bioeconomy transition can indeed be a sustainable transition, using nature's contributions to people (NCPs) as a framework, in line with the new language of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). Unraveling the bioeconomy–biodiversity nexus to analyze the interdependencies, potential synergies and trade-offs is crucial for achieving the Sustainable Development Goals. Multiple national (or supranational) strategies also require the reconciling of bioeconomy and conservation interests, such as the European Union's target to protect biodiversity in at least 30% of its land by 2030—which will mostly come not through strict area protection but through agro-ecologically sound land use [10]. Similarly, Brazil aims to pursue a "green" post-COVID-19 recovery, with bioeconomic development for the Amazon Region [6].

Using the emblematic case of the Brazilian Amazon—the largest expanse of rainforest left on the planet, inhabited by tens of millions of people—as an illustrative example, we delve into the literature on bioeconomy and NCPs to understand the points of convergence as well as tensions between the two. First, we review the emergence of NCPs as a novel concept espoused by the IBPES and how it goes beyond the previous, more conventional notion of ecosystem services. Secondly, based on the scientific literature and drawing lessons from studies on the Amazon, we assess how bioeconomy promotion affects different NCPs and how it could meet the ambition to enhance rather than undermine such contributions.

We show that bioeconomy advances have so far enhanced nature's physical contributions such as energy, foods, and—increasingly—more refined biochemical components. Nevertheless, more attention is needed in order to stop undermining the regulating and other, more complex contributions that require integral ecosystems (e.g., climate regulation, psychological experiences, or the support of social identities). While trade-offs do sometimes exist, it is critical to determine who decides on them. We discuss the importance of discerning the beneficiaries of nature's various contributions under different bioeconomy development scenarios and bring in the 2030 Agenda's imperative to "reach the furthest behind first" [11] (p. 3).

2. Beyond "Ecosystem Services": The Nature's Contributions to People (NCPs) Framework

2.1. Ecosystem Services

In the early 2000s, the reports from the Millennium Ecosystem Assessment on the consequences of ecosystem change on human well-being were published, covering the work of more than 1300 scientists from 95 countries [12,13]. "Ecosystem services" had been used as a concept long before these reports, but it was through the Millennium Assessment that the concept became broadly established in science and policy. Early uses of the concept focused mainly on processes (as opposed to goods) and valuation, often in monetary terms. The Millennium Assessment built on and developed both of these aspects.

Previously, the concept of ecosystem services had been used mainly by biologists and ecologists to emphasize the fact that nature does not only provide human society with essential physical resources or goods. Just as importantly, it carries out processes that are essential for human society, such as photosynthesis and pollination (see [14]). This understanding of the concept was close to that of ecosystem functions, which referred to all processes in ecosystems, whether known to be beneficial to human society or not, and implied the importance of ecosystem health. The concept in the Millennium Assessment covered both goods and processes, referring to the former as provisioning services and the latter as regulating and supporting services. To these three categories of ecosystem services were added the cultural services, consisting of immaterial contributions to society [13]. Table 1 shows the categories of NCPs [15] vis-à-vis the types of ecosystem services listed

in the Millennium Assessment (MA) [14]. Furthermore, Table 1 includes the groups of ecosystem services from the widely used Common International Classification of Ecosystem Services (CICES). This classification also includes classes that give a considerably more detailed description of each ecosystem service (see [16]).

Table 1. List of NCPs alongside the corresponding ecosystem services from the Millennium Ecosystem Assessment and the CICES groups of ecosystem services.

Nature's Contributions to People (NCPs)	Ecosystem Services (MA)	Ecosystem Services CICES Group
Regulating	**Regulating Services**	
1. Habitat creation and maintenance	—	• Genetic material from plants, algae, or fungi • Genetic material from animals • Lifecycle maintenance, and habitat and gene pool protection
2. Pollination and dispersal of other propagules	Pollination	• Lifecycle maintenance, and habitat and gene pool protection
3. Regulation of air quality	Air quality regulation	• Remediation of wastes or toxic substances of anthropogenic origin by living processes • Remediation of nuisances of anthropogenic origin • Atmospheric composition and conditions
4. Regulation of climate	Climate regulation	• Atmospheric composition and conditions
5. Regulation of ocean acidification	—	—
6. Regulation of freshwater quantity, location, and timing	Water regulation	• Regulation of baseline flows and extreme events • Physical and experiential interactions with natural environment • Intellectual and representative interactions with natural environment • Spiritual, symbolic and other interactions with natural environment • Other biotic characteristics that have a non-use value
7. Regulation of freshwater and coastal water quality	Water purification and waste treatment	• Water conditions
8. Formation, protection, and decontamination of soils and sediments	Erosion regulation Soil formation (supporting service)	• Remediation of wastes or toxic substances of anthropogenic origin by living processes • Regulation of baseline flows and extreme events • Regulation of soil quality
9. Regulation of hazards and extreme events	Natural hazard regulation	• Remediation of nuisances of anthropogenic origin • Regulation of baseline flows and extreme events
10. Regulation of detrimental organisms and biological processes	Pest regulation Disease regulation	• Remediation of wastes or toxic substances of anthropogenic origin by living processes • Pest and disease control
Material	**Provisioning Services**	
11. Energy	Fuel	• Cultivated terrestrial plants for nutrition, materials, or energy • Cultivated aquatic plants for nutrition, materials, or energy • Reared animals for nutrition, materials, or energy • Reared aquatic animals for nutrition, materials, or energy
12. Food and feed	Food	• Wild plants (terrestrial and aquatic) for nutrition, materials, or energy • Wild animals (terrestrial and aquatic) for nutrition, materials, or energy

Table 1. *Cont.*

Nature's Contributions to People (NCPs)	Ecosystem Services (MA)	Ecosystem Services CICES Group
13. Materials and assistance	Fiber	• Cultivated terrestrial plants for nutrition, materials, or energy • Cultivated aquatic plants for nutrition, materials, or energy • Reared animals for nutrition, materials, or energy • Reared aquatic animals for nutrition, materials, or energy • Wild plants (terrestrial and aquatic) for nutrition, materials, or energy • Genetic material from plants, algae. or fungi • Genetic material from animals • Regulation of baseline flows and extreme events • Spiritual, symbolic, and other interactions with natural environment
14. Medicinal, biochemical, and genetic resources	Genetic resources Biochemicals, natural medicines and pharmaceuticals Ornamentals	• Cultivated terrestrial plants for nutrition, materials, or energy • Cultivated aquatic plants for nutrition, materials, or energy • Reared animals for nutrition, materials, or energy • Reared aquatic animals for nutrition, materials, or energy • Wild plants (terrestrial and aquatic) for nutrition, materials, or energy • Genetic material from plants, algae, or fungi • Genetic material from animals • Genetic material from organisms
	Freshwater	—
Non-Material	**Cultural Services**	
15. Learning and inspiration	Knowledge systems Educational values Inspiration Aesthetic values	• Intellectual and representative interactions with natural environment
16. Physical and psychological experiences	Spiritual and religious values Recreation and ecotourism	• Physical and experiential interactions with natural environment • Intellectual and representative interactions with natural environment
17. Supporting identities	Cultural diversity Social relations Sense of place Cultural heritage values	• Intellectual and representative interactions with natural environment • Spiritual, symbolic, and other interactions with natural environment
Cross-Cutting		
18. Maintenance of options		• Other biotic characteristics that have a non-use value
—	**Supporting Services** [1] Soil formation Photosynthesis Primary production Nutrient cycling Water cycling	—

[1] Notably, the category of supporting ecosystem services is not included in either the NCPs or CICES. In the former, these features are regarded as components of nature or, to a lesser extent, are included under regulating contributions, and CICES "seeks to identify the final services that link to the goods and benefits that are valued by people" [16], which excludes the supporting services. Source: Authors' own elaboration, drawing from information in [14–16].

The other early use of the concept of ecosystem services, dating back to the 1970s, highlighted that everything nature contributes to society has an economic value, including those goods and services that do not normally have a price tag such as fresh air and carbon sequestration. This was intended to stress the dependence of society on functioning ecosystems and to raise awareness. This use of the ecosystem services concept became mainstream within environmental economics in the 1990s, including in a study [17] in which the economic value of the entire biosphere was estimated (see also [18,19]).

The Millennium Assessment applied economic valuation of ecosystem services, and this was taken further by The Economics of Ecosystems and Biodiversity report in 2010 [20]. Recently, along these lines, the so-called Dasgupta Review [21] investigated the relationship between economic development and biodiversity. The report concludes, among other things, that society has so far failed to include, or even to understand, the true value of nature, and that a first necessary step towards sustainable development is to comprehend that our economies are indeed entirely embedded within nature.

The concept of ecosystem services, however, has received much criticism over the years. Critics argue that the concept is a product of traditional Western thinking, with its anthropocentric perspective on nature as a producer of services for people and its sharp divide between nature and people. The anthropocentric and utilitarian perspective is also reflected in the focus on economic valuation, which risks commodifying nature. Finally, the concept is criticized for its normative character, implying that nature is always good (delivering "services"), for being based predominantly on natural science or economic approaches (i.e., a lack of humanities and social sciences), and for a certain vagueness in definitions [15,22–24] (for a review, see [24]).

2.2. Nature's Contributions to People

In response to the critiques briefly summarized above, particularly the resulting poor accommodation of multiple values, disciplines, and stakeholders, a new conceptual framework was developed within IPBES [15]. This framework illustrates the relationship between nature and human well-being through services/gifts from nature to people on the one hand and impacts on nature from human activities on the other (see [25]). In this new framework, ecosystem services were replaced by "nature's contributions to people" (NCPs), and great care was taken to allow for the inclusion of an increased diversity of worldviews. The decision to launch a new concept when the old one was just becoming settled was, naturally, criticized (see, e.g., [26]). In addition, some have discussed the extent to which the new framework and its influence on the research conducted are really new (see [27] for an overview). There are also critics who argue that neither ecosystem services nor NCPs lead to anything but utilitarian environmentalism, and that a more radical shift in moral and legal systems is needed to establish the kind of human–nature relationship that is necessary for transformational change [28].

Although such discussions are likely to continue, in this paper we take the new framework and the NCPs as a point of departure, for several reasons. It is, after all, now the official framework of IPBES. In addition, in order to investigate a sustainable transition to a bioeconomy, it makes sense to apply the more diverse and integrating framework, with its ambition to include different worldviews. This is done at the expense of detail and clarity in the description of the NCPs, compared to the ecosystem services described and classified by CICES, but the latter has its roots in environmental accounting and does not contribute any framework or language for discussing different worldviews, as needed in our fleshing out of the bioeconomy–biodiversity nexus.

Therefore, we start from the 18 NCP categories in the "generalizing perspective" of the new framework [15], while also giving a few examples of where it is important to consider the "context-specific perspective". The generalizing perspective uses 18 categories of NCPs, listed in column 1 of Table 1, derived from the ecosystem services in the Millennium Assessment. This is the view that most resembles the perspective accompanying ecosystem services, with a unidirectional flow from nature to people, a sharp boundary between the

two, and agency attributed only to people. In contrast, the context-specific perspective opens up a multitude of often highly distinctive and culture-dependent views on the relationship between people and nature. Here, the flow between the two is not necessarily unidirectional, the boundary between them may be fuzzy, and agency can be potentially attributed to nature [29].

The two perspectives on NCPs are reflected in the IPBES framework [25], which applies different terminologies for the two distinct sets of worldviews (or knowledge systems) integrated into the framework: "Western science" and "other knowledge systems". While the former perspective interprets nature as "biodiversity and ecosystems", the latter generally regards it as "Mother Earth and systems of life". Correspondingly, NCPs are interpreted as "ecosystem goods and services" or as "nature's gifts". As we will show below, the latter, broader vocabulary may be helpful when describing a sustainable bioeconomy transition with different ambition levels.

3. The Bioeconomy and Nature's Contributions to People

The bioeconomy is a growing sector—and, increasingly, an emerging paradigm—in which biological resources provide the basis for economic value and goods. Many environmental issues make that an imperative. Adopting bio-based replacements for what today is chiefly produced from fossil fuels (not only energy but also goods such as plastics, lubricants, paints, industrial oils, and others) is fundamental for climate change mitigation. Other environmental issues too, such as marine plastic pollution, ask for product substitution with renewable and biodegradable replacements. Finally, creating novel bio-based value chains can aid in biodiversity valorization and conservation, and spur sustainable development based on local renewable resources. That is particularly critical for local communities at the fringes of forests and other frontier regions where economically viable livelihood alternatives to degrading practices are often scarce [30,31].

What qualifies as bioeconomy and the specific agenda of such a transformation, however, are highly debated issues. The bioeconomy is both a disputed concept and a contested policy field [32–35]. There are multiple and often competing visions, some clearly linked to biotechnology developments (a biotechnological vision), others focused on upgrading biomass-based value chains (a bioresource vision), and broader views that seek to address sustainability issues at large, such as ecosystem health, through bioeconomy promotion (a bioecology vision) [36].

The idea of a "bioeconomy" has its origins in the work of Georgescu-Roegen in the 1970s, with his advocacy for a new economy based on resource conservation and fair distribution to meet human needs, as opposed to resource exploitation driven by profit-seeking (see [35] for a discussion). Nowadays, however, bioeconomy has come to mainly signify the expansion of bio-based economic sectors, leading to criticism that it is just "capitalism and biotechnology" [34]. As such, bioeconomy is not just an umbrella term for various economic activities derived from biological goods and processes; it has also become linked to agendas for post-fossil economic development marketed as a solution to sustainability issues [9,35]. The concerns about conservation or fair resource distribution found in Georgescu-Roegen's original plea are, indeed, not always present in current formulations. There are different "varieties of bioeconomy" in different parts of the world, with different countries and regions espousing their preferred emphases or approaches via different sets of actors.

Generally, bioenergy and novel bio-based goods produced at scale have come mostly from conventional forestry or agriculture—notably industrial crops such as soy, corn, sugarcane, rapeseed, or oil palm, as well as animal fats from large meatpacking conglomerates [2,37]. Such well-established agro-industrial sectors have sought to diversify their outputs (and, hence, their downstream markets) becoming multipurpose and transforming single value chains into "value webs" [38]. In other words, "flex crops" that can deliver multiple goods or commodities have played a major role in bioeconomy developments so far [2]. For example, Brazil's sugarcane currently is mostly used for non-food purposes.

More than half of it in that country is used as feedstock for ethanol fuel—a substitute for gasoline—rather than for sugar production [39]. Nowadays, as many as seven different marketable goods are produced from this single crop, including electricity from bagasse (its crushed remains) and bioplastics [38].

These novel, emerging markets and their associated biotechnological developments may thus be a boon for large-scale and well-capitalized agricultural sectors [8]. However, such a conventional bioeconomy has also entailed social and environmental harms frequently associated with industrial agriculture, such as tropical deforestation, soil degradation, freshwater depletion, pesticide contamination, and the marginalization of local communities [40–43]. Under a conventional monoculture-and-pasture bioeconomy, new markets and demands for fossil fuel or product replacements are known to often exacerbate pressures on the environment [2].

Conventional bio-based sectors contrast with what some have termed a "new bioeconomy." In the Amazon case, one group of authors has labeled it a bioeconomy that keeps a "standing forest and flowing rivers" [6]. This type of more environmentally friendly bioeconomy can be understood as one that builds on the socio-cultural and ecological richness of a place. In other words, it may build on a wide range of NCPs, rather than converting landscapes into pastures or monoculture plantations for meeting specific needs at the expense of others. It is founded on two ideas: first, the maintenance instead of the conversion of ecosystems and second, the development of knowledge, science, and technology around the (often unknown) biological resources present in highly biodiverse ecosystems such as the Amazon. Natural areas, therefore, become reframed from being characterized as idle lands or opportunity costs into richness being lost through deforestation (e.g., genetic and biochemical diversity that could be used in novel economic activities). There are various examples of novel goods that can be developed from native biodiversity and potentially produced at scale, such as organic pesticides for biological control, active principles for medicaments, or bio-based solvents to replaced petroleum-based ones [44,45]. Conservation thus occurs side-by-side with greater recognition for, and valorization of, biodiversity and materials that can spur sustainable economic development. That includes, for instance, many so-called secondary metabolites, which form the basis of much of the pharmaceutical and cosmetics industries [6,46].

Still, we may conceive of something even more ambitious that we could call a restorative bioeconomy, i.e., one that not only maintains the integrity of other NCPs while expanding some contributions but actually expands nature. In other words, a restorative bioeconomy would expand the ecosystem base from which contributions come. Restoration can be understood as "the return to a previous or original state"; something identified as key also for a circular economy [47] (p. 769). As the UN sternly points out as it inaugurates the Decade on Ecosystem Restoration (2021–2030), there is a pressing need to "revive damaged ecosystems." In other words, halting the degradation of ecosystems may not be enough; there is a need to also restore much of what has been lost [48].

The Amazon provides a case in point, where deforestation has threatened the world's most emblematic terrestrial ecosystem with a tipping point that, if crossed, would initiate an ecological dieback process whereby the moist rainforest would turn into a much less biodiverse drier ecosystem, with unpredictable consequences to the global climate [49,50]. Therefore, not only a halt to deforestation but also the promotion of ecosystem restoration, reforestation, or pro-forestation (i.e., the expansion of natural vegetation even beyond the mere covering of recent losses) may need to be on the agenda for a sustainable bioeconomy [51].

The following sections discuss these avenues through the lens of four critical aspects to consider when designing bioeconomy strategies that maintain and possibly enhance NCPs, instead of undermining them.

4. Four Critical Areas for NCP Enhancement through a Sustainable Bioeconomy

4.1. Extent of Habitat and Its Biodiversity

Most NCPs depend on a certain extent of natural habitat and the intactness of its biodiversity [52]. Ecosystem fragmentation is a known problem, as small areas do not equal the ecology of larger ones [53]. Moreover, the relationship between habitat extent and NCPs is rarely linear—many of nature's contributions can be entirely compromised, or at least radically changed, if certain thresholds are crossed. That is the case, for example, in overly constrained or degraded habitats, where animal species responsible for pollination or seed dispersal (NCP 2), or for the regulation of other organisms that might become detrimental to humans or crops (NCP 10), have their populations reduced beyond minimal viable numbers [54].

As seen, the Amazon rainforest offers a crucial case where several NCPs depend on sheer habitat area. Once its forest cover shrinks beyond a certain threshold (currently estimated to range between 22–27% of area loss and dangerously close to the 20% already lost between 1970 and 2020), the ecosystem will reach a tipping point [49,50]. Evapotranspiration from the remaining cover would no longer be sufficient to form the rain that maintains its lush and biodiverse vegetation. The Amazon would thus enter a self-degrading feedback loop, a biophysical dieback process of transformation into a drier ecosystem with considerable loss of many NCPs [55].

Compromised regulating contributions (e.g., climate regulation, air quality, rain formation, freshwater availability) and the loss of species that are of key importance for ecosystem functions—or that could eventually have been useful for a bioeconomy—are not the only issues. Loss of habitat extent and integrity can also compromise immaterial NCPs such as opportunities for learning and inspiration (NCP 15), physical and psychological experiences (NCP 16), or support for social identities (NCP 17). The last one is particularly critical for indigenous peoples, whose cultures and identities are deeply intertwined with their territories and the biodiversity therein [52,56]. Their whole context-specific perspective on NCPs may be compromised [15]. For others too, much of "experiencing nature" depends on habitat extent and biodiversity intactness. The literature has countless examples of social opposition to the erasure or reduction of urban green areas or national parks, sometimes igniting broad popular movements as seen in Istanbul's 2013 protests against government plans to erase Gezi Park [57]. Similarly, in Brazil, a Congress bill to resize the popular Chapada dos Veadeiros National Park to only 73% of its current area was met with fierce resistance from trekkers and other visitors who fear losing the contributions from the park's nature [58].

Brazil's context is illustrative because the country is megadiverse, boasts large and long-established bio-based sectors (e.g., biofuels), and aims to become a bioeconomy "superpower" [8]. That notion is entertained by the country's agribusiness wishing to expand the "webs" of goods produced from agro-industry through biotechnology while also applying it to the wealth of Amazonian biodiversity. However, currently, most of Brazil's bio-based production comes from industrial monocultures or cattle ranching, which are significant drivers of deforestation and other forms of natural habitat clearing [59–61]. The country's ethanol production is entirely derived from corn or sugarcane monocultures [8,38]. Similarly, soybeans—the country's fastest-expanding crop—provide three-quarters of Brazil's biodiesel output, complemented by animal fat from a substantive 220-million-strong cattle herd [39].

Cattle ranching is a crucial deforestation driver both in the Amazon and the Cerrado—the world's most biodiverse savanna [62]. Besides directly degrading areas, cattle ranching spearheads other developments in forest frontiers until the landscape is finally transformed into a monoculture [60]. Agribusiness' compromising of NCPs from Brazilian ecosystems has already been detrimental to itself, as changing temperatures and rain patterns due to deforestation have led to agricultural losses [63,64]. Regardless, this type of conventional large-scale monoculture-and-pasture bioeconomy remains dominant and continues largely unabated [8].

Environmental scientists and civil society organizations have therefore proposed a "new bioeconomy" of standing forests for the Amazon region [6,65]. It is to be based on the country's biodiversity rather than its demise, on species richness and diversity as opposed to their deterioration, and on integral expanses of forest and other ecosystems. This is so that these areas can continue to provide for existing NCPs while possibly adding new ones, in landscapes of native vegetation not converted into pasture or monoculture. This new agenda recognizes the potential of experiential tourism (NCP 16) and focuses particularly on value-chain creation, such as for novel foods (NCP 12) that may emulate the commercial success of the Amazonian açai berry. Likewise, scientists and civil society organizations recognize the potential for producing multiple high-value pharmaceuticals or cosmetic goods based on local medicinal, biochemical, and genetic resources (NCP 14) [6,31,44,45]. In short, such a new bioeconomy seeks to expand on certain Amazon NCPs (seen as having untapped potential) while not compromising on the others.

However, one can conceive of an even more ambitious agenda: that of a restorative bioeconomy that could regenerate lost vegetation. Restoration has become key given the extent of ecosystem degradation in the past decades [66]. Therefore, it might be necessary to counter the environmental impacts already caused (with their already-felt consequences, such as modified heat or rain patterns) [63]. In the Amazon's case, restoration would also move it further away from its menacing tipping point.

Table 2 contrasts these broad bioeconomy development pathways through an NCP lens. In other words, we translate into the IPBES framework what these two forms of bioeconomy promotion have meant in the Amazon context. As seen, under the present conventional bioeconomy, NCPs that depend on the extent of cropland have been increasing. Outputs of food, feed, materials (e.g., timber, paper), and energy (NCPs 11–13) have all been growing, but at the expense of all other NCPs due to continuous ecosystem conversion for agriculture [52]. The new bioeconomy of standing forests and flowing rivers, in contrast, offers conservation prospects for most NCPs while also delivering on goods—not only bulk, high-volume and low-value goods but critically also high-value and low-volume products (e.g., pharmaceutical components) that can spur more local economic development without clearing vast areas. Some questions concerning support for social identities (i.e., overall cultural conservation) do remain, however, and they will be discussed in the following sections. Finally, there is a restorative bioeconomy, which would seek to increase all NCPs from a given ecosystem.

Table 2. The conventional and new types of bioeconomy as contrasting agendas for the Amazon, and the potential for a restorative bioeconomy, in the language of NCPs. The arrows indicate NCPs being generally hampered (arrow down), maintained (arrow forward), or improved (arrow up).

	NCPs	Conventional Monoculture-and-Pasture Bioeconomy	The New Bioeconomy	Restorative Bioeconomy
1.	Habitat creation and maintenance	⇩	⇨	⇧
2.	Pollination and dispersal of other propagules	⇩	⇨	⇧
3.	Regulation of air quality	⇩	⇨	⇧
4.	Regulation of climate	⇩	⇨	⇧
5.	Regulation of ocean acidification	⇩	⇨	⇧
6.	Regulation of freshwater quantity, location, and timing	⇩	⇨	⇧

Table 2. *Cont.*

	NCPs	Conventional Monoculture-and-Pasture Bioeconomy	The New Bioeconomy	Restorative Bioeconomy
7.	Regulation of freshwater and coastal water quality	↓	→	↑
8.	Formation, protection, and decontamination of soils and sediments	↓	→	↑
9.	Regulation of hazards and extreme events	↓	→	↑
10.	Regulation of detrimental organisms and biological processes	↓	→	↑
11.	Energy	↑	↑	↑
12.	Food and feed	↑	↑	↑
13.	Materials and assistance	↑	↑	↑
14.	Medicinal, biochemical, and genetic resources	↓	↑	↑
15.	Learning and inspiration	↓	↑	↑
16.	Physical and psychological experiences	↓	↑	↑
17.	Supporting identities	↓	?	↑
18.	Maintenance of options	↓	?	↑

4.2. Knowledge on Species and Diversity

As some authors point out, bioeconomy is not simply about undertaking economic activities based on biological resources, it also represents an agenda (or agendas) focused on innovations through an increased understanding of nature, species, and overall biodiversity [67]. Gaining more knowledge, therefore, is a key part of bioeconomy promotion. Although reversing habitat destruction is fundamental, a more ambitious bioeconomy strategy will also seek to improve what is already known and enjoyed. This may be crucial for creating societal support for conservation through greater understanding of, and appreciation for, natural habitats [50,68]. Moreover, the new bioeconomy is knowledge- and technology-intensive (even though it is not always capital-intensive in the conventional financial sense) [6]. There are millions of mostly low-income people in regions of high conservation value such as Borneo, Sumatra, or the Amazon (see [69,70]), and the conflicts between conservation needs and often destructive economic activities undertaken under the excuse of local economic development (e.g., logging, mining) are notorious [43,71]. Nevertheless, knowledge is required for developing alternatives through a sustainable bioeconomy.

There is a burgeoning literature on neglected or underused species, whose contributions to people are often lost with the loss of traditional knowledge [72,73]. The UN Food and Agriculture Organization notes that, of thousands of edible species used for food, only a tiny percentage make up the bulk of what people consume [4]. Focusing on just a few crop species (and plant varieties) has led to the continuous erosion of agro-biodiversity, and the same holds for animal breeds [4]. This deterioration, as well as the lesser availability of wild foods, has in turn had significant detrimental effects on dietary diversity, nutrition,

and food cultures [74]. A bioeconomy based on a larger set of species and better knowledge of biodiversity could, in contrast, finally start reversing those impacts.

Lack of biodiversity knowledge (or recognition of such knowledge) also downplays and underrates the wealth of natural ecosystems. The absence of a sustainable development strategy for the Amazon, as for other tropical forest regions of the world, has conversely led to a haphazard and exploitative form of territorial occupation that generally disregards conservation. That particular biome has experienced ever new deforestation hotspots [75], either from state-sanctioned activities sold as necessary for economic subsistence, such as wildcat mining [76], or the clandestine roadbuilding frequently associated with illegal logging [77]. There is a growing push for industrialization in the Amazon but, under a business-as-usual mindset, that has meant broad environmental destruction that some describe as an ongoing "ecocide" [78]. Indigenous peoples and other local populations that hold a wealth of traditional knowledge have, in turn, experienced significant violence in a reproduction of colonial patterns of territorial occupation [70]. Indeed, the neglect of their local livelihoods, worldviews, knowledge, and context-specific perspectives on nature is a fundamental reason why these weaker actors become excluded and dispossessed [71].

There is proven value in onboarding not only the technical knowledge but also indigenous practices and ontologies, all of which have shown potential for conservation and forest governance [79]. In the Amazon, such agroforestry concessions demonstrably help stabilize forest frontiers [80]. Such knowledge is critical for a sustainable bioeconomy, not simply from a utilitarian perspective but also because a more comprehensive bioeconomy vision—one which preserves nature and NCPs instead of simply "mining the ecosystem" for more commodities—requires an ethical shift [28]. Amazon frontiers have continuously suffered from a lack of concern, emotional detachment [50], and a predatory settler mindset based on an old notion of man taming nature through labor [81].

Bioeconomy propositions that acknowledge "socio-biodiversity," with social inclusion and cultural diversity issues at their heart [6], thus contrast with standard biotechnology-oriented approaches merely seeking business opportunities [8]. This also relates to key social equity questions around who benefits from the bioeconomy or from nature's contributions and whose knowledge is used, by whom, and how.

4.3. Social Participation in Novel Forms of Bioeconomy

The so-called new bioeconomy or a restorative bioeconomy may secure the physical existence of natural habitats and may even increase knowledge and technical expertise on biodiversity, yet that may not be sufficiently ambitious in contexts of social exclusion. In some places such as much of the tropics, colonialism and subsequent histories have entrenched persistent patterns of inequality, racism, and marginalization [82]. Certain social groups such as women or specific ethnicities often experience exclusion or uneven access to resources [83]. Elsewhere, contributions from nature are sometimes all that local people have to enjoy and live from in landscapes neglected by others as "remote" [71]. Furthermore, the NCPs they benefit from are sometimes wrenched away as (mal)development arises from outside interventions under the banners of "progress" or "life improvements". This has been the case, for instance, in much of Brazil's Matopiba region of the Cerrado, where local populations have been consistently losing access to water, wild foods, traditionally communal pasturelands, and consequently also livelihoods, as a result of advancing soy monocultures said to bring (bioeconomic) "development" to the region [43].

It is important to realize that, however beneficial from a purely ecological standpoint, bioeconomy promotion may still leave inequity issues untouched or even lead to further resource dispossession [8]. Alternatively, it may seek to redress pre-existing exclusion in line with the 2030 Agenda's Sustainable Development Goals and commitment to "reach the furthest behind first" [11] (p. 3). After all, who is to benefit from the bioeconomy? Who controls the knowledge, technologies, and economic activities embodied in a bioeconomy? These are critical questions related to social participation and inclusiveness in relation to NCPs, which bioeconomy promotion needs to take to heart.

Much has been written on inclusive production systems as well as on the risks of "green grabbing," where conservation actions end up trampling on customary rights and dispossessing local actors [84,85]. Recognizing collective property rights is known to enhance biological conservation while being socially just [86]. In addition, places such as the Amazon have a dire need for improved services to smallholders in the form of technical assistance, market access, organizational capacity enhancement, and strategies that promote sustainable agriculture [87]. If excluded from the novel bioeconomy initiatives being conceived, these local populations would fail to reap any economic or livelihood benefits. In the worst case, they may be dispossessed and lose even the NCPs they customarily enjoy, if investors and newcomers destroy the environment as they knew it or capture NCPs for themselves, as in cases of area-fencing or water-grabbing [43,71].

For these reasons, even under a new bioeconomy of standing forests and flowing rivers, it is essential to ask who is to benefit from such economic development and the contributions from nature under the resource-use regime foreseen, as equity and social identities (NCP 17) are not automatically supported. Instead, indigenous peoples and other traditional communities have frequently been targeted by cultural assimilation efforts [82]. These groups thus experience a heightened risk of losing their social identities along with other context-specific NCPs they might identify, if economic interest in nature increases without regard for local cultures and worldviews. Attention is needed because these generally weaker stakeholders are routinely left out of government planning or landscape-level multistakeholder governance initiatives [2,43]. Social participation, therefore, means not only economic but also political inclusion when designing bioeconomy strategies. It means thinking not simply of "rational" or "sustainable" resource use within "planetary boundaries" but also of access patterns, i.e., the just distribution of resources originally envisaged in Georgescu-Roegen's original formulation (see [35]).

An ambitious bioeconomy plan can thus help prevent social exclusion as well as redress the many pre-existing equity issues. Social participation in bioeconomy initiatives can empower those who have been weak and expand NCPs not only by safeguarding ecosystem functions but also by increasing the number of people who experience contributions (e.g., food, energy, and freshwater). The same applies to immaterial NCPs. A growing literature has discussed, for instance, the prevalence in developing countries of commodified tourism as commercialized "feel good" experiences, mainly catering for wealthy consumers, sometimes occluding situations of social exclusion and resource dispossession [88,89]. If the bioeconomy is to expand also in terms of physical and psychological experiences from nature (NCP 16) or its contributions to learning and inspiration (NCP 15), would only those who can afford it be able to have such experiences, to learn, and to feel inspired? Questions of access are part and parcel of a sustainable bioeconomy agenda that considers NCPs.

4.4. The Bioeconomy beyond Commodification

An ultimate ambition—or deeper leverage point—that bioeconomy promotion may target in a transition towards greater sustainability is moving society beyond nature commodification. The bioeconomy may safeguard habitat extents, improve knowledge on species and biodiversity, increase social participation through inclusive governance and value chains, and yet fail to transcend the dominant unidimensional lens that regards nature essentially from a utilitarian perspective.

Such a utilitarian approach and the value system that underscores it have drawn substantive criticism towards the "ecosystem services" framing [28], and this is one issue the NCPs framework tries to transcend [15,23,25,52,90]. As well as ignoring the cultural importance of having ontological and epistemological diversity, the commodification of nature, detached from discussions on culture and ethics, often occludes societal choices and political decisions [9,91–93]. Usually, that has been to the detriment of local populations, various non-Western cultures, and their worldviews [90,92]. When this happens without acknowledging the various worldviews (or cosmovisions), socio-cultural values, and

political interests of local populations, even economic inclusion can easily become an assimilationist tactic and a form of co-optation.

Conversely, an emerging literature on so-called "convivial conservation" has shown that livelihoods and cultures can often be maintained alongside NCPs. It precisely seeks to transcend historically Western nature–culture dichotomies as well as a capitalist political economy centered around economic growth and consumerism [94]. That is not to deny the market opportunities that may be reaped but to be open to the full spectrum of possibilities, acknowledging and accepting multiple forms of social existence and economic organization.

Some avenues for NCP enhancement through this type of ambitious bioeconomy promotion already exist. The first is the promotion of food sovereignty (understood as local people's ability to control their agri-food system) aligned with traditional livelihoods, solidarity economy networks, and conservation [95]. There are incipient attempts to insert novel bioproducts into such locally controlled systems [96]. Foods and other bioproducts could be identified as part of a region's biocultural heritage in contrast to interchangeable commodities that could have come from anywhere. Such a territorial identification may even offer additional market value, as happens under various geographical identity protection systems commonly used for traditional foods in Europe. The Amazon, for example, possesses a wealth of traditions, knowledge, and practices that could be valued as such, as part of bioeconomy promotion that recognizes the place's richness and transcends commodification (see [6]). Likewise, not all forms of tourism fall under the "commodified" category. Cultural or natural features can make places unique, while activities can be inclusive and locally controlled. The critical issue is balancing the rights of residents and local populations with the interests of visitors [89]. There are, therefore, also ways to promote immaterial NCPs in harmony with local cultural diversity.

Figure 1 summarizes the arguments laid out in this section. We propose that not destroying habitats and biodiversity is a bare minimum for sustainable bioeconomy promotion. The very least requirement is that a bioeconomy should conserve existing habitats and, whenever possible, help restore degraded ones. However, bioeconomy promotion may go beyond that and effectively improve knowledge on species and biological diversity. It can spur concern, care, attention, and social interest, as much as scientific and technological development related to native biodiversity and its conservation. Furthermore, it is important that not only powerful actors benefit from this; nature's contributions need to be widespread and not captured by a selected few. Given the predominantly unequal socio-economic contexts in much of the world, bioeconomy promotion can be even more ambitious and seek to widen social participation. It may help to redress injustices instead of ignoring social sustainability and risking aggravating problems of resource dispossession. Finally, to fully embody the NCPs framework, sustainable bioeconomy promotion may have to overcome a purely utilitarian mindset. That means seeing the maximization of NCPs not as a pecuniary objective—as just "making money" out of nature, as implied in the mainstream notion of "natural capital"—but as acknowledging and promoting various forms of nature–culture understanding. In other words, it can move society beyond the commodification of nature and towards a broader vision of the bioeconomy.

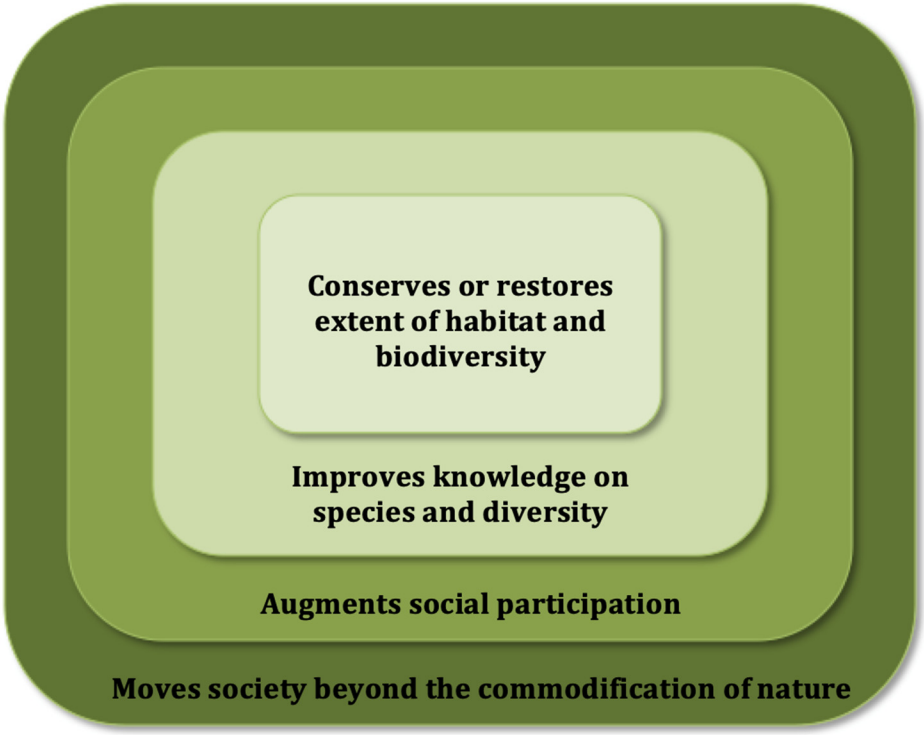

Figure 1. Four levels of ambition on bioeconomy promotion that secure and enhance NCPs.

5. Discussion: Nature's Contributions to Whom?

This analysis of the bioeconomy–biodiversity nexus through the lens of NCPs helps to expose numerous issues. The first is the variety of environmental concerns that a sustainable bioeconomy ought to take into account. The second is that the level of ambition (or depth) of the bioeconomy transition may vary; at a minimum it must ensure habitat conservation or restoration, but it may go beyond that. This transition can promote increased knowledge on biodiversity, augment social participation, and broaden bioeconomy beyond a narrow view of nature along the lines of resource commodification.

Another issue exposed is that of inequality, which comes to the fore even though the NCPs framework at first appears to treat "people" as a monolith. Its context-specific perspective, however, recognizes that social groups sometimes relate differently to nature. They value, recognize, and may also benefit differently from distinct NCPs. As the framework's context-specific perspective acknowledges, socio-cultural backgrounds and understandings of nature vary. These different social groups may even share the same geographical space, as in the Amazon case, where populations of different cultures co-exist (e.g., peasant communities, business entrepreneurs, and multiple indigenous peoples). Such a co-existence, however, is not necessarily harmonious: the political ecology literature repeatedly demonstrates that these actors often compete for the same resources, enmeshed in power relations, and that their actions affect one another.

There are frequently multiple competing context-specific perspectives in the geographies where bioeconomy promotion takes place. Therefore, it may be critical to ask to whom nature's different contributions are made, both those obtained through bioeconomy promotion and other NCPs directly or indirectly affected by it, because bioeconomy initiatives (like other interventions) generally alter the status quo. If local activities are transformed to increase certain contribution flows (e.g., energy, extraction of materials, production of food), some may benefit while others lose. As seen, an extractive bioeconomy approach with a view to just "mining the ecosystem" for more commodity products may easily lead to ecosystem health degradation and thus compromise other, more broadly spread—both in time and space—contributions (e.g., the regulating NCPs).

A key issue that can emerge in ill-conceived bioeconomy strategies is the privatization of certain NCPs at the expense of other contributions regarded as common goods, such as in the case of climate regulation (NCP 4). An "NCP capture" by more affluent or powerful actors may also relate to these actors gaining control over resources at the expense of customary users who frequently lack sufficient legal recognition of their access rights. Hence, social equity has importance even in bioeconomy strategies that accommodate multiple NCPs. It is key to contemplate nature's various contributions as well as the multiple social groups that constitute what the framework regards as "people." For promoting inclusive bioeconomies, that task may need to go in tandem with the overall enhancement of NCPs, due to the risks of skewing the distribution of those contributions even more.

A final insight is that NCP enhancement can arise from changes on either side of the general nature–people equation. A natural area can be conserved or restored to contribute more or better (e.g., richer biodiversity, more material goods provided, greater immaterial benefits, more integral regulatory functions), but NCPs arguably also improve if more people benefit from the same level of contribution due to more equitable access. A freshwater supply that meets more needs contributes more to people than if it was captured by a few. Therefore, there is an immanent dimension of social equity in operationalizing the NCPs framework.

6. Conclusions

Our assessment shows that the bioeconomy has tended to focus on only a few NCPs, namely those associated with material benefits such as energy, foods, and (increasingly) finer biochemical extracts for the cosmetic and pharmaceutical industries. These contributions from nature have benefitted people across ever larger distances as economic relations expand. However, because conventional bio-based production has derived mostly from plantations or livestock farming, which frequently expand at the cost of native vegetation clearing, these systems have (unsustainably) enhanced those specific provisioning contributions at the expense of other NCPs that require integral ecosystems (e.g., climate regulation, psychological experiences, or the support of social identities). As the NCPs framework helps identify those enhanced or hampered contributions more clearly, it may also aid in designing more sustainable and inclusive bioeconomy strategies. In particular, we highlight the potential for a restorative bioeconomy that expands on provisioning goods while also expanding on regulatory and other contributions from ecosystems.

Trade-offs between NCPs may exist at times, and it is critical to determine who decides on them. Usually, vulnerable local actors whose identities rely on integral ecosystems, who consume wild foods, or practice rain-fed agriculture or who, overall, are more directly dependent on locally delivered NCPs, have tended to be excluded and to suffer the most from the expansion of production systems increasingly aimed at long-distance provision of nature's contributions (e.g., food, energy, or bioproducts intended for far-flung markets). Therefore, inclusive landscape governance mechanisms are fundamental to ensure a voice and decision-making capacity to the most affected stakeholders. This aligns with IPBES work, various legal frameworks on the rights of traditional or local populations, as well as the 2030 Agenda's inclusiveness imperative.

We conclude, therefore, that it is essential to discern the beneficiaries of nature's various contributions under different bioeconomy scenarios. The so-called new bioeconomy based on integral ecosystems and new value chains from local biodiversity can significantly improve the sector's sustainability performance compared to conventional production. However, it does not per se fulfill all the sustainability ambitions that the bioeconomy transition can deliver on. A broader sustainability transition also requires improving social participation and moving beyond nature commodification. Such a societal and ethical shift is in the spirit of the NCPs framework as much as in the worldviews and preferences of many indigenous peoples. Further research may clarify how such stakeholders view bioeconomy development in their specific regions and how policy designs can deliver on their expectations, in line with conservation and social needs.

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