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When Do Supply Chains Strengthen Biological and Cultural Diversity? Methods and Indicators for the Socio-Biodiversity Bioeconomy

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Abstract: The bioeconomy has gained traction among the broader discourses on sustainable development, ecological transition, and the circular economy. Governments in the Global North and international institutions maintain that the bioeconomy can gradually replace fossil-based raw materials and nonrenewable resources with biomass and biological renewables. The Global South has increasingly adopted the approach, but with important variations across mega-biodiverse regions. In these regions, the bioeconomy must encourage economic activities that preserve biodiversity and strengthen local communities, promoting their well-being and cultural diversity. This paper argues that conventional research methods and indicators are not fit for this purpose. We therefore propose an alternative method and indicators and present an initial validation of the approach with an application to the pirarucu (*Arapaima gigas*) value chain in the Brazilian Amazon. By applying a bottom-up approach to evaluation that considers the perspective of the individuals and communities involved, the proposed methodology captures relevant dimensions of the value chain—including trade-offs—while identifying bottlenecks and the role of institutions. It also allows for verification of the achievement of the objectives of the socio-biodiversity bioeconomy in this model. The application to the case study finds that the managed pirarucu fisheries are a viable value chain associated with improved fish stocks and lower than average forest loss. Socio-economic benefits include the generation of reasonable income and greater participation by women. Income remains a complement to other sources of livelihood, however, and attractiveness to local communities is an issue. Positive outcomes are owed largely to local knowledge, collective action, and the role played by meta-organizations, while negative ones such as overfishing have resulted from institutional failures. Conventional analysis would likely not have considered these factors and missed these policy lessons. This corroborates the view that alternative methods and indicators are needed for the socio-biodiversity bioeconomy. While the application to the case study suggests the method and the indicators are conceptually suitable, we identify a number of shortcomings regarding the identification of interventions, attribution, and monitoring of the sustainability of the model.

Keywords: methods; evaluating metrics; supply chains; socio-biodiversity; bioeconomy

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1. Introduction

The bioeconomy has been attracting growing attention as an alternative path to face the environmental challenges of the twenty-first century. Recent literature presents pathways for a sustainable and decarbonized economy founded on the use of biomass and other renewable natural resources [1–3]. The term "bioeconomy" is controversial, however, and used with several different meanings. Specific challenges in the Global South—especially in mega-biodiverse regions—have been fostering reflection on social, cultural, and local biodiversity issues [4–8]. This emerging bioeconomy focused on socio-biodiversity still lacks a systematic and consistent analytical framework.

One major challenge for adequately mapping and assessing socio-biodiversity bioeconomy value chains lies in the diverse, sometimes conflicting objectives and, thus, multiple criteria that emerge from value chain actors. Testimonials by local actors have shown that socio-biodiverse value chains cannot aim only at short-term efficiency and enhancing job creation, income generation, or equitable market access; it is paramount that these go hand-in-hand with ecosystem resilience and the conservation of biological and cultural diversity. For instance, value chains in the Amazon, such as palm oil, açaí, coffee, or cocoa, can either promote biological and cultural diversity or undermine it, especially by encouraging monoculture and compromising the autonomy of communities [9]. A qualitative assessment of socio-biodiversity bioeconomy chains is important to bring up inconsistencies and potential incompatibilities.

Traditional and mainstream value chain studies, which were developed based on economic theories such as industrial organizations, transaction costs, and resource-based theory [10], deal with the operational efficiency of the production system as a whole: the chain's function is to serve consumers in a way that offers, simultaneously, lower cost and higher quality products. Nonetheless, inefficiency reduction is often not related to income inequality reduction or improved environmental sustainability. On the contrary, income distribution and environmental preservation are generally seen as restrictions imposed, for instance, by legislative bodies. Only exceptionally, the development of a strategic subsystem is seen as an opportunity for capturing value, such as a brand that builds on social or environmental attributes [11–13]. Even then, a focus on competitiveness imposes a vision of maximizing output in the short term, disregarding long-run socio-environmental limits and risks.

In this paper, we propose a research method using suitable indicators for the analysis and diagnosis of biodiversity value chains, aiming to assess and evaluate paths and obstacles to achieving the objectives of the socio-biodiversity bioeconomy and to advise public policy. Bioeconomy objectives are discussed and defined in Section 2 by contrasting different bioeconomy perspectives and analytical methods that are found in the literature. The need for a distinct socio-biodiversity bioeconomy and its features are emphasized in Section 2.3. Section 3 presents the choice and development of the method and indicators for analyzing socio-biodiversity bioeconomy value chains, encompassing indicators that consider the perspectives of local actors and qualitative criteria to evaluate bioeconomy value chains. The merits of the methodology proposed are discussed in Section 4, based on its application to the pirarucu (*Arapaima gigas*) value chain in the Amazon Region (Brazil). The analysis reveals that sustainable management of pirarucu is the basis of a viable bioeconomy chain, despite relevant trade-offs, bottlenecks, and institutional challenges. Section 5 discusses how possible pathways towards the socio-biodiversity bioeconomy should respond to these ambiguous results, along with our main contributions and limitations, both methodological and concerning the case study.

2. The Need for Socio-Biodiversity Bioeconomy

2.1. Economic-Ecological Bioeconomy: A Biophysical View of the Economy

In the 1970s, Nicholas Georgescu-Roegen [14] advocated for a revolution in economic theory that would consider biophysical aspects of the economic process. In biophysical terms, an economy does not create energy or matter but rather transforms resources extracted from nature, dissipating energy and generating polluting waste. Initially, the term "bioeconomics" was employed to designate a new scientific paradigm to replace neoclassical economics, in which the economy was considered part of nature. Subsequently, "bioeconomy" was used to refer to political and technological recommendations related to Georgescu-Roegen's theoretical contributions and to his "minimum bioeconomic program" [2,3].

Those recommendations are based on the entropic vision of bioeconomics and, more recently, ecological economics. Like a living being, the economic process depends on the input of low entropy matter and the output of degraded matter and heat to keep itself organized. It is a metabolic view of the economy. Technology may improve the economy's environmental efficiency, but it does not eliminate the dependence on new natural resource inputs. At least until solar energy use becomes viable and widespread, the alternative is to meet humanity's needs with minimum natural resource depletion and energy consumption [15].

Analytical methods based on this bioeconomy perspective seek to generate indicators that represent socio-economic metabolism, accounting for material flows and stocks in economic systems (their physical quantity in tons), as well as the energy associated with economic transformations [16–18]. Technological change and development throughout history are characterized by transformations of countries' socio-metabolic profiles and, occasionally, by transitions to different socio-ecological regimes [19,20].

2.2. Mainstream Bioeconomy: Economic Use of Biological Resources

Mainstream bioeconomics originated in the wake of the biotechnological revolution in the 1990s. Advances in genetic engineering were supposed to revolutionize fields such as pharmaceutics, medicine, agronomy, and chemistry, generating wealth and jobs. The concern with environmental benefits was initially not at the core of policy discussions and strategies [1,2,21,22]. We define this strand as mainstream because it is currently the most widespread view in reports from international institutions and governments around the world. However, in contrast to the ecological economics perspective, this strand aligns more closely with the concepts of circular bioeconomy or circular economy, precisely because it also emphasizes the notion of a circular flow of resource use.

In the last decade, this view has become associated with the energy transition and decarbonization of economies and has been incorporated into mainstream policy [23–25]. In this framework, bioeconomy may be defined as the set of economic activities connected to the invention, production, and use of renewable biological resources [23], leading to the progressive substitution of fossil-based raw materials and nonrenewable resources and to circular production methods [1,24,26]. It may encompass a broad range of economic activities, including agriculture, forestry, fisheries, commerce, waste management, and several industries [25,27].

Analytical methods associated with this perspective aim to quantify and qualify the environmental sustainability of production chains as well as their ability to create wealth and jobs. Life cycle analysis (LCA) is one of the most commonly used methods to assess environmental performance [28,29]. LCA quantifies environmental impacts from resource extraction to the end of product life as well as the possible results from more systemic changes, such as the transition to a circular bioeconomy [30]. Regarding economic potential, several methods and models are used to measure the size of the bioeconomy of countries or regions. The most common ones are gross value added, input–output analysis, and computable general equilibrium models [31]. There are estimates for several countries, especially in the Global North [32,33]. In the US, for instance, the bioeconomy accounted for around 5% of the country's gross domestic product (GDP) in 2016 [31]. In Germany, it reached 7.6% of GDP in 2007, a share close to that in the Netherlands (6.6–7.2%) [34].

2.3. Socio-Biodiversity Bioeconomy: The Cultural and Natural Richness of "Poor" Regions

A third, more recent, perspective on bioeconomy is emerging in mega-biodiverse countries of the Global South [4–8]. In addition to its emphasis on biodiversity, an important distinctive trait of this socio-biodiversity bioeconomy is the recognition of local populations whose livelihoods depend on nature and biodiversity conservation. Indigenous populations in mega-diverse regions are often vulnerable to the expansion of economic activities such as mineral and agricultural exploitation. Here, bioeconomy is seen as a way to preserve the forest and protect biodiversity while empowering local communities and securing their well-being [7,8,35–37]. The knowledge and culture of indigenous, fishermen and fisherwomen, riverside, and peasant populations are also often described as part of this bioeconomy, with local populations and social movements holding local knowledge for scientific and technological advancements connected to biodiversity [38,39].

The Amazon region, with Its important biological diversity and relevance to climate regulation, stands out in the debate on a socio-biodiverse bioeconomy [7,8,37]. Among the principles for a bioeconomy in the region, the following loom: zero deforestation; biodiversity conservation; strengthening of ancient practices of the region; science and technology (S&T) for the sustainable use of socio-biodiversity; and reduction in social and territorial inequality [36–40].

Socio-biodiversity bioeconomy contrasts with the previous mainstream perspective for both its emphasis on people and biodiversity. A bioeconomy based on the use of renewable biological resources may contribute to the energy transition but does not necessarily ensure biodiversity conservation. For instance, a bioeconomy based on biofuels or forest monocultures is generally harmful to biodiversity [1,41,42] and therefore counterproductive in mega-biodiverse regions. In those regions, socio-biodiverse economies should be based on value chains that respect ecosystem resilience.

In contrast to both previous perspectives, the socio-biodiversity bioeconomy is based on concrete experiences and activities conducted by populations living in mega-biodiverse regions. There is a consolidated literature on such activities, particularly non-timber forest products (NTFPs). Several case studies analyze whether NTFPs bring about development or improvements for local communities without overloading forest resources or ecosystems, with mixed results [43–45]. These empirical results are often ignored by proponents of the socio-biodiversity economy, which has a more normative character when proposing a new economic model, despite not yet having delineated clear strategies to overcome the social and environmental challenges identified in the literature.

3. Materials and Methods

The first step towards methodological approaches consistent with a socio-biodiversity bioeconomy was to consider the social and cultural features of the various territorial contexts in the Amazon region. To focus on the socio-environmental and economic criteria compatible with bioeconomy targets, the method had to capture local values and indicators. Indicators used to analyze value chains in general are not based on the perspective of producers or the local population [11–13,46]. Through citizen science and the participation of local actors in the identification of appropriate criteria and indicators, an original analysis may capture crucial aspects connected to human well-being and environmental issues. These values and indicators were identified in interviews with actors in the chains of pirarucu, açaí, cocoa, and Brazil nuts in the Amazon, specifically in Amazonas State (Brazil). From March 2021 to August 2022, 22 semi-structured online interviews lasting 45–120 min each were conducted with members of producer associations, researchers and staff of research institutes, social organizations, and public sector agents interacting with producers and actors in other chain links such as middlemen, processors, buyers, a tannery, and a restaurant. Finally, in June 2022, field research was conducted in the Mamirauá Sustainable Development Reserve (Amazonas), where we took part in the assembly of the Federation of Pirarucu Management Fishermen and Fisherwomen of Mamirauá (FEMAMPAM, acronym in Portuguese) and applied face-to-face questionnaires to 31 pirarucu fishermen and fisherwomen. Each interview took between 30 and 120 min.

Based on the priorities identified in interviews and field research, we performed a critical reexamination of traditional value chain analysis and their focus on economics skewed towards competitiveness [9]. In order to deal with crucial dimensions such as value distribution among production chain segments and environmental impacts over time, we considered approaches to value chain upgrading [47–50] and polycentric governance [50,51]. Building on the intersection of these theoretical perspectives with research analyses, we present a proposal for mapping and evaluating value chains using metrics consonant with socio-biodiversity bioeconomy principles. This proposal is detailed next.

3.1. Value Chain Mapping

Figure 1 presents our proposed method for analyzing socio-biodiversity bioeconomy value chains, detailing the stages of the chain, the production flow (gray arrows), and the income flow (orange arrows). The orange arrows denote the orientation of the analysis. While in the traditional analysis the objective was to propose competitive improvements (gray arrows), here the focus is to raise the economic and social benefits for communities while preserving the ecosystem. In each box, we exemplify factors to be evaluated and suggest relevant questions for the chain analysis. The value chains are seen as embedded in broader institutional contexts, operating under formal and informal rules [51–53]. Interviews with local actors revealed the decisive role of institutions such as community associations and social organizations in value chains. The analysis of macro- (regulation), meso- (implementation), and micro- (coordination of production arrangements) levels aims to identify bottlenecks at each level and the determining factors for value distribution throughout the chain [54].

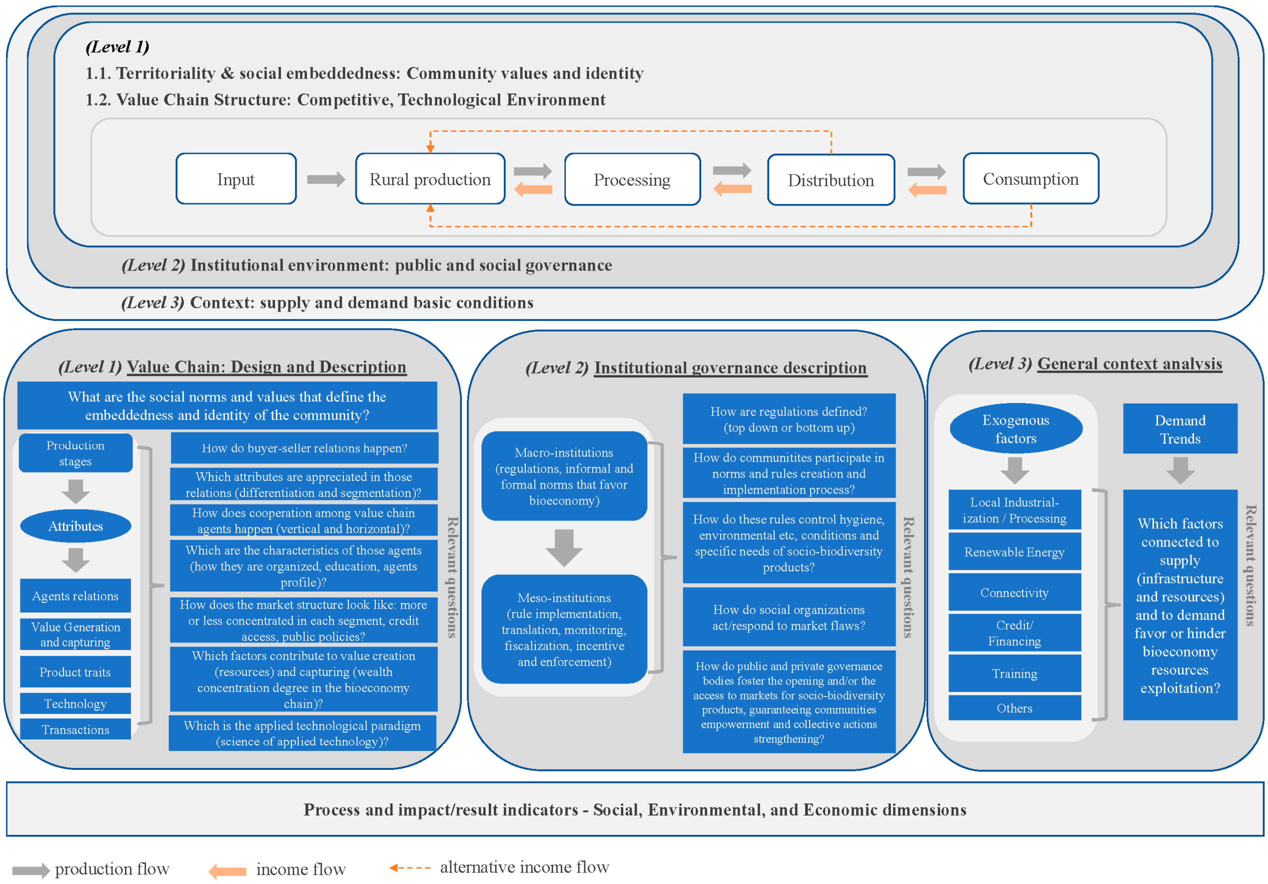

Figure 1. Proposed method for analyzing socio-biodiversity bioeconomy value chains. Source: elaborated by the authors based on [11–13,46,53,54].

The first level addresses (1.1) the characteristics linked to territoriality and identity of communities and (1.2) how the value chain is configured and chain actors relate to one another, regarding (a) social and cultural norms and locality-specific common property management practices, (b) competition (e.g., actors and organizations involved, size of each production segment, growth and competition strategies, product attributes, consumption frequency, and substitutes); (c) technology; and (d) market transactions (e.g., relationships among productive segments, their actors and objectives, leading actors, and degrees of dependence among actors).

The second level addresses institutional arrangements, i.e., the rules of the game at the macro- and meso-levels. Macro-level relates to formal institutions, including regulation and pertaining legislation, as well as informal and cultural rules that may enable or restrict immaterial infrastructure development (e.g., certification and labeling, branding, and declaration of origin). The meso-level regards how organizations implement rules, i.e., public, private, and collective governance.

The third level (general context) regards the general factors linked to supply and demand that favor or hinder the development of value chains. Exogenous trends are identified to analyze demand shifts related to globalization, dietary and lifestyle changes, or environment and climate change, as well as basic supply conditions (e.g., infrastructure, logistics, storage, credit/financing, connectivity and access to digital services, know-how, and natural resources).

3.2. Value Chain Evaluation

In addition to the value chain mapping, metrics were built to assess the coherence of the chain with the socio-biodiversity bioeconomy. The proposed evaluation is based on the concept of upgrading developed by Gary Gereffi and colleagues [47–50,55]. Upgrading refers to increasing the economic, social, and environmental value generated by a chain while benefiting all stakeholders. For each dimension of upgrading—economic, social, and environmental—metrics must be adapted and broadened to reflect the concerns and perspectives of local communities as well as territorial dynamics.

Economic upgrading reflects productivity gains, price improvements for producers, and more equitable gain sharing throughout the value chain. It leads to improvements in (i) products, when moving towards more sophisticated product lines; (ii) processes, by achieving a more efficient transformation of inputs into products through superior technology or better organization; (iii) product/service functionality, adding new uses to a product; and (iv) chain architecture, turning relations among agents more efficient. Social upgrading improves income and employment, empowers individuals and communities, and enhances their autonomy [50,55,56]. Finally, environmental upgrading reflects environmental performance and outlines changes in technology or social and organizational processes that prevent or minimize impacts and strengthen environmental services and biodiversity.

The choice, definition, and interpretation of indicators benefit from Elinor Ostrom's insights into the governance of the commons [51,52]. Indicators were built considering the evidence that polycentric governance reinforces the resilience of eco-systemic services by providing: (i) opportunities for learning and experimenting; (ii) ample stakeholder participation, mobilizing traditional and local knowledge; and (iii) diversity, minimizing and/or correcting errors in decision making. Table 1 presents the socio-biodiversity bioeconomy objectives and potential evaluation criteria to analyze bioeconomy value chains. Indicators reflect communities' priorities and perceptions and allow for community monitoring along with value chain development. It is important to note that the bioeconomy value chain can upgrade the entire locality (territorial scale) or only those who participate in the value chain. Data collection often requires fieldwork and interviews with actors in the value chain.

Table 1. Bioeconomy objectives and potential criteria for evaluation.

Bioeconomy Objectives	Scale of Analysis	Type and Source of Data	References
Social: Strengthening cultural diversity. Integration of S&T knowledge with local community knowledge, aiming at human well-being			
Potential evaluation criteria			
Education and training of human resources	C/T	SD/PD	[38,49–52,55–58]
Health quality	T	SD	
Social governance: community participation in decision making (top down/bottom up). Youth and women participation	C/VC	PD/N	
Collective action, and Respect for local culture and knowledge, Decision-making modal, Community attributes	C/VC	N	
Environmental: Production process of goods and services that safeguard biome resilience and biodiversity conservation			
Potential evaluation criteria			
Biodiversity conservation (Forest area and composition, Lake protection)	T	SD	[59–61]
Water/Soil condition	T	SD	
Waste recovery (Circular economy)	T	SD	
Economic: Improved income generation/well-being; transparent and equitable market access			
Potential evaluation criteria			
Income generation and distribution	C/VC	PD/N	[39,51,62,63]

Note: (T) Territorial; (VC) Value Chain; (C) Community; (SD) Secondary Data; (N) Narratives, (PD) Primary Data. Source: The authors.

4. Results

Participatory pirarucu management in the Mamirauá Sustainable Development Reserve—RDSM (in the Portuguese acronym), Amazonas (Brazil) (Sustainable Development Reserve (SDR)—is defined as a natural area that houses traditional communities, whose existence is based on sustainable systems for natural resource use. RDSM, which was created by the Amazonas Government on 16 July 1996), is an emblematic case for the Amazonian socio-biodiversity bioeconomy, as it seizes economic and nutritional potential while conserving the environment and enabling active community participation to generate income and improve well-being.

4.1. Value Chain Structure

Figure 2 presents the RDSM pirarucu value chain, including key actors and relations among agents. The configuration of the value chain was mapped based on documents from the Mamirauá Sustainable Development Institute (IDSM, Portuguese acronym) [64] and interviews with local actors (Field research, 2021).

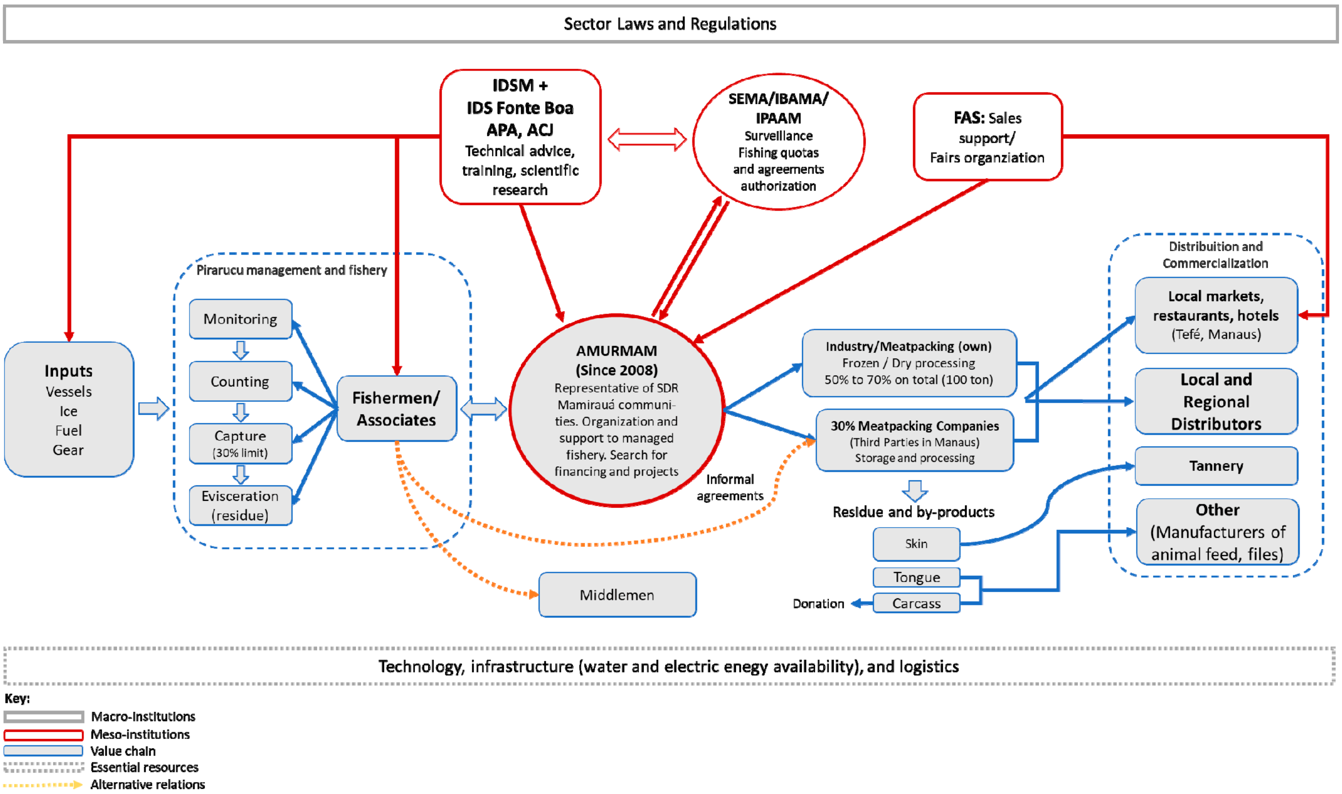

Figure 2. SDR Mamirauá Pirarucu Value Chain. Source: elaborated by the authors.

Pirarucu fishing involves a series of activities: monitoring lakes all year round to curb invaders who practice illegal fishing; planning the fishing schedule, i.e., counting the fish in the lake in order to decide the number of fish to be caught and how the income will be distributed that year; organization; and actual fishing (catching and cleaning the fish, preparing food for the team, etc.).

Fish processing is completed partly by the fishermen's association and partly by slaughterhouses that buy fresh fish. The fish is distributed through different channels, such as local fairs, restaurants, or hotels, as well as local and regional distributors and a tannery that purchases pirarucu skin for leather. Finally, consumption is mainly restricted to the local market. The chain is supported by a set of meso-institutions—public and non-governmental organizations—that help the fishermen and fisherwomen organize collective actions, provide training, and seek to enable their access to markets with better prices.

Two points have risen in the chain mapping: (i) the collective actions of fishermen and fisherwomen in organizing fishing supported by non-governmental organizations, which also play a prominent role in improving pirarucu trade; (ii) the absence of public rule enforcement, with the communities responsible for watching over the lakes to prevent illegal fishing. This represents about 50% of fishing operating costs and is important for communities' perceptions of fishing gains: 74.2% stated that their income was low, and their activity costs were high.

4.2. Institutional Governance

Three key regulations condition the institutional environment in which the pirarucu value chain is embedded: (a) the establishment of environmental conservation units in Amazonas State (Decree no. 12,836, on 9 March 1990), regulating human activity to ensure sustainable exploitation; (b) the imposition of a closure period (*defeso*), during which capture, commercialization, and transportation are prohibited (IBAMA Ordinance no. 480, on 4 March 1991, updated by NI IBAMA no. 34/2004), and during which fishermen and fisherwomen are eligible for a monthly income from unemployment insurance; and (c) criteria and procedures for pirarucu fishing in protected areas (NI IBAMA no. 01/2005). Beyond state regulation, an array of formal and informal rules have been created by local communities that participate in pirarucu management and are enforced through collective action. We highlight fishery agreements that regulate the use of fishing resources as defined by community members (such as quantities that can be fished, equipment allowed, number of vessels authorized to be simultaneously on the lake, and fishing period, among others), including measures and sanctions to be taken against violators.

Interviews showed that meso-institutions support the implementation of macro-institutional rules by creating incentives, enforcing them, or monitoring them. The organizations standing out are: (i) the IDSM, which translates general rules, protocols, and government policies, such as fishery agreements, into specific guidelines adapted to local contexts, aiming to make them more effective; (ii) the Sustainable Amazon Foundation (FAS, in the Portuguese acronym), which coordinates the activity of local actors, fills institutional voids created by the State, and helps to improve commercialization infrastructure; and (iii) the Association of Residents and Users of SDR Mamirauá Antonio Martins (Amurmam), representing local dwellers before governmental, environmental, landholding, and legal institutions. The association defends the rights of communities and organizes decision making in fishing management, also playing a key role in overseeing contractual relationships through formal and informal control mechanisms and sanctions in cases of non-compliance.

4.3. General Context

Pirarucu fish is part of the traditional diet in Northern Brazil but is also consumed in other regions and in international markets. In the 1960s and 1970s, the expansion of the fishing fleet and ice factories stimulated by government policies led to overfishing [64]. As reproduction did not keep up with capture, the pirarucu was classified as an endangered species in 1976. Since then, regulatory measures, such as closures of fisheries for six months every year (October to March), and fishing management in reserve areas, have been put in place aiming at sustainable use [65].

The RDSM was the first to implement sustainable management in Amazonas State. The policy had a clear effect: from 1999 to 2017, fish stocks grew by 427%, and the number of fishermen and fisherwomen who joined management projects jumped from 42 to 1590. In 2017, pirarucu fishing generated an average gross income of R$1739.38 (US$536.85) per fisherman per year, with individual amounts reaching up to R$6533.70 (US$2016.57), with each fisherman or fisherwoman working directly in fishing for a maximum of 50 days throughout the year. In comparison, the Brazilian minimum wage at the time was R$973.00 (US$289.20) per month [64] (p. 88).

Nevertheless, communities still face several bottlenecks: infrastructure (logistics, fish transport, processing, distance from ice factories), financing (to purchase boats and fishing gear), trade (dependence on a few channels and, given that the product is highly perishable, prices are lower than in larger regional markets), bureaucracy (documentation for sale), and lake surveillance. These are partially due to institutional voids left by the state, which contrast with the resolute action of meso-institutions and the collective action of communities.

4.4. Process, Impact, and Results Indicators

To assess coherence with the objectives of the socio-biodiversity bioeconomy, Table 2 presents indicators for the social, economic, and environmental dimensions, including several indicators based on the local communities' priorities and concerns. Despite the bottlenecks found in the context analysis, indicators show that the value chain has evolved over the years, with some upgrading in all three dimensions: social, economic, and environmental.

Table 2. Process and Impact/Result Indicators.

Bioeconomy Targets: Social Dimension **Strengthening Cultural Diversity. Integration of S&T Knowledge with Local Community Knowledge, Aiming at Human Well-Being.**					
Potential Evaluation Criteria		**Metrics/Indicators**	**Tiers**	**Outputs/Outcomes**	**Source**
Education and training of human resources	1	HDI education	T	Education: average of the Maraã, Fonte Boa and Urani municipalities: 2005—0.308 and 2016—0.498 (rate of growth: 61.69%)	Firjan [1]
	2	% of fishermen trained within the year	T	25.94% of fishermen in 2021 (between men and women) (Trained = 248 people; Total = 956 fishermen)	IDSM [66]
Health	3	HDI health	T	Health: average of the Maraã, Fonte Boa and Urani municipalities: 2005—0.398 and 2016—0.621 (rate of growth: 56.03%)	Firjan [1]
Social governance: communities' participation in decision-making process (top down/bottom up). Youth and women participation.	4	% of women participating in fishing activities	C	Average participation rate of women in fishing = 38.2% in 2021.	IDSM [66]
	5	Participation of women in assemblies	C	It was reported during the conversation circle that women began to have a large participation in assemblies and in the definition of income distribution rules.	(FR)
Collective action, and Respect for local culture and knowledge, Decision making rule, Community attributes	6	Rate of change in the number of communities participating in fishing	T	Number of communities involved in fishing: 1999 = 4 communities, 2017 = 42 communities. Rate of change: 950% (13.95% per year)	IDSM [66]
	7	Generations involved in fishing in the community	C	83.9% of respondents mentioned having started fishing because of family influence, grandparents and parents were fishermen.	FR
	8	Support from social organizations: qualitative, type of organization (local, international, university, church)	VC	Amurnam: local, role: coordination of fishermen. FAS: local coverage, chain coordination, and training. IDSM: Regional coverage, training, and development. Sebrae: National coverage, training, and entrepreneurship initiatives.	FR

Table 2. *Cont.*

Bioeconomy Targets: Social Dimension Strengthening Cultural Diversity. Integration of S&T Knowledge with Local Community Knowledge, Aiming at Human Well-Being.					
Potential Evaluation Criteria		**Metrics/Indicators**	**Tiers**	**Outputs/Outcomes**	**Source**
Bioeconomy targets: Environmental dimension Goods and services production process that safeguards biomes' resilience and biodiversity conservation					
Potential evaluation criteria		Metrics/Indicators	Scale	Outputs/Outcomes	Source
Biodiversity conservation (Forest area, Lake protection)	9	Vegetation cover	T	Vegetation coverage: average of the areas Maraã, Fonte Boa and Urani: 2000—1,165,197 ha; 2020—1,153,268 ha; growth rate: −1.02 (Amazon biome growth rate was—5.81 for the same period)	MapBiomas [67]
	10	Pirarucu population growth rate (average per community)	T	Increase in pirarucu population in lakes: 533%, 10.8% per year (1999 = 627 un; 2017 = 3970 un)	IDSM [66]
Water/Soil management	11	Rate of evolution of the water surface	T	Water surface: average of the areas Maraã, Fonte Boa and Urani (municipalities where the main source of economic activity is pirarucu): 2000—87,263 ha and 2020—92,166 ha; growth rate: +5.62%.	MapBiomas [67]
Bioeconomy targets: Economic dimension Improved income generation/well-being: transparent and equitable market access.					
Potential evaluation criteria		Metrics/Indicators	Scale	Outputs/Outcomes	Source
Income generation and distribution	12	Employment and income	T	Employment and income: average of the Maraã, Fonte Boa and Urani municipalities: 2005—0.272 and 2016—0.247	Firjan [1]
	13	Number of fishermen benefited per year	T	Number of communities involved in fishing: 1999 = 42 fishermen and 2017 = 1590 (growth rate: +3.685%~average 22.37% per year)	IDSM [66]
	14	Other sources of income	VC	Fishermen receive closed season insurance (*defeso*) or *Bolsa Floresta* or *Bolsa Família* (government programs).	FR
	15	Gross average income per fisherman	VC	Average gross earnings per fisher (deflated value, IPCA-1995=100): 1999—R$315.26; 2011—R$575.61 and 2017—R$466.93	IDSM [66]

Table 2. *Cont.*

Bioeconomy Targets: Social Dimension Strengthening Cultural Diversity. Integration of S&T Knowledge with Local Community Knowledge, Aiming at Human Well-Being.					
Potential Evaluation Criteria		**Metrics/Indicators**	**Tiers**	**Outputs/Outcomes**	**Source**
Market access and commercialization	16	Participation in fairs	C	58.1% of respondents sell at fairs. Participation in fairs promoted by FAS in Manaus was reported. FAS mobilizes fishermen to negotiate their production, promoting the practice of better prices.	FR
	17	Number of buyers	C	58.1% of respondents reported having only one buyer.	FR
	18	Market share of commercialization	VC	86.4% state regional market (Manaus, Manacapuru and Parintins) 9.6% interstate market (Santarém/PA, Itapoã and Oeste/RO) 4.0% local regional market (Tefé, Alvarães and Maraã).	IDSM [66]
	19	Participation in institutional programs		No cases were reported where commercialization was carried out for institutional/governmental programs.	FR
	20	How it is traded (whole/processed/salted/leather)	C	The community does not process the pirarucu, they just remove the viscera and sell it, which means that the fish is sold with less added value. Field research data: 87.1% of fishermen sell whole (“charuto”) Data from the IDSM report: 97.7% were traded as gutted whole fish and only 2.3% as fresh manta.	FR IDSM [66]
	21	Distribution of income along the chain	VC	Communities 15%; Intermediaries 35%; slaughterhouses 50%.	[68]
Certification	22	Types of certification/collective trademark	VC	Denomination of Origin Mamirauá for managed pirarucu in nine municipalities (Alvarães, Fonte Boa, Japurá, Juruá, Jutaí, Maraã, Tefé, Tonantins and Uarini).	INPI [69]
Production costs	23	Estimated critical production cost	VC	Cost of monitoring the lakes represents about 50% of the total cost	FR

Table 2. *Cont.*

Bioeconomy Targets: Social Dimension Strengthening Cultural Diversity. Integration of S&T Knowledge with Local Community Knowledge, Aiming at Human Well-Being.					
Potential Evaluation Criteria	**Metrics/Indicators**		**Tiers**	**Outputs/Outcomes**	**Source**
Infrastructure	24	Drinking water	C	67.74% have access to piped water.	FR
	25	Electricity	C	90.3% have access to electricity. They use a diesel generator (light engine, in some cases available only from 6 pm to 10 pm)	FR
	26	Internet	C	22.58% of respondents have poor quality internet access.	FR
	27	Basic sanitation	C	Absence of basic sanitation in the visited community	FR
	28	Media	C	93.5% of respondents use cell phones	FR

Note: (T) Territorial; (VC) Value Chain; (C) Community; (SD) Secondary Data; (N) Narratives, (PD) Primary Data; Human Development Index (HDI); Field Research (FR); Associação dos Moradores e Usuários da RDSM Antonio Martins (Amurmam); Fundação Amazonas Sustentável (FAS); Instituto de Desenvolvimento Sustentável Mamirauá (IDSM); Serviço Brasileiro de Apoio às Micro e Pequenas Empresas (Sebrae). Source: The authors. 1 The Firjan index ranges from 0 (minimum) to 1 point (maximum) to classify the level of each location into four categories: low (from 0 to 0.4), regular (0.4 to 0.6), and moderate (from 0.6 to 0.8) and high (0.8 to 1) development. Source: https://www.firjan.com.br/ifdm/ (accessed on 1 August 2022).

By including women in the production process, participatory fisheries management has improved gender equality in the region. Collective actions reinforce the role of fishermen and fisherwomen in performing all the tasks related to fishing and commercialization, as well as in the decision-making process. Moreover, fisheries management has not only improved pirarucu supply in the region but also contributed to the conservation of lakes and other species, as evidenced by strong increases in fish stocks and very low deforestation.

Meso-institutions have enabled the internalization of innovation, such as training, and improved infrastructure for processing and commercialization, contributing to production costs that are more compatible with prices. This is reflected in the relative improvement in income and well-being of communities, albeit timid in several indicators, which suggest room for additional economic and social upgrading.

5. Discussion

Our results show that the assessment of the socio-biodiversity bioeconomy may benefit from indicators that consider the perspectives of individuals and communities and from a qualitative evaluation of bioeconomy value chains. Based on this assessment, the participatory pirarucu management in the RDSM has proved to be a successful case of bioeconomy development. This finding is in line with positive outcomes reported in previous studies on pirarucu management in the Amazon [70–73]. The measured impacts reflect the generally positive perception of communities about fisheries management, although several social and economic aspects have yet to be upgraded, particularly local income generation. In most cases, fishing provides just a small complement to household income and is often considered insufficient. Regarding the positive environmental and social outcomes, the analysis of the broader institutional context, such as the facilitation role of meso-institutions, was important in accessing key drivers of the pirarucu bioeconomy. To point out opportunities and challenges related to advancing the socio-biodiversity bioeconomy, we close this article by discussing some implications of our results.

The value chain mapping indicates that meso-institutions may organize and aggregate local actors in contexts with social and regional disarticulation, as found in many socio-biodiverse regions in the Global South. The literature has shown that polycentric institutions can have a positive role in the governance of common-pool resources when fostering innovation, learning, cooperation between participants, and the achievement of more equitable and sustainable results [51,52]. In participatory pirarucu management, public and non-governmental organizations changed the dynamics of socio-biodiversity chains by increasing transparency and fairness in production chains and by enhancing existing self-organizing initiatives, thereby creating conditions for the bioeconomy to flourish. These organizations met ample community participation, contributing to strengthening economic alternatives adapted to the communities environmental and cultural contexts. This finding is consistent with the evidence that local settings and the active participation of local communities are important to successful outcomes in the management of common-pool resources [52,74].

Still, the deficient economic outcomes in the pirarucu chain contrast with the bioeconomy's promise of win-win solutions and synergies between sustainability and economy, often emphasized in bioeconomy perspectives [2,3,6,40]. The vast literature on non-timber forest products, including several studies in the Amazon, also challenges this emphasis on synergies by showing that NTFP commercialization often implies a trade-off between environmental conservation and economic development [10,43,45,66,75–77].

At the same time, our criteria and indicators based on the perspective of communities help define priorities and the notion of development that are compatible with local livelihoods. For example, indicators related to the role of women in the economic activities of the communities (participation in fishing and in assemblies) in the case analyzed show attention to gender inequality. Similarly, the emphasis on information about lake surveillance indicates concern with security and illegal activity in the region. Positive outcomes related to the empowerment and autonomy of communities, economic stability, and security to carry out their activities may be more important than increases in income alone. Indeed, studies that consider socio-cultural aspects such as reproduction of culture, creation of social capital, and empowerment find more positive outcomes in NTFP trade than analyses focused only on material gains (mainly income) [45].

Strategies and policies to foster a socio-biodiversity bioeconomy should respond to ambiguous results. On the positive side, collective action is not a complication but a critical ingredient in fisheries management. Meso-institutions can play a vital role in filling governance and technical voids in isolated regions. They translate legislation into practices, provide access to appropriate technology, and can improve local value-added retention. On the other hand, the dramatic overfishing following heavily subsidized, over-dimensioned cooling facilities sends a clear warning: politicians should be wary of quick fixes and of 'throwing money at the problem'. Rather, they should adopt a more realistic view of social and environmental challenges and respond to local prospects and concerns regarding development. Policies such as the unemployment insurance paid during fishery closures, for example, are more in sync with the needs of the community and the dynamics of the value chain.

Finally, the proposed methods and indicators have some limitations. Our holistic and systemic approach was instrumental in revealing inter-relations and trade-offs, such as the need for and success of surveillance through collective action, while weighing cost/benefit ratios and community perceptions. The study has identified bottlenecks and potential areas for intervention to enhance the functioning of the value chain, but it has not yet been able to prioritize them and draw up an intervention plan. A more rigorous and action-oriented assessment requires further data, co-validation, and co-construction of solutions with the community. This would also require the construction of solid cause-effect cascades for attribution. Those would guide short- to medium-term action and monitoring, but a reliable diagnosis of sustainability may require long-term follow-up. That, in turn, would be greatly helped by methods and indicators amenable to 'citizen science' by members of the local communities, a question we have not yet been able to explore. Finally, the need to adapt indicators to capture the relevant specificities of each chain may compromise the comparability of bioeconomy cases.

The present assessment of the pirarucu bioeconomy provided a broad picture of the current strengths and challenges of the productive chain, but it could not produce sufficient information about the past trajectory of communities. To evaluate and monitor the evolution of this bioeconomy, the study needs to be replicated over time. Communities should evaluate these results and indicate possible gaps and new criteria to be included. Ideally, communities themselves would perform such continuous monitoring and evaluation. We also believe the method should be applied to more cases to confirm its suitability, especially its ability to generate reliable comparisons and evidence to guide public policies.

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References

1. Bugge, M.M.; Hansen, T.; Klitkou, A. What is the bioeconomy? A review of the literature. *Sustainability* **2016**, *8*, 691. [CrossRef]
2. Vivien, F.D.; Nieddu, M.; Befort, N.; Debref, R.; Giampietro, M. The hijacking of the bioeconomy. *Ecol. Econ.* **2019**, *159*, 189–197. [CrossRef]
3. Giampietro, M. On the circular bioeconomy and decoupling: Implications for sustainable growth. *Ecol. Econ.* **2019**, *162*, 143–156. [CrossRef]
4. Ortega-Pacheco, D.V.; Silva, A.; López, A.; Espinel, R.; Inclán, D.; Mendoza-Jiménez, M.J. Tropicalizing Sustainable Bioeconomy: Initial Lessons from Ecuador. In *Towards a Sustainable Bioeconomy: Principles, Challenges and Perspectives*; Leal Filho, W., Pociovălișteanu, D., Borges de Brito, P., Borges de Lima, I., Eds.; Springer: Cham, Switzerland, 2018. [CrossRef]
5. Rodríguez, A.G.; Rodrigues, M.; Sotomayor, O. Towards a sustainable bioeconomy in Latin America and the Caribbean: Elements for a regional vision. Natural Resources and Development Series; N°191, (LC/TS.2019/25 Santiago, Economic Commission for Latin America and the Caribbean (ECLAC). 2019. Available online: https://repositorio.cepal.org/bitstream/handle/11362/44994/1/S1901014_en.pdf (accessed on 1 April 2022).
6. Nobre, I.; Nobre, C. Projeto 'Amazônia 4.0′: Definindo uma Terceira Via para a Amazônia. *Futuribles* **2019**, *2*, 7–20.
7. Abramovay, R.; Ferreira, J.; Costa, F.D.A.; Ehrlich, M.; Castro Euler, A.M.; Young, C.E.F.; Villanova, L. The new bioeconomy in the Amazon: Opportunities and challenges for a healthy standing forest and flowing rivers. *Sci. Panel Amaz.* **2021**. Available online: https://www.theamazonwewant.org/wp-content/uploads/2022/05/Chapter-30-Bound-May-16.pdf (accessed on 1 August 2022).
8. Costa, F.; Nobre, C.; Genin, C.; Frasson, C.M.R.; Fernandes, D.A.; Silva, H.; Vicentes, I.; Santos, I.T.; Barbieri, R.F.; Ventura Neto, R.; et al. *Uma Bioeconomia Inovadora para a Amazônia: Conceitos, Limites e Tendências para uma Definição Apropriada ao Bioma Floresta Tropical*; Texto para Discussão; WRI Brasil: São Paulo, Brasil, 2022.
9. Ros-Tonen, M.A.; Wiersum, K.F. The scope for improving rural livelihoods through non-timber forest products: An evolving research agenda. *For. Trees Livelihoods* **2005**, *15*, 129–148. [CrossRef]
10. Davis, J.H.; Goldberg, R.A. *A Concept of Agribusiness*; Harvard University Graduate School of Business Administration: Boston, MA, USA, 1957.
11. Neves, M.F.; Kalaki, R.B.; Rodrigues, J.M.; Gray, A.W. Strategic planning and management of food and agribusiness chains: The chainplan method (framework). *Rev. Bus. Manag.* **2020**, *21*, 628–646. [CrossRef]
12. Farina, E.M.M.Q.; Zylbersztajn, D. *Competitividade No Agribusiness Brasileiro*; PENSA/FIA/FEA/USP: São Paulo, Brasil, 1998; Volume 1, p. 196.
13. Saes, M.S.M.; Silveira, R.L.F. Novas Formas de Organização das Cadeias Agrícolas Brasileiras: Tendências Recentes. O Mundo Rural no Brasil do Século 21: A Formação de um novo Padrão Agrário e Agrícola. Brasília, Embrapa. 2014. Available online: https://repositorio.usp.br/item/002496579 (accessed on 10 July 2022).
14. Georgescu-Roegen, N. *The Entropy Law and the Economic Process*; Harvard University Press: Boston, MA, USA, 1971.
15. Georgescu-Roegen, N. Energy and economic myths. *South. Econ. J.* **1975**, *41*, 347–381. [CrossRef]
16. Gerber, J.F.; Scheidel, A. In search of substantive economics: Comparing today's two major socio-metabolic approaches to the economy–MEFA and MuSIASEM. *Ecol. Econ.* **2018**, *144*, 186–194. [CrossRef]
17. Giampietro, M.; Mayumi, K.; Ramos-Martin, J. Multi-scale integrated analysis of societal and ecosystem metabolism (MuSIASEM): Theoretical concepts and basic rationale. *Energy* **2009**, *34*, 313–322. [CrossRef]
18. Fischer-Kowalski, M. Society's metabolism: The intellectual history of materials flow analysis, Part I, 1860–1970. *J. Ind. Ecol.* **1998**, *2*, 61–78. [CrossRef]
19. Krausmann, F.; Fischer-Kowalski, M.; Schandl, H.; Eisenmenger, N. The Global Sociometabolic Transition. *J. Ind. Ecol.* **2008**, *12*, 637–656. [CrossRef]
20. Fischer-Kowalski, M.; Haberl, H. *Socioecological Transitions and Global Change: Trajectories of Social Metabolism and Land Use*; Edward Elgar: Cheltenham, UK, 2007.
21. Patermann, C.; Aguilar, A. The origins of the bioeconomy in the European Union. *New Biotechnol.* **2018**, *40*, 20–24. [CrossRef]
22. Bröring, S.; Laibach, N.; Wustmans, M. Innovation types in the bioeconomy. *J. Clean. Prod.* **2020**, *266*, 121939. [CrossRef]
23. OECD. *The Bioeconomy to 2030: Designing a Policy Agenda*; OECD: Paris, France, 2009. [CrossRef]
24. EU-European Commission. Directorate-General for Research and Innovation, a Sustainable Bioeconomy for Europe: Strengthening the Connection between Economy, Society and the Environment: Updated Bioeconomy Strategy. 2018; Publications Office. Available online: https://data.europa.eu/doi/10.2777/792130 (accessed on 15 January 2022).
25. Philp, J.; Winickoff, D. *Innovation Ecosystems in the Bioeconomy, OECD Science, Technology and Industry Policy Papers, No. 76*; OECD Publishing: Paris, France, 2019. [CrossRef]
26. EU-European Commission. *Innovating for Sustainable Growth: A Bioeconomy for Europe*; European Commission: Brussels, Belgium, 2012.
27. Keegan, D.; Kretschmer, B.; Elbersen, B.; Panoutsou, C. Cascading use: A systematic approach to biomass beyond the energy sector. *Biofuels Bioprod. Biorefining* **2013**, *7*, 193–206. [CrossRef]
28. D'Amato, D.; Gaio, M.; Semenzin, E. A review of LCA assessments of forest-based bioeconomy products and processes under an ecosystem services perspective. *Sci. Total Environ.* **2020**, *706*, 135859. [CrossRef]
29. Talwar, N.; Holden, N.M. The limitations of bioeconomy LCA studies for understanding the transition to sustainable bioeconomy. *Int. J. Life Cycle Assess.* **2022**, *27*, 680–703. [CrossRef]

30. Sevigné-Itoiz, E.; Mwabonje, O.; Panoutsou, C.; Woods, J. Life cycle assessment (LCA): Informing the development of a sustainable circular bioeconomy? *Philos. Trans. R. Soc. A* **2021**, *379*, 20200352. [CrossRef]
31. NAS-National Academies of Sciences, Engineering, and Medicine. *Safeguarding the Bioeconomy*; The National Academies Press: Washington, DC, USA, 2020. [CrossRef]
32. Wesseler, J.; von Braun, J. Measuring the Bioeconomy: Economics and Policies. *Annu. Rev. Resour. Econ.* **2017**, *9*, 275–298. [CrossRef]
33. D'Adamo, I.; Falcone, P.M.; Morone, P. A new socio-economic indicator to measure the performance of bioeconomy sectors in Europe. *Ecol. Econ.* **2020**, *176*, 106724. [CrossRef]
34. Heijman, W. How big is the bio-business? Notes on measuring the size of the Dutch bio-economy. *NJAS-Wagening. J. Life Sci.* **2016**, *77*, 5–8. [CrossRef]
35. Becker, B.K. Novas territorialidades na Amazônia: Desafio às políticas públicas. Boletim do Museu Paraense Emílio Goeldi. *Ciências Hum.* **2010**, *5*, 17–23. Available online: http://scielo.iec.gov.br/scielo.php?script=sci_arttext&pid=S1981-81222010000100003&lng=pt&nrm=iso (accessed on 1 March 2022).
36. Bergamo, D.; Zerbini, O.; Pinho, P.; Moutinho, P. The Amazon bioeconomy: Beyond the use of forest products. *Ecol. Econ.* **2022**, *199*, 107448. [CrossRef]
37. WTT&COI. Bioeconomia Amazônica: Uma Navegação Pelas Fronteiras Científicas e Potenciais de Inovação. 2022. Available online: https://wttventures.net/bioeconomia-amazonica-uma-navegacao-pelas-fronteiras-cientificas-e-potenciais-de-inovacao/ (accessed on 8 September 2022).
38. UNSDN. Empowerment: What Does It Mean to You? 2012. Available online: https://www.un.org/esa/socdev/ngo/outreachmaterials/empowerment-booklet.pdf (accessed on 1 March 2022).
39. Petesque, M.; Cipriani, S.; Arriaza, P. *Community Empowerment Manual*; Community Protection Approach. We World; 2020; 59p. Available online: https://reliefweb.int (accessed on 8 April 2022).
40. Amazonas. *Nota Técnica: Um Panorama Sobre a Bioeconomia No Estado do Amazonas*; SEDECTI: Manaus, Brazil, 2021.
41. Pfau, S.F.; Hagens, J.E.; Dankbaar, B.; Smits, A.J. Visions of sustainability in bioeconomy research. *Sustainability* **2014**, *6*, 1222–1249. [CrossRef]
42. Piplani, M.; Smith-Hall, C. Towards a Global Framework for Analysing the Forest-Based Bioeconomy. *Forests* **2021**, *12*, 1673. [CrossRef]
43. Arnold, J.M.; Pérez, M.R. Can non-timber forest products match tropical forest conservation and development objectives? *Ecol. Econ.* **2001**, *39*, 437–447. [CrossRef]
44. Belcher, B.; Ruiz-Pérez, M.; Achdiawan, R. Global patterns and trends in the use and management of commercial NTFPs: Implications for livelihoods and conservation. *World Dev.* **2005**, *33*, 1435–1452. [CrossRef]
45. De Mello, N.G.R.; Gulinck, H.; Van den Broeck, P.; Parra, C. Social-ecological sustainability of non-timber forest products: A review and theoretical considerations for future research. *For. Policy Econ.* **2020**, *112*, 102109. [CrossRef]
46. Neven, D. Developing Sustainable Food Value Chains; FAO: 2014. Available online: https://www.fao.org/3/I3953E/i3953e.pdf (accessed on 10 April 2022).
47. Gereffi, G. Economic upgrading in global value chains. In *Handbook on Global Value Chains*; Edward Elgar Publishing: Cheltenham, UK, 2019. [CrossRef]
48. Gereffi, G.; Lee, J. Economic and Social Upgrading in Global Value Chains and Industrial Clusters: Why Governance Matters. *J. Bus. Ethics* **2016**, *133*, 25–38. [CrossRef]
49. Gereffi, G.; Humphrey, J.; Sturgeon, T. The governance of global value chains. *Rev. Int. Polit. Econ.* **2005**, *12*, 78–104. [CrossRef]
50. Humphrey, J.; Schmitz, H. Chain governance and upgrading: Taking stock. In *Local Enterprises in the Global Economy*; Schmitz, H., Ed.; Edward Elgar: Cheltenham, UK, 2004; pp. 349–382. Available online: https://www.elgaronline.com/view/1843760991.xml#page=361 (accessed on 5 May 2023).
51. Ostrom, E.; Chang, C.; Pennington, M.; Tarko, V. *The Future of the Commons—Beyond Market Failure and Government Regulation* (December 10, 2012). Institute of Economic Affairs Monographs, 2012, Indiana University, Bloomington School of Public & Environmental Affairs Research Paper No. 2012-12-02. Available online: https://ssrn.com/abstract=2267381 (accessed on 5 May 2023).
52. Ostrom, E. Beyond Markets and States: Polycentric Governance of Complex Economic Systems. *Am. Econ. Rev.* **2010**, *100*, 641–672. Available online: http://www.jstor.org/stable/27871226 (accessed on 5 May 2023). [CrossRef]
53. North, D.C. Institutions, Institutional Change and Economic Performance. In *Political Economy of Institutions and Decisions*; Cambridge University Press: Cambridge, UK, 1990. [CrossRef]
54. Ménard, C.; Shirley, M.M. *A Research Agenda for New Institutional Economics*; Edward Elgar Publishing: Cheltenham, UK, 2018. [CrossRef]
55. Barrientos, S.; Gereffi, G.; Rossi, A. Economic and social upgrading in global production networks: A new paradigm for a changing world. *Int. Labour Rev.* **2011**, *150*, 319–340. [CrossRef]
56. Rossi, A. Does economic upgrading lead to social upgrading in global production networks? Evidence from Morocco. *World Dev.* **2013**, *46*, 223–233. [CrossRef]
57. Reinecke, G.; Posthuma, A.C. The link between economic and social upgrading in global supply chains: Experiences from the Southern Cone. *Int. Labour Rev.* **2019**, *158*, 77–703. [CrossRef]

58. Mani, V.; Gunasekaran, A.; Delgado, C. Enhancing supply chain performance through supplier social sustainability: An emerging economy perspective. *Int. J. Prod. Econ.* **2018**, *195*, 259–272. [CrossRef]
59. Achabou, M.A.; Dekhili, S.; Hamdoun, M. Environmental upgrading of developing country firms in global value chains. *Bus. Strat. Environ.* **2017**, *26*, 224–238. [CrossRef]
60. Azevedo-Ramos, C.; Moutinho, P.; Arruda, V.L.D.S.; Stabile, M.C.; Alencar, A.; Castro, I.; Ribeiro, J.P. Lawless land in no man's land: The undesignated public forests in the Brazilian Amazon. *Land Use Policy* **2020**, *99*, 104863. [CrossRef]
61. Peralta, M.E.; Luna, P.; Soltero, V.M. Towards standards-based of circular economy: Knowledge available and sufficient for transition? *Int. J. Sustain. Dev. World Ecol.* **2020**, *27*, 369–386. [CrossRef]
62. Golini, R.; De Marchi, V.; Boffelli, A.; Kalchschmidt, M. Which governance structures drive economic, environmental, and social upgrading? A quantitative analysis in the assembly industries. *Int. J. Prod. Econ.* **2018**, *203*, 13–23. [CrossRef]
63. Jindra, B.; Hatani, F.; Steger, T.; Hiemer, J. Social upgrading and cooperative corporate social responsibility in global value chains: The case of Fairphone in China. *Glob. Netw.* **2019**, *19*, 371–393. [CrossRef]
64. Gonçalves, A.C.T.; Cunha, J.B.C.; Batista, J.S. *O Gigante Amazônico: Manejo Sustentável de Pirarucu*; Instituto de Desenvolvimento Sustentável Mamirauá: Tefé, Brazil, 2018.
65. CONAB. Boletim da Sociobiodiversidade; 2020; Volume 4, pp. 1–52. Available online: https://www.conab.gov.br/info-agro/analises-do-mercado-agropecuario-e-extrativista/boletim-da-sociobiodiversidade/boletim-sociobio (accessed on 15 May 2022).
66. IDSM. Relatório Técnico Anual 2021 dos Projetos de Manejo dos Recursos Pesqueiros nas Reservas de Desenvolvimento Sustentável Mamirauá, Amanã e Entorno. Tefé-AM. 2022. Available online: https://www.mamiraua.org.br/noticias/relat%C3%B3rio-tecnico-aponta-que-manejo-de-pesca-rendeu-mais-de-r$-3,5-milhoes-a-comunidades-do-m%C3%A9dio-solim%C3%B5es-em-2021 (accessed on 1 August 2022).
67. Mapbiomas. MAPBIOMAS—The Brazilian Annual Land Use and Land Cover Mapping Project. 2022. Available online: https://mapbiomas.org/ (accessed on 1 October 2022).
68. Homma, A.K.O. Amazônia: Da bioeconomia das "drogas do sertão" à bioeconomia do século (Cap.1). In *O Brasil rural contemporâneo: Interpretações. Geraldo Sant'Ana de Camargo Barros e Zander Navarro (Org.)*, 1st ed.; Editora Baraúna: São Paulo, Brazil, 2022; p. 385.
69. INPI-Insituto Nacional de Propriedade Industrial. INPI Reconhece a Denominação de Origem Mamirauá para o Pirarucu Manejado. 2021. Available online: https://www.gov.br/inpi/pt-br/central-deconteudo/noticias/inpi-reconhece-a-denominacao-de-origem-mamiraua-para-o-pirarucu-manejado (accessed on 10 May 2022).
70. Campos-Silva, J.V.; Peres, C.A.; Hawes, J.E.; Haugaasen, T.; Freitas, C.T.; Ladle, R.J.; Lopes, P.F. Sustainable-use protected areas catalyze enhanced livelihoods in rural Amazonia. *Proc. Nat. Acad. Sci. USA* **2021**, *118*, e2105480118. [CrossRef]
71. Campos-Silva, J.V.; Peres, C.A. Community-based management induces rapid recovery of a high-value tropical freshwater fishery. *Sci. Rep.* **2016**, *6*, 34745. [CrossRef] [PubMed]
72. Gamarra, N.C.; Hawes, J.E.; Costa, A.C.L.; Vieira, F.A.S.; Rodrigues, A.C.; Ladle, R.J.; Campos-Silva, J.V. Arapaima co-management through the lens of the Protected Areas Assets Framework. *J. Nat. Conserv.* **2022**, *67*, 126161. [CrossRef]
73. Freitas, C.T.; Espírito-Santo, H.M.; Campos-Silva, J.V.; Peres, C.A.; Lopes, P.F. Resource co-management as a step towards gender equity in fisheries. *Ecol. Econ.* **2020**, *176*, 106709. [CrossRef]
74. Cox, M.; Arnold, G.; Villamayor-Tomas, S. *A Review of Design Principles for Community Based Natural Resource Management*; Elinor Ostrom and the Bloomington School of Political Economy: Resource Governance; Lexington Books; Lanham, MD, USA, 2015; pp. 249–280. Available online: http://www.ecologyandsociety.org/vol15/iss4/art38/ (accessed on 2 January 2022).
75. Brites, A.D.; Morsello, C. Efeitos ecológicos da exploração de produtos florestais não madeireiros: Uma revisão sistemática. *Desenvolv. Meio Ambient.* **2016**, *36*, 1–18. [CrossRef]
76. Kusters, K. Non-Timber Forest Product Trade: A Trade-off between Conservation and Development: Assessing the Outcomes of Non-Timber Forest Product Trade on Livelihoods and the Environment, with Special Emphasis on the Damar Agroforests in Sumatra, Indonesia. Ph.D. Thesis, Universiteit van Amsterdam, Amsterdam, The Netherlands, 2009.
77. Bartkus, V.O.; Brooks, W.; Kaboski, J.P.; Pelnik, C. Big fish in thin markets: Competing with the middlemen to increase market access in the Amazon. *J. Dev. Econ.* **2022**, *155*, 102757. [CrossRef]