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Food and biomass production systems are among the most prominent drivers of biodiversity loss worldwide. Halting and reversing the loss of biodiversity therefore requires transformative change of food and biomass systems, addressing the nexus of agricultural production, processing and transport, retailing, consumer preferences and diets, as well as investment, climate action and ecosystem conservation and restoration. The RAINFOREST project will contribute to enabling, upscaling and accelerating transformative change to reduce biodiversity impacts of major food and biomass value chains. Together with stakeholders, we will co-develop and evaluate just and viable transformative change pathways and interventions. We will identify stakeholder preferences for a range of policy and technology-based solutions, as well as governance enablers, for more sustainable food and biomass value chains. We will then evaluate these pathways and solutions using a novel combination of integrated assessment modelling, input-output modelling and life cycle assessment, based on case studies in various stages of the nexus, at different spatial scales and organizational levels. This coproduction approach enables the identification and evaluation of just and viable transformative change leverage points, levers and their impacts for conserving biodiversity (SDGs 12, 14-15) that minimize trade-offs with targets related to climate (SDG13) and socioeconomic developments (SDGs 1-3). We will elucidate leverage points, impacts, and obstacles for transformative change and provide concrete and actionable recommendations for transformative change for consumers, producers, investors, and policymakers.

EXECUTIVE SUMMARY

Transformative change has emerged as a central concept framing the action needed to achieve sustainable futures and is increasingly targeted by multilateral agreements for climate and biodiversity. There is however limited knowledge about what might be feasible targets and pathways for transformative change in EU food and biomass supply chains, and how this could vary according to alternative worldviews. In order to address this knowledge gap and accelerate transformative change the RAINFOREST project aims to co-produce and explore dedicated new pathways, focused on just, viable and actionable interventions. These shall be able to halt or reverse the ongoing global biodiversity decline through transformative change in the EU food and biomass nexus between climate action, production, trade, consumption, and human behaviour (with a focus on terrestrial and to some extent freshwater ecosystems).

As a first step towards this goal, this report:

- Reviews foundational elements required to build pathways: existing and emerging pathways (section 2), the importance of alternative worldviews and equity considerations (section 3), and a detailed review of relevant aggregated targets, effective interventions and feasibility considerations relevant to the EU food and biomass supply chains (section 4).
- Provides a description of our approach to generate the new RAINFOREST pathways, and a draft of their narrative (section 5): building on the reviewed foundational elements and stakeholder feedback, we link existing value-explicit pathways from the Sustainable Development Pathways and the Nature Futures framework, and enrich them with an environmental justice framework, before translating these into 3 distinct narratives.

By bridging key emerging value-explicit scenario frameworks and complementing them with a more explicit focus on environmental justice, the RAINFOREST pathways are expected to fill an important gap and to have a greater potential for wider engagement. Yet, as highlighted in section 6, the pathway narratives described in this report should be considered as preliminary, with the potential for both broadening (to make the pathways relevant to a boarder context) and refining (to

increase internal consistency and contrast) the narrative elements. While some of these improvements may be beyond the reach of the project, further activities within the RAINFOREST project (e.g., downscaling of aggregated action and outcome targets according to distributive justice principles of each pathway, pathway quantification with the model toolbox, case study contextualization) and active engagement with stakeholder groups and broader scientific community is expected to contribute to revisions of the pathway narratives towards a final version targeted for the end of 2024.

1. INTRODUCTION

Transformative change, defined in the glossary of the IPBES Global Assessment report (IPBES, 2019) as a "fundamental, system-wide reorganization across technological, economic and social factors, including paradigms, goals and values", is a pre-requisite for reaching climate & biodiversity goals (e.g., IPBES (2019), Leadley et al. (2022), Obura et al. (2023)), and is at the heart of the recently adopted Kunming-Montreal Global Biodiversity Framework KMGBF (CBD, 2022). As illustrated by the EU Green Deal (EC, 2019) , the EU intends to be a key player in this transformation, with implications for the EU food and biomass supply chains and the use of land and water resources inside and outside Europe. There are, however, several knowledge gaps about what transformative change in the EU food and biomass supply chains entails and how to accelerate it: What are the actor-level targets & interventions required? How do they vary along alternative worldviews & equity principles? Which are economically, institutionally & ethically viable?

A key assumption of the RAINFOREST project is that one way of addressing this knowledge gap is to co-produce and explore new, just, viable and actionable targets and pathways able to halt or reverse the ongoing global biodiversity decline through transformative change in the EU food and biomass nexus between climate action, production, trade, consumption, and human behavior. Within WP1, we set to co-design such pathways, to support other WPs in model- and scenario-based exploration of such future pathways, as well as case studies focused on specific actors and interventions. We decided to focus on terrestrial ecosystems and to some extent freshwater ecosystems, as a first step. The co-design process proceeds with the following steps:

i. providing a literature review of ambitious pathways for biodiversity to date, key concepts such as worldviews, equity and feasibility and their relation to transformative change for biodiversity, and key elements (targets, actors, interventions) that might constitute such just and viable transformative change pathways for EU food and biomass supply chains,

ii. developing a draft of pathway narratives input from the RAINFOREST stakeholder reference group, through a) project partners designing an

initial scope for the pathways, b) collecting feedback from the RAINFOREST reference stakeholder group on the scope through a dedicated workshop, c) project partners proposing a first draft of the pathway narrative through a report (this document, D1.1),

iii. extending the narrative with a database of downscaled targets (D1.3, foreseen fall 2024), and revising the pathway narratives into their final version through incorporation of insights on feasibility, effectiveness and acceptability of targets and interventions gathered from WP3 and WP4, as well as additional feedback from the RAINFOREST reference stakeholder group and broader engagement with the scientific community, leading to a report containing the final version of the pathway narratives (D1.2, foreseen fall 2024).

This provides the literature review (step i), as well as a draft of the draft of pathway narratives (step ii).

2. PATHWAYS FOR TRANSFORMATIVE CHANGE: STATE OF THE ART AND GAPS

The SSP-RCP scenario framework (O'Neill et al., 2014; Riahi et al., 2017; van Vuuren et al., 2011) has been developed over the last decade to support the analysis of pathways towards long-term climate targets, as well as analysis on climate change mitigation, adaptation and impacts along these pathways. It featured storylines about the main drivers of challenges to climate mitigation and adaptation over multiple dimensions (demographics, human development, economy and lifestyle, policies and institutions, technology, and environment and natural resources), and supported a large range of modelling applications seeking to quantify various aspects of these pathways, featured heavily in recent IPCC reports. These included detailed qualitative and quantitative elements for the food and biomass supply chains from a climate mitigation and adaptation perspective (Hurtt et al., 2020; Popp et al., 2017), and several multi-model assessments for the agriculture (Stehfest et al., 2019; von Lampe et al., 2014), forestry (Daigneault et al., 2022), water (Schewe et al., 2014) and marine (Lotze et al., 2019) sectors, as well as multi-sectoral global change impacts on land, water and energy sectors (Byers et al., 2018).

As drivers of climate change mitigation and adaptation are relevant to several other aspects of global sustainability, and as the SSP-RCP applications spurred many recent developments in global environmental change modelling, this scenario framework led to a much larger range of environmental change scenario and pathway analyses (O'Neill et al., 2020). Focusing on terrestrial and to some extent freshwater ecosystems, these analyses include several applications relevant for RAINFOREST:

- The investigation of future pathways for biodiversity and nature contributions to people (NCP). These ranges from the quantification of biodiversity and NCP outcomes for available scenarios (Hof et al., 2018; Kim et al., 2018; H. M. Pereira et al., 2020; Powers & Jetz, 2019) to adaptations to the scenario framework to explore how to reach futures consistent with long-term goals for biodiversity alone (Leclère et al., 2020) or in combination with climate goals (M. T. J. Kok et al., 2018, 2023; van Vuuren et al., 2015) and a broader range of sustainable agenda objectives including hunger and poverty in so called 'sustainable

development pathways' (Soergel et al., 2021). These studies provided a key contribution to the first IPBES global assessment report (IPBES, 2019) and to the joint IPCC-IPBES workshop (Pörtner et al., 2021) on what pathways are able to reach ambitious climate and biodiversity goals and the broader sustainable development agenda. These studies notably point to the need to address indirect drivers of climate and biodiversity change (e.g., such as sustainable consumption and production) and address the trade-offs and synergies across sustainable development objectives through integration across policies. These two aspects are necessary ingredients to any pathway meeting the global sustainability goals and are features defining transformative change (Chan et al., 2020).

- The design and investigation of novel SSP extensions complementing the SSPs for a) other environmental pressures of importance for biodiversity – e.g., nitrogen cycle (Kanter et al., 2020) – and b) more sectoral and geographic details for the European context – e.g., refined SSP narratives for Europe with the EUR-SSPs (Kok et al., 2019), or further refinement for the agricultural sector with the EUR-AGRI-SSPs (Mitter et al., 2020) –. In cases, both are combined: e.g., EUR-AGRI-SSP extension for pesticides (Nagesh et al., 2023), or SSP extensions for chemical pollutants in Europe with more or less focus on agriculture (Desrousseaux et al., 2022; Hader et al., 2022; Nagesh et al., 2023). Often relying on additional stakeholder consultations, these extensions provide additional details relevant to the context of the agricultural sector in Europe (although with limited efforts to differentiate regions within Europe) and to its broader pollution impacts beyond land use, while seeking to maintain consistency with the original SSPs.

Beyond scenarios quantifying or extending the SSP framework, additional scenarios can be gathered to explore the transformation of the global and EU food and biomass systems, including:

- EU-focused studies covering both stylized and policy-oriented scenarios focused on the uptake of both more sustainable dietary choices and agroecology practices and related interactions (Billen et al., 2021; Poux & Aubert, 2018; Röös et al., 2022) and exploring the impact of various measures from the EU Green Deal initiative such as the EU Biodiversity & Farm to Fork strategies (European Commission. Joint Research Centre., 2021; Guyomard et al., 2023; Henning & Witzke, 2021) as well as the climate mitigation-related impacts on forest biomass

(Gusti et al., 2020; F. Rosa et al., 2023).

- Multi-national to global scale initiatives to designing and exploring alternative set of scenarios that relate to expected future trends in the land-based sectors and steering those towards sustainability targets, such as the Agrimonde-Terra initiative (Le Mouël et al., 2018), the EAT Lancet Commission (e.g., Springmann, Clark, et al., 2018), the FABLE initiative (e.g., Jones et al., 2023; Schmidt-Traub et al., 2019), the Food System Economics Commission (e.g., Bodirsky et al., 2023; Gaupp et al., 2021) or the Chattam House research paper on sustainable agriculture and food systems (Benton & Harwatt, 2022). While these studies often relate to the SSP-RCP framework to some extent, they also cover additional / alternative scenario narratives and can investigate some aspects beyond the SSP narratives. For example, Springmann, Clark, et al. (2018) provided an exploration of more ambitious dietary shifts than considered in the SSP2, while Bodirsky et al. (2022) assessed for the land sector what a degrowth trajectory for the food system could look like. The FABLE initiative provided an ensemble of globally coordinated participative national-scale assessments of land system transformations towards sustainability goals in 12 countries (Jones et al., 2023). Bodirsky et al. (2023) provides a comprehensive global-scale analysis of scenarios covering 23 food system transformation measures grouped in various portfolios and combined with alternative assumptions about other global change drivers, to explore the contributions of a global food system transformation to global goals, as well as synergies and trade-offs associated with various food system transformation interventions.
- Foresight projections and policy reviews from institutional sources at both global (e.g., OECD, FAO) and EU (e.g., EEA, EC, European parliament). On the one hand, institutional foresight projections can be used as reference for forward-looking policy analysis and planning: for example, the periodic OECD-FAO Agricultural Outlook (OECD & Food and Agriculture Organization of the United Nations, 2023), the EU Agricultural Outlook (European Commission. Directorate General for Agriculture and Rural Development., 2022) or the EU Reference scenario (European Commission. Directorate General for Energy. et al., 2021). Foresight exercises may also cover modelling and scenarios towards sustainable targets (for example, the EC's in-depth analysis in support of the EU Long-term

Strategy[1]) or qualitative scenarios exercises (for example, the EEA & EIONET foresight exercise on "Imagining sustainable futures in Europe"[2]) exploring what a sustainable Europe could look like in 2050 explorations of potential . On the other hand, policy reviews for food systems can be used as sources of information for potential interventions for transformative change: for example, the OECD review on making better policies for food systems (OECD, 2021), or the EEA assessment of the EU policy mix for transforming Europe's food systems (European Environment Agency., 2022).

While above-mentioned studies allowed to uncover some aspects of the transformative change needed in the EU food and supply chains to achieve global and EU goals for nature, climate and people, the potential of scenarios and modelling applications to support such a transformative change could be leveraged further. In particular, the scenario and model applications to date tend to overlook key questions related to a large range of equity considerations (e.g., from the participation of marginalized communities and inclusion of their perspectives in the scenario design, to distributive justice of costs and benefits across actors and generations) and human-nature interactions that may be key in unlocking transformative change action (Chan et al., 2020; Obura et al., 2023; Zurek et al., 2021).

The focus on scenarios that consider multiple perspectives and make their underpinning values more explicit have been proposed as a step in this direction (IPBES Value Assessment), and the Nature Futures framework recently adopted by the IPBES is an example of such a scenario framework (Durán et al., 2023; L. M. Pereira, Davies, Belder, et al., 2020; I. M. D. Rosa et al., 2017). It focuses on futures in which goals for human wellbeing, nature and climate are met, while exploring multiple value perspectives about human-nature relationships, through a tryptic of intrinsic values (nature for nature), instrumental values (nature for society) and relational values (nature as culture). While examples of scenarios are being developed, including global (Durán et al., 2023) but also European (Dou et al., 2023; Fornarini et al., 2023) contexts, they focus primarily on exploring alternative value

[1] https://knowledge4policy.ec.europa.eu/publication/depth-analysis-support-com2018-773-clean-planet-all-european-strategic-long-term-vision_en
[2] https://www.eea.europa.eu/ds_resolveuid/ee84070dd11f4f1f8dd6ffe781dafeda

perspectives about human-nature relationships, while justice aspects have been given less explicit consideration. While including human-nature relationship in a less detailed manner and encompassing them broader, the Sustainable Development Pathways (Kriegler et al., 2022, SHAPE project) represent another scenario framework that aims to explore alternative futures in which the goals from the sustainability agenda are met, differing in terms of key assumption about human well-being, societal organization, economy, technology, nature and resource provisions. These are based on value-explicit considerations covering individual (e.g., human rights), economy (e.g., private vs public sector, property rights), society (liberalism vs collectivism, progressive vs traditional), nature (human-centric vs nature-centric) and universality of value dimensions, and may provide a promising ground to explore a range of justice considerations.

3. PLURAL WORLDVIEWS AND EQUITY CONSIDERATIONS

From Wicked Problems to Co-Produced Solutions: The Importance of Worldviews and Justice in the creation of just and transformative biodiversity pathways

3.1 Why do worldviews matter?

In the early 1970s Rittel and Webber (1973) made a bold claim that, "the search for scientific bases for confronting problems of social policy is bound to fail, because of the nature of these problems". The challenge they identified was that for these policy problems there was no "undisputable public good" or "objective definition of equity" and no solution, "[s]ocial problems are never solved. At best they are only re-solved–over and over again." This was due to the differentiated ways in which the problems could be elaborated with people holding contesting beliefs on the causes, consequences and importance of the problems. The fundamental differences in peoples' views then led to inter-group conflict in the policy planning phase leading to difficulties in implementation of proposed solutions. They coined the term "Wicked problems" for these issues and the climate crisis (Lazarus, 2008; Ney & Verweij, 2015; Thompson, 2018) and biodiversity loss (DeFries & Nagendra, 2017) are seen as archetypal "wicked problems".

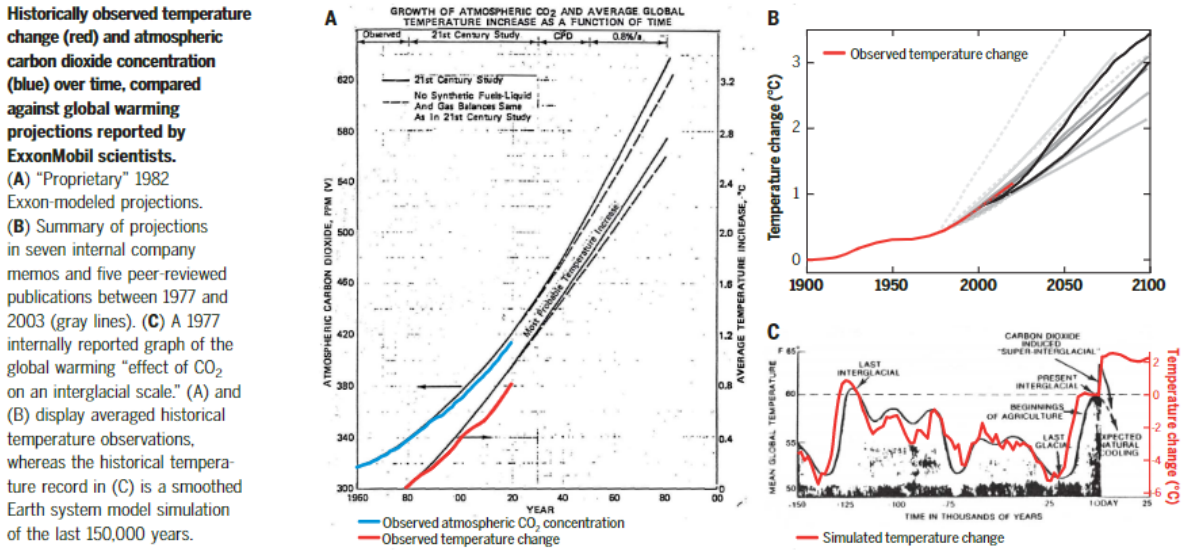
Not all environmental crises are seen as "wicked problems". The depletion of the ozone layer due to the use of Chlorofluorocarbons (CFCs) is the most often cited example of a non-wicked environmental problem (Ney & Verweij, 2015; Thompson, 2018). After the discovery of the impact of CFCs on the ozone layer by Molina & Rowland (1974), it took only 15 years until the Montreal Protocol, curbing the use of CFCs, came into force. This was because industry identified a possible harm being created by their products and funded open research which led to a specific cause to the depletion of the ozone layer being agreed upon and investments being made into substitutes, Hydrochlorofluorocarbons (HCFCs) and Hydrofluorocarbons (HFCs). At the same time, government action was taken with unilateral national bans taking effect in the US, regional ones in the EU and international agreements being enacted (Powell, 2002). All these actions were taken with widespread public support because

the depletion of the ozone layer was shown to cause higher rates of UV-B radiation and so a direct threat to human health through increased incidence of basal and squamous cell carcinomas, the most common forms of skin cancer (Kripke, 1988). This governance response can be seen as one of the most effective examples of environmental harm reduction with the use of all types of governance structures; government, industry, research and civil society. So why have the climate and biodiversity crises not followed the same governance process for eliminating the harm and risk posed?

One can start to understand why the climate crisis is a "wicked problem" from the solution to the o-zone crisis. HFCs were considered to be the long-term solution to the problem of ozone depleting substances (ODS) and were not included in the original Montreal Protocol but they are a potent greenhouse gas (GHG) and were included in the Kyoto protocol (Velders et al., 2012). They were then added to the Montreal Protocol in 2016 for accelerated global reduction in use as a climate protection measure to avoid 80 billion metric tons of carbon dioxide equivalent emissions by 2050 (US EPA, 2015). The problem with GHG emissions is that, unlike ODS, they do not come from a specific sector or set of products but are produced across nearly all economic activities that require a far broader set of actions to mitigate their production. These actions then have far-reaching social consequences for wide-ranging groups and therefore open up wider questions of how society should be managed. Policy responses to biodiversity loss, also, open these same questions because of the importance of land and material use in combatting direct drivers of biodiversity loss require us to ask questions such as how should society value the environment and how should resources be shared and allocated?

In these circumstances, the governance structures that produced coherent policy responses to the ozone crisis become sites of conflict with the science community advocating very different narratives to industry lobby groups, the general public becoming divided between protecting material wellbeing and environmental wellbeing, and governments being unable to coherently deliver effective policy measures. And, importantly, the response of the scientific community to the denials, downplaying and obfuscation of the climate crisis was to make the science more accurate and more compelling in the belief that those refuting it would eventually have to come on board. But as we now know (Supran et al., 2023; Supran & Oreskes,

2017), the deniers already had the same scientific findings. The issue at hand was not the credibility of the scientific evidence on the causes and consequences of temperature increases but the consequences, to certain interest groups, of the policies that needed to be enacted.



Historically observed temperature change (red) and atmospheric carbon dioxide concentration (blue) over time, compared against global warming projections reported by ExxonMobil scientists. (**A**) "Proprietary" 1982 Exxon-modeled projections. (**B**) Summary of projections in seven internal company memos and five peer-reviewed publications between 1977 and 2003 (gray lines). (**C**) A 1977 internally reported graph of the global warming "effect of CO_2 on an interglacial scale." (A) and (B) display averaged historical temperature observations, whereas the historical temperature record in (C) is a smoothed Earth system model simulation of the last 150,000 years.

Figure 1. Illustration showing ExxonMobil modelled projections of anthropomorphic climate change. Source: Supran et al. (2023).

This then produces the necessity for scientific research into the pathways for positive transformational change to resolve environmental degradation to include diverse interests, worldviews and risk perceptions. The understanding of the nature of these problems is spreading and in response the tactics of the scientific community are changing with examples such as the Shared Sustainable Pathways (Riahi et al., 2017) and the UNDP (2022) Human Development Report 2021-22 but can be most clearly seen in the IPBES Nature's Contribution to People and Nature Futures framework (see Ellis et al., 2019; IPBES, 2019) . The Nature Future Framework seeks to,

> "shift traditional ways of forecasting impacts of society on nature to nature-centred visions and pathways that will integrate interlinkages of social-ecological systems across direct and indirect drivers, biodiversity, ecosystem functions and services, and human well-being, incorporating multiple systems of knowledge across scale and sectors." (I. M. D. Rosa et al., 2017)

This requires not only an intersectoral and multiscale approach to scenarios and modelling but the inclusion of multiple belief systems for valuing nature which are represented by the tripartite model, shown below, with intrinsic, relational and instrumental values as apex values. These different beliefs in the valuation of nature allow the incorporation of different worldviews into policy and scenario development.

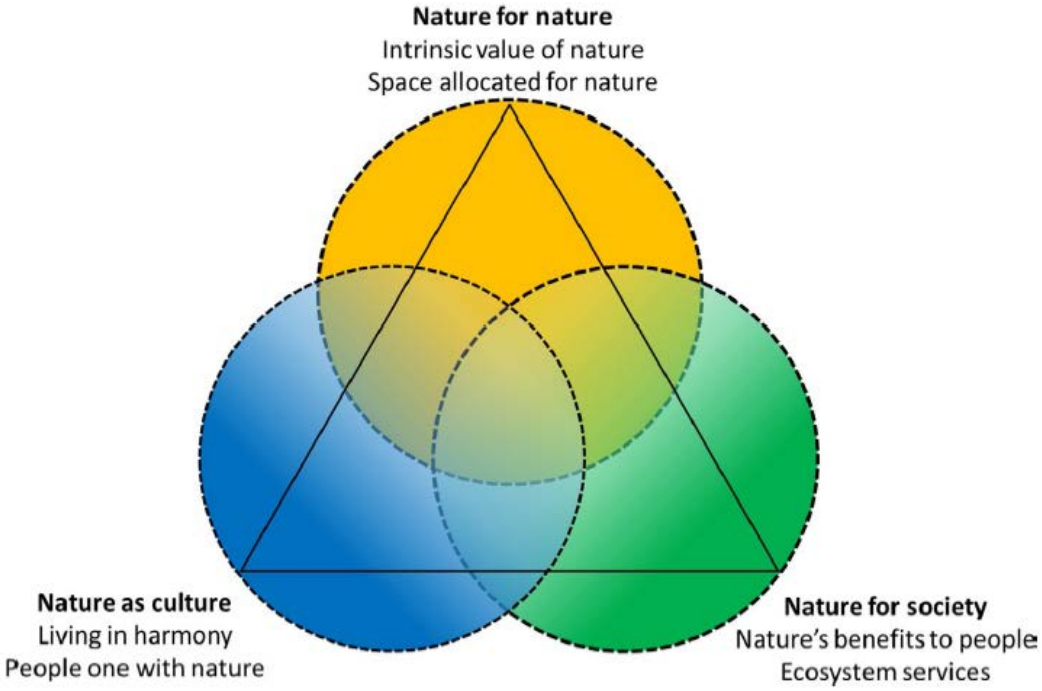


Figure 2. Pluralistic Nature Futures Framework. Source: IPBES (2019)

3.2 What are Worldviews?

Hedlund-de Witt (2014), following Koltko-Rivera (2004), defines worldviews as,

"complex constellations of ontological presuppositions, epistemic capacities, and ethical and aesthetic values that converge to dynamically organize a synthetic apprehension of the exterior world and one's interior experience. They consist of foundational assumptions and perceptions "regarding the underlying nature of reality, "proper" social relations or guidelines for living, or the existence or non-existence of important entities""

They are the very way in which we divine meaning from and about the world and this has important effects on our actions and behaviours by providing interpretations

of why events occur and how we should respond to them. This then impacts policy and pathway acceptability because of their adherence or inconsistency with our worldview and narratives of policy problems.

Worldviews are incorporated to the NFF through three different concepts from three disciplines: incommensurability of values from Ecological Economics, social representations from social psychology and relational models from cultural anthropology (Muradian & Pascual, 2018). These, respectively, help us understand how different people value objects, frame events and build relationships. This framework for recognising different worldviews allows the design of pathways and scenarios that will be most acceptable to individual worldviews by aligning with their values, framings, and relationships. This is because rather than view all people as inherently the same in their rationality and self-interest (the rational choice model), worldview frameworks understand the collective similarities that exist in groupings, communities and institutions and looks to compare these with other groupings, communities, and institutions to understand their collective outlooks. Then by understanding the underlying reasons for the conflict between differing parties, it is possible to produce workable policy solutions by finding values, framings and relationships which are the least contentious. The argument is that rather than a single rational choice policy option to be chosen that a debated and co-produced policy cluster is preferred. This then allows policy compromises and institutional tools to be implemented that cater towards the needs and beliefs of different groups to allow co-production of policy pathways (McNeeley & Lazrus, 2014; Ney & Verweij, 2015; Verweij et al., 2006).

3.3 Justice in Global Environmental Policy

As we have seen with worldviews, and beliefs around justice tend to correspond to worldviews (Stroebe et al., 2015), when wider questions of social structures are invoked through policy debates and interventions underlying tensions are brought to the fore and as (Plutynski & Fujita-Lagerqvist, 2016, p.282) state, “Biodiversity is at the intersection of a host of political and economic conflicts over land, resources, and power.” But whereas worldviews are about our underlying assumptions about how the world is and how it should be, justice debates are more focused on the

processes and actions that need to be undertaken to lead to fair outcomes.

In current research and policy debates, justice is most often discussed in terms of equity principles, agreed concepts of fairness in how costs and benefits should be shared, and is commonly referred to as distributive justice. The most common equity principles discussed are need, responsibility, capacity and equality. These principles are often instrumentalized in the form of resource or burden allocations, e.g. a national carbon budgets, that are then used to create goals and targets for national and local governments. Depending on the principles selected these can lead to very different distributions or allocations that create the need for greater or lesser interventions by different countries, especially between lower and higher income countries (see Höhne et al., 2014).

For example, in international climate negotiations, the key equity principle is the "common but differentiated responsibilities" (CBDR) principle that is captured in Principle 7 of the Report of the United Nations Conference on Environment and Development, Rio de Janeiro (1992), Article 3.1 of the United Nations Framework Convention on Climate Change (1992) and Article 2 of the Paris Agreement to the United Nations Framework Convention on Climate Change (2015). This principle acknowledges that higher income countries have a greater responsibility and capacity to mitigate climate change compared with lower income countries that need to prioritise poverty reduction. This was applied through the distinguishing of responsibilities between "Annex I" parties (member of the OECD in 1992) and "Non-Annex I" parties (Pauw et al., 2014) where Annex I parties were expected to lead on finance and technology transfers. And while CBDR is not directly mentioned in the Convention on Biological Diversity (1992), Article 20 does state that developed countries should provide the financial resources for less developed countries to meet their commitments.

This may signal that there are then agreed equity principles for burden sharing, but this is not the case. This continues to be a very live debate due to the growth in middle income countries since 1992. Higher income countries and regional blocks, such as the US and EU, want current high emitters, like China and India, to contribute more, even though their populations remain relatively impoverished, in opposition to the CBDR principle based on Annex I parties. This means that it is still necessary

to show the impact of various equity principles on burden sharing to support political negotiations.

One example is Lucas et al. (2020), where they use three different allocation approaches; 'grandfathering'[3], 'equal per capita' shares[4], and 'ability to pay'[5], to downscale burden sharing to the national level to reduce environmental pressure to within planetary boundaries. Their results show that grandfathering gives the EU and the US the highest allocated budgets whereas ability to pay and equal per capita are more favourable to China and India. For CO2 emissions, grandfathering allocates shares of 15% to the EU and 18% to the US but only 7% and 5%, respectively, when allocating equally per capita. And even goes as far as a negative emissions budget of -7% when using ability to pay. These stark differences in allocation show the importance of the selection of equity principles in outcomes underlining why they continue to be of great interest in climate negotiations.

This selection process is not always so transparent and is often suggested to be value-free but as Dooley et al. (2021) explain attempts to create value-free approaches leads to the inclusion of equity principals that are directly opposite to just outcomes. They use the example of grandfathering which runs counter to the CBDR principle and allows current imbalances to be continued and does consider need or responsibility. It can, also, lead to the inclusion of contrary principles being applied at the same time that render outputs opaque and even meaningless. They then argue that it is necessary to be explicit about any normative or ethical choices that underpin equity principle selection for modelling an that they need to be coherent and meaningful for different groups so outcomes can then be clearly negotiated. So we should ask how can coherent and meaningful principles be identified?

It is important to realise that distributional Justice is not the only dimension of justice. Dawson et al. (2018) explain three key dimensions to justice; procedural, recognition and distributional, and that while distribution has traditionally been the

[3] Grandfathering is based on a sovereignty principle where current resource use is seen as an acquired or 'status quo right'. This approach allocates their budget based on a country's current share in global environmental pressure.
[4] Equal per capita allocation is based on the equality principle where a country's share in the global population designates their allocation.
[5] The ability to pay approach is based on the capability principle where allocation of the global transgression of planetary boundaries are based on a country's GDP per capita.

focus of conservation policy that it is insufficient if the overall objective is justice for all. The prioritization of distributional concerns leads to a focus on access restrictions to conservation areas and compensation. While such these policies may be accepted by some groups, for others being included in the decision-making process or having cultural or historical ties acknowledged are considered as important.

Table 1. Main types of environnemental justice. Source: Dawson et al. (2018)

Types of Justice	Explanation
Procedural	Procedure refers to how decisions are made and by whom, whether formal rules and processes or informal interactions, necessitating attention to unequal power relations and differential ability to assert or oppose different claims.
Recognition	Recognition revolves around the status afforded to different social and cultural values or identities and to the social groups who hold them
Distributional	Distribution concerns the different subjects who realize benefits or incur costs and risks, whether material or non-material, objective or subjective.

This over prioritization of distribution is exemplified by traditional "fortress" conservation, the strict removal of economic activities from areas of natural beauty and high or unique biodiversity in the 1960s and 1970s in sub-Saharan Africa, that led to injustices for local peoples including forced eviction and denial of rights of passage for migratory routes for herders (Plutynski & Fujita-Lagerqvist, 2016). These perceived injustices led to a change in conservation science and a focus on community-based approaches to conservation. When approaching the development of just pathways it is important to have in place an understanding of the implications of these policies and contextualize them with a diversity of views and opinions. The inclusion of a diversity of voices allows normative and ethical choices to be clarified and leads to appropriate selection of justice and equity principles.

3.4 Worldviews as catalyst and barrier

The ecological crises currently being experienced globally; such as climate change and biodiversity loss, require responses that entail a paradigmatic shift not only in our energy and material usage but, also, in fundamental changes to our economies and the organization of our societies. To produce this transformative change, it is necessary to utilize effective levers and leverage points that shift our legal, political, economic and social systems towards a nature positive future (Chan et al., 2020). In the IPBES (2022) Assessment Report on the Diverse Values and Valuation of Nature,

values and worldviews are identified as “deep leverage points” that increase the effectiveness and stability of policy interventions. But it is important to recognise that worldviews and values can also be a potential barrier to transformational change because they impact policy and pathway acceptability through their adherence or inconsistency with stakeholder worldviews and values (Feola et al., 2019). Therefore, it is important to understand stakeholder worldviews and values and tailor policy pathways so that they are consistent and coherent with them.

The IPBES (2022) values report also states that the relationship between transformative change and worldviews and values is not linear but cyclical so worldviews and values are both the input for change and the outcome of this change. To understand this cyclical relationship, we model it using three sociological conceptions around structure and agency; Giddens' '(1984) structuration theory, Bourdieu' '(1977) habitus and Weber's (2013) conception of emergent behaviour (see *Figure 3*). These provide an understanding of how norms and rules create ontological framings, what we refer to as worldviews, of what is happening and why. These then lead to actions being routinised into everyday practices but also how emergent behaviours can appear out of changes in these worldviews that can gain wider support and lead to transformational change. Under this conception, interventions should be designed to support nature positive emergent behaviours that can then become habituated through concrete practices.

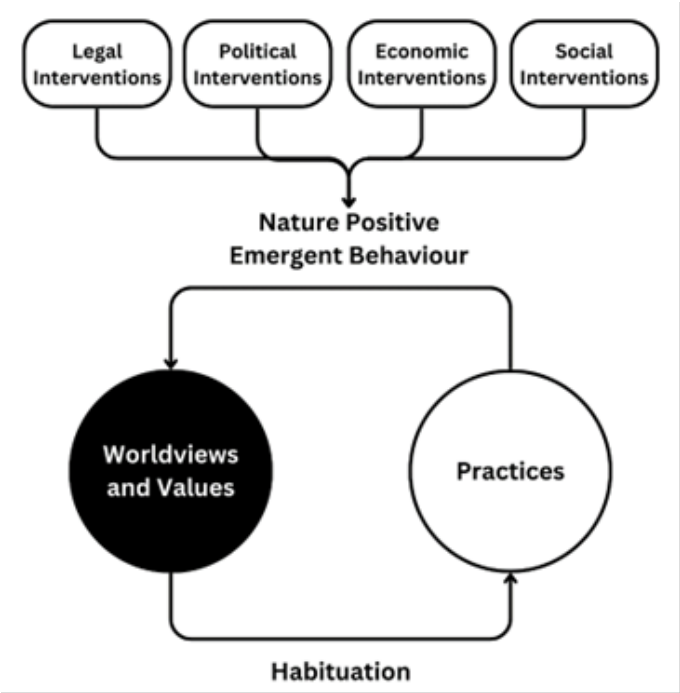


Figure 3. Conceptualization of how worldviews and values can be used as a leverage point.

4. TARGETS, INTERVENTIONS AND FEASIBILITY CONSIDERATIONS

4.1 Aggregated targets

4.1.1 Global and European frameworks and policies for climate, biodiversity and people

In the face of severe planetary crises, such as global biodiversity loss and rapid climate change (IPBES, 2019; IPCC, 2014, 2019, 2023), numerous ambitious goals and targets for nature, climate and people have been set out globally and at the European level. These goals and targets cover direct drivers, indirect drivers and outcomes for biodiversity and climate and can inform the endpoints and interventions of pathways of transformative change in biomass production and consumption systems. We here provide a review relevant to terrestrial and to some extent freshwater ecosystems.

At the global level, the Kunming-Montreal Global Biodiversity Framework (CBD, 2022), adopted by the parties of the Convention on Biological Diversity (CBD) in 2022, aims to initiate transformative action to halt and reverse biodiversity loss. In addition, the Paris Agreement (UNFCCC, 2015), agreed on by the parties of the United Nations Framework Convention on Climate Change (UNFCCC) in 2015, aims to combat climate change and enable countries to tackle its consequences.

For the EU, the European Green Deal (European Commission, 2019), adopted in 2019, represents a growth strategy with no net emissions of greenhouse gases in 2050 and economic growth decoupled from resource use. The EU Green Deal addresses several relevant areas, such as the energy, building, and mobility sectors, or ambitions towards zero pollution and a circular economy. Two core strategies of the European Green Deal are the EU Biodiversity strategy for 2030 (European Commission, 2020b) and the Farm to Fork strategy (European Commission, 2020a). The former intends to put Europe's biodiversity on the path to recovery by 2030, while the latter addresses the challenges of sustainable food systems and recognises that healthy people and societies are inextricably linked to a healthy planet. The

new common agricultural policy (CAP) for 2023-27[6] represents an important tool to achieve the goals and targets in these two strategies and sets out some objectives for the agriculture in Europe. The EU Forest strategy for 2030 (European Commission, 2021b) complements these frameworks. It aims at improving the quantity and quality of EU forests and strengthening forest protection, restoration and resilience. The EU regulation on deforestation-free supply chains is also worth mentioning, which intends to prevent the placement of products that have caused deforestation or forest degradation on the EU market. The EU Fit for 55 package (European Commission, 2021a) refers to the EU's goal to reduce GHG emissions by 55% until 2030 and aims at bringing the EU legislation in line with this goal.

These global and European agreements and policies align with and refer to the 2030 Agenda for Sustainable Development (UN General Assembly, 2015) adopted by the United Nations in 2015, which guides a sustainable, peaceful and prosperous present and future for humanity and the planet. In addition to these policy agreements, the scientific framework of planetary boundaries (Richardson et al., 2023; Rockström et al., 2009; Steffen et al., 2015) defines a safe operating space for humanity within a functioning Earth system, while the concept of the safe and just Earth system boundaries (Rockström et al., 2023) develops this further accounting for minimizing human's exposure to significant harm from Earth system change. The planetary boundaries framework has been taken up by policy, e.g., the EU's environment action programme to 2030 (European Parliament & Council of the European Union, 2022), a common agenda for the EU's environmental policy until 2030, emphasising the objective that Europeans should live within the planetary boundaries by 2050. The IPBES Nature Futures Framework represents a flexible tool[7] for developing scenarios and models of desirable futures for people and nature (L. M. Pereira, Davies, den Belder, et al., 2020). It represents three non-mutually exclusive value perspectives for nature: nature for nature, nature for culture, and nature for society, within which scenarios of nature-positive futures can be

[6] https://agriculture.ec.europa.eu/common-agricultural-policy/cap-overview/cap-2023-27/key-policy-objectives-cap-2023-27_en; https://agriculture.ec.europa.eu/common-agricultural-policy/cap-overview/cap-2023-27_en

[7] https://www.ipbes.net/scenarios-models; https://www.ipbes.net/node/48281

developed. The IPBES Nature Futures Frameworks emphasises the inclusion of diverse worldviews as vital to policy and scenario development (Muradian & Pascual, 2018; Pascual et al., 2017).

In section 4.1.2, we present a compilation of goals, targets and objectives from the abovementioned documents that can guide pathways of transformative change in biomass production and consumption systems. Some of these targets occur throughout different documents underlining the high relevance of these targets. For example, the Kunming-Montreal Global Biodiversity Framework, the EU biodiversity and Farm to Fork strategies, and the planetary boundary framework all acknowledge the importance of pollution from pesticides and excess nutrients. Similarly, restoration and protected areas have been emphasised in global and European agreements as essential for enhancing and conserving biodiversity. In section 4.1.3, we elaborate on why and how we selected a subset of the long list of goals and targets presented in 4.1.2. Finally, in section 4.1.4, we describe the implications these goals and targets may have for the EU biomass supply chain and beyond.

4.1.2 Goals and targets for climate, biodiversity and people

Here, we introduce a compilation of goals and targets from the documents highlighted in 5.1.1 and provided as a large supplementary table in an additional excel file. This table aims to give an overview of the multitude of targets, help navigate among them and narrow them down to targets we want to focus on within RAINFOREST to inform pathways of transformative change in biomass production and consumption systems. The columns of this large table are described in Table 2.

For some documents we present all targets/ paragraphs (EU-BS, EU-FTF, EU-CAP, GBF, PB), while for others, we present a preselection of those targets that we deem relevant (EU-GD, PA, SDG, COP27). Some documents clearly present targets (e.g., GBF, SDG, and EU-BS), while others mix background information, actions and targets (e.g., EU-FTF).

Table 2. Content of compilation of goals and targets in supplementary table. Source: own compilation.

Column name	Description	Values - detail
Global/EU	Indicates whether the document has a global or EU focus/ is a global/ EU policy	
Body	The document the target was taken from	**EU-BS** – EU Biodiversity Strategy for 2030 ; **EU-CAP** – Common Agricultural Policy; **EU-CL** – European Climate Law ; **EU-FS** – EU Forest Strategy for 2030; **EU-FTF** – EU Farm to Fork Strategy; **EU-GD** – European Green Deal; **EU-LULUCF** – EU Land Use, Land Use Change and Forestry Regulation; **EU-ZP** – EU Action Plan: 'Towards Zero Pollution for Air, Water and Soil'; **GBF** – Kunming Montreal Global Biodiversity Framework; **NFF** – Nature Futures Framework; **PA** – Paris Agreement; **PB** – Planetary boundaries; **SDG** – 2030 Agenda for Sustainable Development; **COP27** – COP 27 cover agreement.
Identifier	A unique identifier for each target, usually containing the body and keywords	
Target text	The original target/ paragraph text	
Direct driver/ indirect driver/ outcome	This column classifies whether the target in question addresses an outcome for climate, biodiversity or society, or a direct or indirect driver of change. The classification is based on the classification by the IPBES. We classify a target as "multiple" if it addresses direct and indirect drivers or drivers and outcomes	
Topic	This column indicates the topic of each target. For targets addressing direct and indirect drivers, we use the categories provided by the IPBES. We added greenhouse gas emissions as topic for targets addressing direct drivers. For targets related to outcomes, we chose our own topics. The topics intend to help group and select targets for informing pathways of transformative change	**Direct driver**: land/ sea use, direct exploitation, climate change, pollution, invasive alien species, greenhouse gas (GHG) emissions, others; **Indirect driver**: demographic and sociocultural, economic and technological, institutions and governance, (Conflicts and epidemics); **Outcome**: climate, biodiversity (genes, species, ecosystems), nature's contributions to people (NCP), food, nutrition and health, employment and income
Potential indicators	Indicators that have been published along with the targets (not the case for all targets)	
Short listing	We group the targets into four groups, see 3.1.3	(1) Short-listed, quantitative: target addresses a focal topic and will be part of the pathways and quantified/ downscaled; (2) Short-listed, qualitative: target addresses a focal

		topic and will be part of the pathways but (tentatively) not quantified/ downscaled (due to potential data deficiency); (3) Not short-listed, qualitative: target does not address a focal topic but is important for pathway development and will be included qualitatively, e.g., most of the targets addressing indirect drivers; (4) Not included: target is beyond the scope of our project

4.1.3 Rationale for goal and target selection

Given this multitude of goals and targets, it will be important to select a subset of focal targets for further work in RAINFOREST. There are two applications of the targets for which the subsets will likely differ. First, targets will inform the pathways that will be developed in D1.1 and refined in D1.2 both quantitatively and qualitatively. Second, targets will be downscaled to geographies, sectors and actors to explore world views and justice principles (D1.3). To create these subsets, we decided on a set of focal topics for the pathway development and downscaling and identified topics that are beyond the scope of these tasks. Our focal topics are the consumption, production and trade of biomass products, pollution from excess nutrients and pesticides, area protection and restoration, greenhouse gas emissions from agriculture, forestry, and other land use, the extend and potentially intactness of natural ecosystems, extinction risk and potentially pollination as example for nature's contribution to people. Accordingly, we derived four groups of targets: (1) Short-listed, quantitative: target addresses a focal topic and will be part of the pathways and quantified/ downscaled. (2) Short-listed, qualitative: target addresses a focal topic and will be part of the pathways but (tentatively) not quantified/ downscaled (due to potential data deficiency), (3) Not short-listed, qualitative: target does not address a focal topic but is important for pathway development and will be included qualitatively, e.g., most of the targets addressing indirect drivers, (4) Not included: target is beyond the scope of our project.

4.1.4 Implications for the EU biomass supply chain and beyond

To understand the implications of these goals and targets for the EU biomass production and consumption system, we can identify targets that describe desired outcomes for nature, climate and people and derive interlinkages with targets that address direct and indirect drivers of these desired outcomes and are relevant for biomass production and consumption.

Global biodiversity targets

A desired outcome for biodiversity has been formulated in goal A in the GBF, i.e., "The integrity, connectivity and resilience of all ecosystems are maintained, enhanced, or restored, substantially increasing the area of natural ecosystems by 2050; Human induced extinction of known threatened species is halted, and, by 2050, the extinction rate and risk of all species are reduced tenfold and the abundance of native wild species is increased to healthy and resilient levels; The genetic diversity within populations of wild and domesticated species, is maintained, safeguarding their adaptive potential" (GBF).

It is crucial to address the direct drivers of declines in biodiversity and nature to deliver this desired outcome. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) identified land and sea use change, direct exploitation, climate change, pollution, and invasive alien species as main direct drivers of biodiversity loss to date (IPBES, 2019). Below, we highlight targets addressing two of these direct drivers and their relationship to biomass production: land use and pollution through excess nutrients and pesticides.

Biomass production, agriculture in particular, affects nature and biodiversity via land use change and intensification (Dudley & Alexander, 2017; Foley et al., 2005; IPBES, 2019). The GBF formulates several targets addressing the direct driver of land use, starting with ensuring "that all areas are under participatory, integrated and biodiversity inclusive spatial planning and/or effective management processes addressing land and sea use change […]" (GBF target 1). It further sets the targets to put 30% of areas of degraded terrestrial, inland water, coastal and marine ecosystems under effective restoration (GBF target 2) and to effectively conserve and manage at least 30% of terrestrial, inland water, coastal and marine areas by 2030 (GBF target 3). The GBF also directly addressed areas under biomass production

by aiming at ensuring "that areas under agriculture, aquaculture, fisheries and forestry are managed sustainably, in particular through the sustainable use of biodiversity, […] contributing to the resilience and long-term efficiency and productivity of these production systems and to food security, conserving and restoring biodiversity and maintaining nature's contributions to people […]" (GBF target 10). These targets cover three key elements of reducing biodiversity impacts of the land use sector, i.e., conservation/ protected areas, restoration, and sustainable use/ management. These elements complement each other: Halting the conversion of remaining intact ecosystems (GBF target 1) should go hand in hand with sustainable management of existing areas under biomass production (GBF target 10) to achieve positive outcomes for biodiversity (DeClerck et al., 2023); and a combination of sustainable agriculture and increased conservation and restoration, together with other interventions, has the best potential to halt biodiversity loss caused by habitat conversion (Leclère et al., 2020).

Biomass production further contributes to the deterioration of biodiversity through the use of fertiliser and pesticides, often tied to agricultural intensification (Dudley & Alexander, 2017; Geiger et al., 2010; Li et al., 2020; Wurtsbaugh et al., 2019). To reduce the negative impacts of these and other pollutants on biodiversity, the GBF targets to "Reduce pollution risks and the negative impact of pollution from all sources by 2030, to levels that are not harmful to biodiversity and ecosystem functions and services […] including: reducing excess nutrients lost to the environment by at least half […] reducing the overall risk from pesticides and highly hazardous chemicals by at least half […]" (GBF target 7). Managing areas under biomass production sustainably (GBF target 10) will ideally also reduce pollution risk from excess nutrients and pesticides (GBF target 7).

Several indirect drivers influence the direct drivers of the decline in biodiversity and nature. The IPBES defines indirect drivers as "human actions and decisions that affect nature diffusely by altering and influencing direct drivers as well as other indirect drivers" (IPBES 2019) and discusses economic, demographic, technological and cultural drivers as well as drivers related to governance (IPBES 2019). The GBF formulates several targets addressing indirect drivers of biodiversity change ranging from integrating biodiversity and its values into policies (GBF target 14), ensuring that people are enabled and encouraged to make sustainable consumption choices

(GBF target 16) to targets related to incentives and financing (GBF targets 18 and 19) as well as capacity-building, data and knowledge (GBF targets 20 and 21). The GBF also addresses questions of equity and participation (GBF targets 22 and 23).

Human consumption represents a critical indirect driver of biodiversity decline. Human consumption, production, and global trade are interconnected, jointly causing environmental impacts and biodiversity loss (Chaudhary & Kastner, 2016; Kastner et al., 2011; Notarnicola et al., 2017; Wilting et al., 2017). Food consumption affects biodiversity through agricultural production and consumption choices can shape these effects. For example, the consumption of plant-based products tends to have a lower environmental impact, such as lower GHG emissions and land use pressure, than the consumption of animal products (Aleksandrowicz et al., 2016; Chai et al., 2019; Hallström et al., 2015; Pimentel & Pimentel, 2003). Food loss and waste are also crucial in causing environmental impacts and biodiversity decline (Kummu et al., 2012; Rohini et al., 2020). Consequently, the GBF targets to "ensure that people are encouraged and enabled to make sustainable consumption choices […] and by 2030 reduce the global footprint of consumption in an equitable manner, including through halving global food waste, significantly reducing overconsumption and substantially reducing waste generation […]" (GBF target 16).

EU biodiversity targets

Targets set in the EU-GD and related documents similarly address desired outcomes for biodiversity and direct and indirect drivers of declines in biodiversity and nature. Partly, these EU targets mirror global biodiversity targets; partly, they are more detailed and specific to the EU.

The EU-BS articulates the vision that all ecosystems of the world are "restored, resilient, and adequately protected" by 2050; and the goal to put the biodiversity within Europe "on the path to recovery by 2030 for the benefit of people, the planet, the climate and our economy." To this end, targets to protect and restore nature, enable transformative change and support biodiversity globally have been formulated.

Several EU targets address the direct driver of land use, considering the three elements of conservation/ protected areas, restoration, and sustainable use/ management. Regarding conservation, the aim is to legally protect at least 30% of

the EU's land area and seas, at least one third of these strictly (EU-BS pillar 1). In particular, all primary and old growth forests and other carbon rich ecosystems, such as peatlands, grasslands, wetlands, mangroves and seagrass meadows should be strictly protected (EU Forest Strategy, EU-FS, EU-BS pillar 1). Moreover, protected areas should be connected via ecological corridors (Trans European Nature Network) and managed effectively (EU-BS pillar 1). In terms of restoration, the EU-BS aims at restoring significant areas of degraded and carbon-rich ecosystems by 2030, making significant progress in remediating contaminated soil sites and restoring at least 25000 km of free-flowing rivers (EU-BS pillar 2). Emphasis is also laid on reversing the decline of pollinators (EU-BS, EU-FS). The proposed EU Nature Restoration Law will refine this and set binding restoration targets for specific habitats and species[8].

Regarding area management, the EU-BS and EU-FTF target to ensure that at least 10% of EU agricultural areas are under high-biodiversity landscape features (e.g., buffer strips, hedges, or non-productive trees), to place at least 25% of agricultural land under organic farming management, and to significantly increase the uptake of agro-ecological practices (EU-BS pillar2, EU-FTF). The EU-BS further encourages member states to increase forest quantity, quality and resilience, aims to plant an additional 3 billion trees and to increase the share of forest areas covered by management plans especially promoting biodiversity-friendly practices (EU-BS pillar 2). Management practices that support biodiversity and forest resilience include the creation or maintenance of genetically and functionally diverse, mixed-species forests, uneven-aged and continuous-cover forestry, enough deadwood, regulation of wildlife densities and the establishment of protected habitat patches or set aside areas in production forests (EU-FS).

To tackle the issue of pollution from fertilisers and pesticides, the EU-BS sets the target to reduce nutrient loss from fertilisers by 50%, resulting in at least 20% reduced fertiliser use (EU-BS pillar 2). It further targets to reduce the use of chemical and more hazardous pesticides each by 50% by 2030 (EU-BS pillar 2). These targets are emphasized in the EU Zero pollution action plan (EU-ZP, European Commission, 2021c) and the EU-FTF.

[8] https://environment.ec.europa.eu/topics/nature-and-biodiversity/nature-restoration-law_en

The EU-GD also acknowledges the role of human consumption. The EU-FTF explicitly covers the entire food chain including food consumption. It is specifically stated that current food consumption patterns are unsustainable for human health and the environment, and that "moving to a more plant-based diet with less red and processed meat and with more fruits and vegetables will reduce not only risks of life threatening diseases, but also the environmental impact of the food system." The aim is to enable consumers to make informed, healthy, and sustainable food choices, e.g., through harmonised mandatory front-of-pack nutrition labelling and voluntary green claims (EU-FTF). Importantly, making the most sustainable food the most affordable is one of the overarching goals of the EU-FTF. In line with this, tax incentives should drive the transition to a sustainable food system and sustainable and healthy consumption choices. Furthermore, the food industry and retail sector should increase the availability and affordability of healthy, sustainable food options. In addition, the aim is to half per capita food waste at retail and consumer levels by 2030 (EU-FTF).

Global climate targets

A well-established desired outcome for the climate has been formulated in the PA, i.e., to limit global warming to well below 2 °C, ideally to 1.5 °C above pre-industrial levels (PA article 2.1). Reaching this target would significantly reduce climate-related risks for nature and people (IPCC, 2019). It would minimise the impact of climate change and ocean acidification on biodiversity (GBF target 8) and contribute to delivering the desired outcome for biodiversity (GBF goal A).

The cover agreement of the COP27 (UNFCCC, 2022) recognises that limiting global warming to 1.5°C requires rapid and sustained greenhouse gas reductions of 43% by 2030 relative to the 2019 level.

In 2019, about 22% of global GHG emissions came from agriculture, forestry and other land use (IPCC, 2023). Consequently, actions related to land use, i.e., conservation, restoration and management, have the potential to contribute to climate mitigation (Griscom et al., 2017). Increasing the global share of protected areas (GBF target 3) can contribute to climate mitigation when currently unprotected high-carbon areas (which can coincide with high-biodiversity areas) are

conserved, and forest conversion is avoided (Dinerstein et al., 2020; Griscom et al., 2017). Reforestation and restoration of natural ecosystems (GBF target 2) can be an additional tool to capture and reduce GHG emissions (Cook-Patton et al., 2021; Griscom et al., 2017).

In line with this, the PA asks parties to conserve and enhance sinks and reservoirs of GHG, including forests (PA article 5.1) and the cover agreement of the COP27 "emphasises the importance of protecting, conserving and restoring nature and ecosystems to achieve the Paris Agreement temperature goal, including through forests and other terrestrial and marine ecosystems acting as sinks and reservoirs of greenhouse gases and by protecting biodiversity, while ensuring social and environmental safeguards".

Acknowledging the relevance of restoration for both biodiversity and climate, numerous countries and organisations across the globe have made restoration pledges under the Bonn Challenge[9], which aims to bring 350 million hectares of degraded and deforested landscapes into restoration by 2030.

The sustainable management of areas under biomass production (GBF target 10) might also contribute to delivering the desired outcome for the climate. E.g., agricultural management practices, such as matching nitrogen input to crop needs or protecting soil health by reducing tillage and increasing soil coverage, can reduce GHG emissions and increase carbon sequestration from agriculture (Johnson et al., 2007). Moreover, forest management can affect the role of forests as GHG sinks as well as their water vapour and energy fluxes (Naudts et al., 2016).

Agriculture is essential for food security, a crucial goal in global and European frameworks (SDG, EU-FTF). Hence, for the first time, the UNFCCC recognises the fundamental priority of safeguarding food security and ending hunger, as well as the vulnerabilities of the food production systems to the adverse impacts of climate change (UNFCCC, 2022). This aligns with SDG 2, which addresses food security, including hunger, malnutrition, agricultural productivity and sustainable food production and with the ambitions of the EU-FTF to "ensure food security in the face of climate change and biodiversity loss".

[9] https://www.bonnchallenge.org/about

The PA and the COP 27 cover agreement also recognize the relevance of sustainable lifestyles, sustainable production and sustainable consumption for achieving the desired climate outcome.

EU climate targets

To contribute to delivering the desired outcome for climate, the EU-GD set the overall goal to make the EU climate neutral by 2050 (EU-GD). The aim for net zero GHG emissions by 2050 was written into law in 2021 (EU-CL, European Parliament & Council of the European Union, 2021). The EU-CL includes further objectives, among others: to reduce net GHG emissions by at least 55% compared to 1990 until 2030; a process for setting a 2040 climate target, considering an indicative greenhouse gas budget for 2030-2050; and a commitment to negative emissions after 2050.

To achieve climate neutrality, the EU-GD addresses several relevant areas: energy, the economy, building and renovating, pollution, mobility, ecosystems and biodiversity, and the food system (EU-GD).

The role of land use in climate mitigation is emphasized in several EU documents. Both the conservation and restoration endeavours of the EU-GD are tied explicitly to carbon-rich ecosystems (EU-BS). Moreover, the LULUCF regulation (European Parliament & Council of the European Union, 2018, 2023), a part of the EU Fit for 55 package, covers emission and removal of GHG from land use, land use change and forestry. It sets out the commitment that each member state ensures that for the periods from 2021 to 2025 and from 2026 to 2030, emissions from land use, land use change and forestry do not exceed removals, and regulates GHG accounting in several areas, including afforested and deforested land, managed forest land and managed cropland, grassland, and wetland.

According to the EU-FTF, agriculture causes 10.3% of the EU's GHG emissions, and nearly 70% of those originate in the animal sector (non-CO2 GHG, i.e., methane and nitrous oxide; EU-FTF). To reduce these emissions, the EU-FTF suggests measures such as facilitating the placing on the market of sustainable and innovative feed additives or examining EU rules to reduce the dependency on critical feed materials (e.g., soya grown on deforested land) by fostering EU-grown plant proteins and alternative feed materials. Research also suggests that reduced food waste and

reduced consumption of life stock products (in this example, beef and dairy), related to reduced production of these products, can contribute to climate mitigation (Bellarby et al., 2013), which is in line with the notion that moving to a more plant-based diet will benefit the environment (EU-FTF).

Implications

Below we present a non-exhaustive list of implications from these targets for conservation, restoration, biomass production, consumption, and trade.

Implications for conservation and restoration:

- more, more strictly protected, better connected and better managed protected areas
- more/ all degraded areas under restoration
- trying to capture both different dimensions of biodiversity and carbon reservoirs and sinks

Implications for production:

- increased share of organic farming
- increasing uptake of sustainable agricultural practices
- more high-biodiversity landscape features in agricultural areas
- lower fertiliser and pesticide use
- increased application of biodiversity-friendly forestry practices
- decreasing GHG emissions and increasing GHG removals through biomass production systems

Implications for consumption:

- increased consumption of sustainable products, e.g., organic food, plant-based food
- reduced food waste
- reduced overall footprint of consumption

Implications for trade:

- reduced impacts on ecosystems and biodiversity through trade (e.g., deforestation)

4.2 Focus areas of the RAINFOREST pathways and downscaling

To enable progress and transformative change for climate, biodiversity and people, a consensus is needed what contributions are expected from whom. This ideally includes quantitative information on specific contributions to reach overarching targets. In the setup of the RAINFOREST project, we aim to identify such contributions by breaking down targets, both narratively and quantitatively, across different *geographies*, *sectors*, and *actors* relevant for the EU agri-food sector.

Many targets to address the ongoing biodiversity and climate crises are formulated at the global level in the context of international conventions (see section 4.1), as these crises can only be tackled through global cooperation. Negotiations around these targets are typically led by representatives of nation states, and the commitments, reporting and monitoring of actions related to their implementation rests on national legislations. Similarly, targets negotiated at the EU level are then often further broken down into contributions by individual member states. In the RAINFOREST pathways and downscaling, we will explore the role of the European Union in the global context and the individual member states within the EU.

Breaking down contributions to ongoing pressures and to meeting targets along economic sectors can be insightful and potentially help establishing sector-wide benchmarking. In the context of the RAINFOREST pathways a main focus will lie on highlighting the role of the livestock sector in contrast to the plant-based food sector. This is motivated by the high environmental footprint of the current livestock sector both within the EU and globally, and the fact that it has been recognized as a main entry point making agri-food systems more sustainable (see Section 4.1). Many areas within the EU have a history of extensive pastoral systems or integrated crop-livestock farming, which have been replaced by industrial livestock systems with increasing spatial specialization in recent decades. Presently a substantial part of the EU's agricultural area is devoted to livestock feed production and large areas of the EU's oversea footprint is linked to the provision of feed, mainly for protein rich feeds such as soybean cakes (Vanham et al., 2023).

Moving from the multitude of targets and goals formulated in policy documents (Section 4.1) towards targeted interventions (Section 4.3) will require the involvement of a wide range of actors within the food and biomass nexus. In the RAINFOREST pathways and downscaling, particular attention will be paid to the roles of consumers and producers. Environmental impacts of the agri-food system can be attributed to either production or consumption activities. This can serve as a baseline to explore what impacts interventions along supply chains will have on both producers and consumers and how production-consumption systems would change in different pathways.

4.3 Interventions

4.3.1 Conceptualizing interventions

In the following section, we will have a closer look at transformative change interventions that can potentially function as measures to achieve the goals to conserve and restore biodiversity, as described in section 4.1. We review the relevant literature, including policy documents such as the EU Green Deal proposal, the EU regulation on deforestation, as well as national sustainability- and biodiversity reports, to provide an overview of the most important interventions in the European food and biomass nexus to conserve biodiversity. For selected interventions, we discuss the intended goals and how they relate to biodiversity, the main intended working mechanisms, as well as the main actors and target groups involved and affected by these interventions.

Dorninger et al. (2020) define interventions in the context of sustainability as "deliberate human actions targeting sustainability in a given system of interest". It must be mentioned that interventions can vary in their level of abstraction. They range from rather general advice for strategic actions like cross-sectoral coordination, adaptive decision making, or pre-emptive action (e.g., Chan et al., 2020) to very specific tools and instruments such as due diligence obligations, eco taxes, or CSR measures. Interventions can be initiated by the political sector, seeking to influence the behaviour of organizations and individuals toward more sustainable practices and to provide society with a framework for their actions. However, interventions that originate from the private sector like voluntary labels or CSR measures as well as interventions from civil society like urban gardening or food

sharing can also be valuable contributions towards transformative change.

Because interventions vary widely in their characteristics, there are many different typologies of how they can be structured and categorized. In the field of sustainable policy interventions, for example, two major distinctions can be made between 'old' instruments, which are usually 'command-and-control' regulations, and so called 'new' environmental policy instruments (NEPIs)) (Gunningham et al., 1998; Jordan et al., 2005; R. Wurzel et al., 2019; R. K. Wurzel et al., 2013). NEPIs can be further structured into informational (e.g., eco-labels and environmental management schemes), voluntary (e.g., voluntary agreements), and market-based instruments (e.g., eco-taxes and emissions trading) (Wurzel et al. 2019). Another example on how to categorise interventions is the typology suggested by Börner and Vosti (2013), which is based on how interventions are intended to influence human behaviour. The approach distinguishes between enabling measures, incentive-based measures, and disincentive-based measures (Börner & Vosti, 2012). When it comes to classifications for environmental policy instruments, a common classification is to distinguish between regulatory ("sticks"), economic ("carrots") and information-based ("sermons") (Harrison, 1998).

In the context of the RAINFOREST project, our focus lies on European food and biomass production systems. We pay attention to the fact that unsustainable value- and supply chains are prominent drivers of biodiversity loss — also in many other parts of the world that are connected to Europe via trade. Embracing this perspective and in line with the intent that the project wants to provide recommendations for actors within European food and biomass value chains, we developed a conceptual model that structures interventions along the value chain (*Figure 4*).

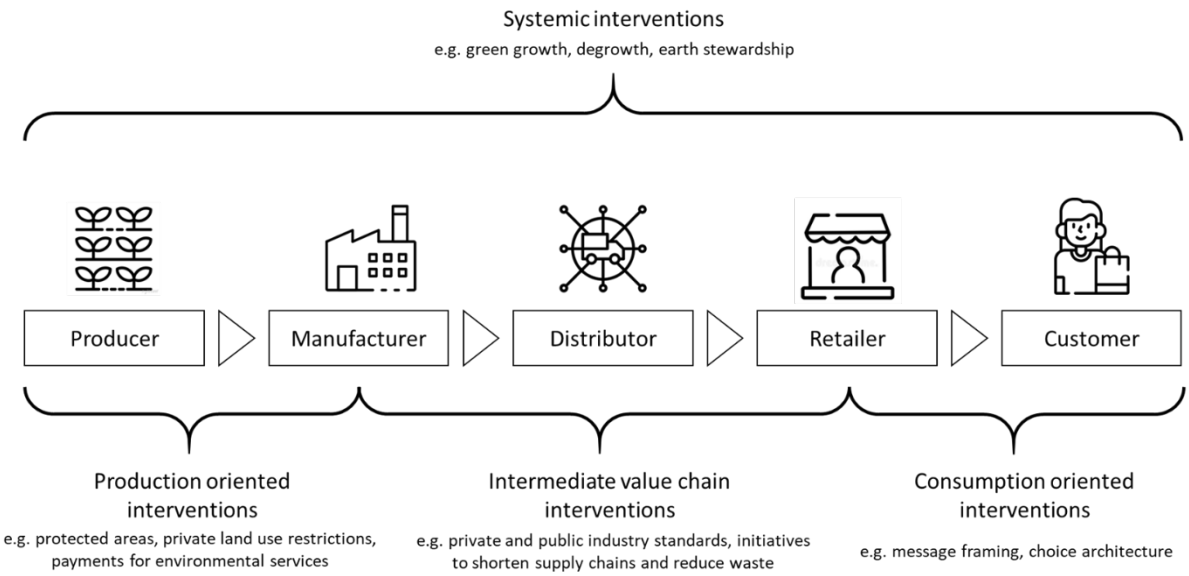


Figure 4. A conceptual model to structure interventions along the value chain within four categories: Production-oriented interventions, intermediate value chain interventions, consumption-oriented interventions, and systemic interventions. Source: own compilation.

Our model emphasises the role of actors within value chains, who are often target groups of interventions for biodiversity conservation. We distinguish between:

1) Production-oriented interventions
2) Intermediate value chain interventions
3) Consumption-oriented interventions
4) Systemic interventions

Production-oriented interventions target the producer of food and biomass, i.e., agricultural businesses and smallholders. Examples for production-oriented interventions targeted at biodiversity outcomes include protected areas, private land use restrictions, and payments for environmental services. *Intermediate value chain interventions* focus on organisations that mediate between producers and consumers, such as manufacturers, distributors, or retailers. Interventions in this category include corporate sustainability standards and similar private or public sector initiatives for sustainable supply chains. *Consumption oriented interventions* target corporate and private consumers with interventions like certifications, nudging, or user fees. *Systemic interventions* are different from the other categories in the sense that they do not target a specific group of actors, but rather influence the supply chain, stakeholder network or interaction of actors as a whole. Hence,

they encompass interventions with a broad field of application such as new technologies and education, as well as interventions on a high level of abstraction like cross-sectoral coordination and adaptive decision making. In the following, the most relevant interventions for biodiversity conservation and restoration are described and discussed within these four categories in more detail.

4.3.2 Production-oriented interventions

Production-oriented interventions can have strong effects on the behaviour of producers of food and biomass in the agricultural, forestry, and fishery sectors. Governments around the world predominantly rely on regulatory interventions, often called **"command-and-control" policies** to reduce environmentally or socially harmful impacts of food and biomass production (Lambin et al., 2014). These policies usually come in the form of rules and regulations that are enforced by fines, asset confiscation, or imprisonment and thus aim to disincentivize undesirable modes of production (E. J. Robinson et al., 2010). Common motivations to impose command-and-control policies range from the protection of water resources and biodiversity to pollution reduction and climate mitigation.

One of the most important policy instruments for biodiversity conservation in this category is the creation of protected areas (PA) in both terrestrial and marine environments (Maxwell et al., 2020). PA restrict use and access to defined zones in usually publicly owned areas of terrestrial and aquatic ecosystems to avoid economic use and extraction activities that harm key ecological functions. To function effectively, PA require appropriate monitoring and enforcement capacities and must be sited in regions under relevant pressure from human uses (Börner et al., 2020) . Countries have adopted diverse approaches to governing PA systems, including centralized and decentralized management responsibilities (e.g., at national and subnational scales) and multiple protection categories ranging from strict protection, banning any type of use, to PA that are designed to cater to the needs of specific traditional or indigenous populations groups (Tran et al., 2020). In some regions of the world, countries collaborate across national boundaries in so-called trans-boundary conservation zones. Nature protection primarily affects local resource users and producers and eventually implies resettlement to enable strict protection

(Pullin et al., 2013). Large-scale PA systems can also have effects on economic development at regional scale, for example, by attracting tourism or by limiting agricultural development (Pullin et al., 2013).

Another key intervention to conserve biodiversity on land under private tenure relates to land zoning, use restrictions and changes in land tenure rules (including private as well as communal land ownership). Governments commonly attach various rules and liabilities to land ownership to limit environmentally harmful land uses. Often these rules are not uniform but adapt to regional peculiarities including aspects of biodiversity following national or subnational zoning plans (Oliveira & Meyfroidt, 2021). Like in the case of protected areas, zoning and related use restrictions require an enforcement infrastructure run by public authorities at national and/or subnational levels. Beyond the directly affected landowners (or tenants) private land use restrictions, if effectively enforced, can have considerable impacts on economic development at local and regional scales.

Beyond private land use restrictions, many countries impose taxes on landowners, albeit seldom out of environmental motivations. Recent research, however, suggests that land taxes could significantly contribute to the conservation of biodiverse ecosystems if appropriately designed and enforced (Fendrich et al., 2022).

Since the 1990s, governments and civil society organizations increasingly experiment with **incentive-based interventions**, such as payments for environmental services (PES) to conserve natural resources, including biodiversity (Schomers & Matzdorf, 2013). PES are conditional, often monetary, incentives provided to land users in exchange for the adoption of production practices that provide additional environmental services, for example, via biodiversity or watershed protection. Such payments are intended to compensate recipients for the income foregone when abandoning environmentally harmful, but privately profitable land use and production practices. As such, PES encourage voluntary action and usually come with conditions that exceed the requirements imposed by pre-existing command-and-control interventions (Barton et al., 2017). This feature, in principle, allows for private and civil society actors to engage in the design and implementation of PES schemes, because no public mandate is required for the enforcement of voluntary contracts.

In conservation practice, PES schemes are often combined with components of integrated conservation and development projects (ICDP, Blom et al., 2010). The underlying rationale for such combined intervention design is that many poor land users in ecologically sensitive and biodiverse world regions require support for investments in environmentally more friendly production practices that can ideally be sustained once PES transfers are suspended. Concrete ICDP interventions focusing on biodiversity conservation include, for example, support for the creation of eco-tourism facilities or local processing infrastructure for non-timber forest products (Bauch et al., 2014).

Both command-and-control and incentive-based (fiscal) interventions can be and are often designed specifically to conserve and restore biodiversity. However, conservation research has repeatedly confirmed that a number of non-specific production-oriented intervention options are as important for biodiversity as the interventions discussed so far (Börner et al., 2020; zu Ermgassen et al., 2019).

For example, in many of the world's most biodiverse regions, ownership, access and use rights to land and aquatic resources are either poorly defined, ill-enforced or both (Lockwood et al., 2012; B. E. Robinson et al., 2018). If governments (or proponents of PES schemes) know too little about who owns the land, liability for illegal forms of use cannot be established and natural resource owners / users cannot credibly secure the environmental services that potential beneficiaries are willing to pay for. Moreover, even if ownership and use rights are well defined, monitoring and enforcement capacities are needed to ensure regulatory compliance. Clarifying land tenure and strengthening monitoring and enforcement capacities thus often come to be effective **enabling interventions** to conserve and restore biodiversity. Land ownership is linked directly to incentives to maintain land for the long term. Unless regenerative agriculture is financed in a way that does not rely on asset ownership (land ownership) farmers are likely to continue struggling to access funding for the necessary transition.

Moreover, governments and corporate actors around the world engage in numerous production-oriented interventions that primarily target other than environmental objectives and conflict with biodiversity conservation and restoration goals. Examples include production subsidies for bio-based primary sectors and

related trade regulations or investments in rural transport and processing infrastructure. Mainstreaming biodiversity conservation and restoration objectives in the design and implementation processes of these interventions represents a key leverage point for biodiversity conservation.

Another major driver for change can be a stronger integration of biodiversity in agricultural education. Examples for policy changes in farmer education include mandatory modules on alternative applications and monitoring methods to adopt precision agriculture (stewardship regarding chemical interventions) or mandatory modules on pollination services, including training on wild pollinators.

4.3.3 Intermediate value chain Interventions

Due to the increased global demand for food and biomass and the liberalization of global agricultural trade, a complex network of supply chains has emerged that causes pressure on biodiversity and ecosystems beyond national borders. Supply chain intermediaries, such as wholesalers, manufacturers, distributors, and retailers, can therefore play a key role in preventing biodiversity loss through improvements in biodiversity standards and practices. Four key categories of interventions have been identified for the intermediate value chain; private sector supply chain initiatives, public sector supply chain initiatives, short food supply chains (SFSCs), and interventions for preventing food loss and waste (FLW) along the supply chain.

Private Sector supply-chain initiatives

The private sector has a key role to play in improving biodiversity standards as it includes the majority of actors involved, including very large multinational corporations such as the Schwarz Group and Nestle, which alone count for €220 billion in revenue. Lambin et al. (2018) identify four categories of interventions to reduce deforestation that are also used to combat many areas of biodiversity loss: collective aspirations, company pledges, company codes of conduct, and sectoral standards. These work by expressing a commitment to sustainability in supply chains, defining production and sourcing practices and agreeing principles and standards

that come with positive incentives or sanctions. When companies adopt these initiatives, other actors further down the supply chain can be compelled to adopt these standards to be able to maintain their trading relationships. As there are a few very large actors in the manufacturing and retailing sector, the making of company pledges and adoption of codes of conduct can have widespread impacts across producers.

Example: Unilever is a global consumer goods company, including many food and drink brands. They have pledged to fulfill six so called "Protect and Regenerate Nature" goals:

- Deforestation-free supply chain by 2023 (palm oil, paper and board, tea, soy and cocoa)
- Help protect and regenerate 1.5 million hectares of land, forests and oceans by 2030
- 100% sustainable sourcing of their key agricultural crops
- Empower farmers and smallholders to protect and regenerate farm environments
- Implement water stewardship programmes in 100 locations in water-stressed areas by 2030
- 100% of their ingredients will be biodegradable by 2030

Public Sector supply-chain initiatives

Due to globalization and heightened support for free markets since the 1980s, governments have played a weakened role in supply chain management and have preferred corporate self-regulation through private standards and codes of conduct (Nezakatï et al., 2016; Vermeulen & Kok, 2012). But governments can play a key role in supply chains management through setting minimum standards, providing incentives or taxing harmful products. Vermeulen and Kok (2012) explain three strategies for governments interventions for sustainable supply chain governance: 1) central regulation by means of coercion and incentives (government initiates), 2) interactive regulation and internalization (government and market collaborate), and 3) facilitating self-regulation (market and civil society initiate).

Strategy 1 follows traditional command and control governance practices that either directly restrict the import of certain goods or through tax and incentives which supports improvements to biodiversity through removing, reducing, or increasing certain markets and or / risks associated with produced and traded products. Strategy 2 involves the direct funding and creation of codes of conduct and standards for industry to adopt. Strategy 3 works by financing studies and NGOs in the creation of codes of conduct or standards used in self-regulation, therefore indirectly supporting these changes.

The upcoming EU regulation on deforestation-free supply chains provides an example for such public-sector supply chain interventions. Following a process started in 2013, the regulation is aimed at minimizing the EU's contribution to global deforestation and forest degradation and the associated biodiversity loss and greenhouse gas emissions. The regulation is set to come into effect by mid-2023 with companies expected to comply to it by late 2024/2025. It targets specific products (oil palm, soybeans, cattle meat, leather, cocoa, coffee, natural rubber and wood) and compliance is expected for all these products that are imported into, produced in or exported from the EU.

The covered products must be "deforestation free", following FAO's definition of what constitutes a forest and not be produced on lands converted from forest after the 31st of December 2020, which serves as a baseline date. The products must be produced in line with relevant laws of the producing country and – in the case of imports – a due diligence declaration (including for instance the geographic coordinates of production) must be submitted when they enter the EU market. Companies must assess the deforestation risk of products they trade with and in case of substantial risks being identified take measures to reduce these risks. If a reduction of the risks is not possible, the products may not enter the EU market.

The EU will perform a benchmarking categorizing products and production countries into the categories of low, medium, and high risk, respectively. Based on this benchmarking checks by the EU on compliance of companies will be carried out with different frequencies (9% of the relevant companies for high risk, 3% for medium risk, 1% for low risk). Companies that do not comply with the regulation can be sanctioned by publication of the company name on publicly available lists, fines up

to 4% of the company's EU-wide revenue, confiscation of the products where the requirements are not met, or exclusion from public procurement and temporary loss of the trading company's license.

In addition, the EU plans to engage in coordinated multi-stakeholder dialogues with partner countries, both in the roles of countries importing into the EU or receiving exports from the EU. The EU also plans to regularly review the regulation with the option of, for instance, including different products should they become relevant for deforestation, with a focus on the loss of natural ecosystems beyond forests, and looking into potential leakage and displacement effects induced by the regulation.

Short food supply chains (SFSCs)

SFSCs are defined by the EU as "a supply chain involving a limited number of economic operators, committed to co-operation, local economic development, and close geographical and social relations between producers, processors and consumers" (Regulation (EU) No 1305/2013 of the European Parliament and of the Council and Repealing Council Regulation (EC) No 1698/2005, 2013) and have been shown to be beneficial towards environmental sustainability beyond just reduced CO2 emissions through reductions transportation (Malak-Rawlikowska et al., 2019). They are often linked to organic farming, agroecology, farmland preservation and improved biodiversity and ecosystem services, especially in peri-urban areas (Chiffoleau & Dourian, 2020; Lin et al., 2015). Due to increased globalization of food supply chains, farmers have replaced local fruit and vegetable production with more profitable crops supplied to global markets, which has led to reductions in biodiversity (Evola et al., 2022). By encouraging SFSC, there is a return to the use of seasonal local products and attempts to wean consumers off year-round supplies of certain products through greater producer-consumer interactions. These interventions are often support by local, national or EU level funding provided to support rural communities or agroecology projects such as Strategies for Organic and Low-input Integrated Breeding and Management (SOLIBAM).

Example: SOLIBAM supported Cultivons la Bio-Diversité en Poitou-Charentes (Let's Cultivate Biodiversity in Poitou-Charente) (CBD) is a regional association established

in 2009, which brought together ten farmers to produce wheat varieties that would allow them to be cultivated with forage crops. Most farmers sell their products directly or to local cooperatives (Chable et al., 2019).

Reduction in Food Loss and Waste (FLW)

The FAO reports that 31% of all edible food produced is lost or wasted and equates to about 1.3 billion tons per year. Food loss and waste has three quantifiable environmental footprints: GHG emissions (carbon footprint), pressure on land resources (land footprint), and pressure on water resources (water footprint), which may directly impact biodiversity (FAO, 2019). Around 44% of global FLW is lost during post-harvest and processing stage in low-income countries due to inadequate practices or technical limitations, labor and financial weaknesses, and limited infrastructure for transportation and storage (Gustavsson et al., 2011). Key interventions to reduce food loss during the supply chain include improved harvesting, storage, processing, and transportation techniques (Kiaya, 2014; Kumar & Kalita, 2017). Small scale producers require technical and financial support from local, national, and international organizations to benefit from these interventions.

Example: The "Reducing Food Losses in Sub-Saharan Africa (improving Post-Harvest Management and Storage Technologies of Smallholder Farmers). An 'Action Research' evaluation trial from Uganda and Burkina Faso" showed that by moving to hermetically sealed storage technologies participating farmers were able to retain 98% of their harvest, regardless of the crop or duration of storage (Costa, 2014).

4.3.4 Consumption-oriented interventions

Consumption oriented interventions target changes in consumption patterns (diets), consumption quantities, and waste at consumer end, both private and corporate (García-Herrero et al., 2021; Simon et al., 2023; Springmann, Wiebe, et al., 2018) . The impact on biodiversity can be two-fold. First, it can be direct, through increased demand for diverse foods or underutilized crops and species, leading to higher agricultural diversity (Zimmerer & De Haan, 2017), or through demand shift to organic foods that support biodiversity (Bengtsson et al., 2005; Gomiero et al.,

2011). Second, it can be indirect, mediated by land-use change. It can be channelled through a shift to plant-based diets (Leclère et al., 2020), which require less land under agricultural production (Henry et al., 2019), or through overall reduced demand for food, e.g., because of lower waste or higher equality of food distribution (Hasegawa et al., 2015). Lower demand for agricultural land results in less land conversion from natural land (lower biodiversity loss) and potential land release from agriculture. The resulting impact on biodiversity depends on the fate of the released land (Bond et al., 2019; Veldman et al., 2019).

Supermarkets can be of major influence in case they drive prices of certain products down artificially for competitive advantage against their peers. These products are often the top products in national baskets, such as milk, tea, bread, etc. They are often blended products that are hard to trace. Producers cannot get any value across the value-chain due to a lack of proximity to the consumer. These producers are the most affected by such commercial tactics and consumers are unaware of such practices and the true cost that is paid by human and animal rights violations in the supply chain. Sustainable consumer choices are influenced by a combination of conscious evaluation of product attributes and unconscious responses to situational and product features. These decision-making processes are also affected by personal motivations and identity, as well as social norms and the behaviour of other customers. Evaluating the environmental sustainability of food products poses significant challenges for consumers, as it involves weighing multiple product characteristics that may sometimes be in conflict, such as packaging, labelling, and content information.

Types of interventions

Interventions targeting food waste reduction at consumer level are, for example, awareness campaigns and education programs, food waste recycling interventions like composting and proper food waste management, or upgraded technological solutions and innovation, such as smart fridge and innovative packaging (Schanes et al., 2018).

Interventions that strive to modify dietary choices towards a balanced, sustainable, and healthy diet featuring reduced meat and processed food require a

multifaceted approach. Information campaigns disseminated through e-mails, posters, and other means, highlighting the advantages of consuming plant-based and minimally processed food, can have a significant impact. Nevertheless, the most compelling evidence is in support of fiscal and restrictive measures. Isolated measures such as information provision and 'nudges' are unlikely to significantly alter consumption patterns at the population level. Nonetheless, combination strategies are likely to be of utmost importance. Evidence suggests that public interventions are effective, albeit the extent of the effect may be insufficient to cause a radical shift in consumption patterns (Traill, 2012). Social media and emerging technologies, such as dedicated mobile applications, exhibit substantial potential for the promotion of public health (OECD, 2017).

The realization of a substantial transition towards a diet featuring reduced meat and processed food necessitates collaboration amongst policymakers and diverse stakeholders such as consumers, producers, retailers, and researchers, at both national and international levels. Policies advocating for the promotion of sustainable and healthy consumption patterns have already been implemented (Cambeses-Franco et al., 2022). More than 100 countries have established their respective dietary guidelines, founded upon their unique food availability, culinary culture, and dietary habits (FAO, 2023).

Collaborations with the private sector are established to support the dietary change using novel plant-based meat and milk alternatives as a substitute for the animal source food. This new technology offers dietary change following a behaviourally viable path (Herrero et al., 2020)). Potentially, such a dietary shift could yield substantial benefits to biodiversity.

Corporate consumers interventions can target for example school and work canteens, where collaboration between the food providers and policymakers can take place. School interventions that educate school children about diets and nutrition can alter their food choices, especially if sustained over a long period of time and complemented by other actions (Spence et al., 2013).

Personality and motivational factors influencing decision making

Biodiversity-friendly decision making is influenced by a variety of personality and motivational factors. As an example, studies have consistently shown that men are less likely to select vegetarian meals than women, and more likely to select meat meals, resulting in meals with higher greenhouse gas emissions and land use (Rosenfeld & Tomiyama, 2021; Scarborough et al., 2014). However, both men and women are equally likely to select fish meals (E. Garnett, 2021). This finding suggests that interventions aimed at reducing meat consumption may have a greater impact on men than women, albeit with women being more receptive to them. Additionally, (Laroche et al., 2001)found that consumers who are willing to pay more for environmentally friendly products are more likely to be female, married and with at least one child living at home. These consumers also place high importance on security and warm relationships with others and often consider ecological issues when making a purchase. Local produce and community connections can play a significant role in biodiversity-friendly decision making. (Foti et al., 2019) used social network analysis to analyse the social relationships that influence consumer preferences for local produce or areas that they feel connected to (place identity) or an ethical-social affinity. The research highlights the role of low-volume producers and local communities in encouraging biodiversity-friendly farming and respective consumption.

School programs can play a role in improving nature connectedness and promoting biodiversity-friendly decision making. (Harvey et al., 2020) found that a program of biodiversity-focused activities carried out over one academic year in the school grounds produced significant improvements in children's mood and wellbeing, which were sustained across the academic year. Improvements in wellbeing were not found in a control sample of children who did not take part in the activities. Children with initially lower feelings of connection to nature became more connected over the course of their participation. Biospheric values and childhood nature experiences can also play a role in shaping adulthood environmental self-identity and promoting sustainable food choices. (Molinario et al., 2020) found that childhood nature experiences and exposure to pro-environmental social norms during childhood are related to adulthood development of connectedness with nature and biospheric values, which in turn help shape adulthood environmental self-identity ultimately

influencing the enactment of sustainable food choices during adulthood.

Regarding the acceptability of interventions, (Kukowski et al., 2023) found that people who are not able to successfully regulate their meat consumption (hence, who have low self-control) are more in favour of regulatory governmental strategies (e.g. increased prices) to make meat consumption more difficult. Consumers from high-income countries interpret environmental governance as an encouragement to participate in sustainable consumption, whereas consumers from low-income countries feel discouraged by strong governmental leadership supporting sustainability (Wang, 2017). In addition, in high-income countries, people with strong pro-environmental attitudes are more likely to consume sustainably when governance is weak whilst the attitude–behaviour association is stronger with effective governance in low-income countries.

In conclusion, biodiversity-friendly decision making is influenced by a complex interplay of personality and motivational factors, community connections and reactions to environmental governance. Understanding these factors can help policymakers and educators to promote more sustainable and environmentally friendly choices.

Message framing

The impact of message framing on biodiversity-friendly consumer choices has been examined in several studies. (Klöckner & Ofstad, 2017) conducted three studies on the reduction of beef consumption on Norwegian samples, using a stage-based model to provide information on why and how to reduce beef consumption. The studies showed that tailored information outperformed other conditions significantly. However, the results for the reduction of beef consumption were inconclusive. (Carfora et al., 2019) examined the impact of different messages, including health, environment, and health and environment combined, as daily reminders on the phone about meat reduction. The results showed a significant reduction for health and environment messages but not combined. The effect remained stable four weeks after and was mediated by attitudes.

Another study by Palomo-Vélez et al. (2018) examined the effectiveness of different message frames, including disgust, moral, and health, in influencing meat

attitudes. The results showed that disgust-oriented messages were more effective than health-oriented messages, and at least as effective as moral messages in influencing meat attitudes. Taufik (2018) conducted a study in China, where the level of meat consumption has increased rapidly. The findings indicated that prospective "warm-glow" feelings are positively related to consumers' intention to reduce meat consumption, and this relation is stronger than the respective relations of both perceived sustainability and perceived health benefits with the intention to reduce meat consumption.

Furthermore, Tate et al. (2014) found that priming with conservation of biodiversity increased sustainable purchasing behaviour afterwards. Those primed with an environmental protection goal automatically evaluated loose products more positively and selected more loose consumer products than a control group. The increased implicit positivity towards loose products mediated the observed behaviour change. Importantly, the effect of environmental goal priming on choices or implicit attitudes towards packaging was not contingent on existing environmental attitudes.

(Hanss & Böhm, 2013)examined the effectiveness of persuasive messages aimed at strengthening intentions, promoting sustainable purchases, and strengthening self-efficacy beliefs. The intervention successfully strengthened consumers' intentions to purchase domestic, seasonal, and certified ecological products. In addition, the intervention promoted the actual purchasing of certified ecological and fair-trade products in a choice task. However, the effects of the intervention on self-efficacy beliefs about contributing to sustainable development did not improve significantly.

Finally, (Whitley et al., 2021)investigated the impact of images of animals on empathy and emotions. The study found that those who were exposed to animal portraits reported increased empathy and decreased positive and relaxed emotions. The authors argued that animal portraiture may serve as an ideal "attention grabber," after which wildlife images can serve as "educators" to encourage conservation efforts. They also emphasized the importance of critical anthropomorphism in using such images as tools to encourage conservation efforts.

Choice architecture

Choice architecture is an important concept when it comes to promoting biodiversity-friendly consumer choices without depending on consumer characteristics and motivation. A randomized controlled trial (RCT) study conducted by Boronowsky et al. (2022) assigned participants to either a plant-based or meat default condition at different university events. The difference between groups was the RSVP form that either indicated a meat- or a plant-based dish as default option for dinner. The study found that participants assigned to the plant-based default were 3.52 times more likely to select plant-based meals than those assigned to the meat default. This highlights the impact that default settings can have on food choices. Garnett (2021) found that placing the vegetarian option first and increasing the distance to meat can also increase the percentage of vegetarian meals consumed. Increasing the number of vegetarian meals as compared to meat also increases the percentage of vegetarian meals chosen. However, price is also an important consideration, as decreasing the vegetarian option in price and increasing the meat option in price led to an increase in vegetarian sales overall, as well as among the most vegetarian quartile of customers (E. E. Garnett et al., 2021).

Food naming and labelling is another important aspect of choice architecture that can affect consumer behaviour. (Rosenfeld et al., 2022) found that items were 24% more likely to sell when they were marketed as vegetarian/vegan than when they were marketed as plant based. This highlights the potential for frames to promote plant-based food choices, offering a subtle strategy for changing consumer behaviour and supporting sustainability efforts. However, labelling for grazing beef to support biodiversity did not turn out to be effective due to low levels of understanding of biodiversity among consumers, as well as the profusion of labelling schemes on the market (Stampa & Zander, 2022). It is also important to consider how consumers judge the environmental friendliness of different products. A choice experiment conducted by Tobler et al. (2011) found that current product information for vegetables is insufficient for judging their environmental friendliness.

Other interventions, such as information nudges and procedural information, can also influence dietary behaviour. Morren et al. (2021) found that pre-intervention knowledge about sustainable or healthy diets is related to the sustainability of

participants' dietary choices. Procedural knowledge on how to prepare a healthier meal has the greatest potential to influence dietary behaviour, particularly for participants without prior self-reported dietary restrictions. Additionally, a resource dilemma simulation conducted by Baxter & Pelletier (2020) found that a centralized sanctioning system can increase sustainable behaviour in the resource dilemma when added, and decrease sustainable behaviour when removed, affecting the quality of participant motivation and goal content.

Overall, choice architecture can significantly impact biodiversity-friendly consumer choices. Default settings, food naming and labelling, price, information nudges, and even the way products are judged for environmental friendliness all play a role. By considering these factors and implementing interventions accordingly, it is possible to promote more sustainable and biodiversity-friendly consumer choices.

4.3.5 Systemic interventions

To meet the challenges of current environmental crises, including the climate crisis (Calvin et al., 2023) and biodiversity loss (IPBES, 2019), it has been consistently stated that there is a need for systemic changes to how our societies and economies function. As previously noted, systemic interventions are actions that do not target specific actors or sectors but transform the structures in which these actions take place. Four approaches for systemic change regarding biodiversity loss have been identified by the IPBES (2022) via the NFF framework narrative perspectives: Green Growth, Degrowth, Earth Stewardship and Nature Protection. This section will briefly outline these approaches to systemic change and give examples of key policy interventions as examples of already existing scenarios.

Green Growth

To meet the challenges mentioned above, Green Growth seeks to reduce material and energy use to sustainable levels while allowing continued economic growth through appropriate valuing and pricing of ecosystem services and their management. This approach seeks to coopt current mainstream economic tools such as national accounting systems, tax and subsidies, and fiscal spending to shift the economy towards a sustainable path. This is done by the compensation of ecosystem

service providers by ecosystem service users through schemes including tradable permits for resource use/pollution or payments for ecosystem services (PES). There are, also, positive incentivizing interventions that try and value protection and stewardship of nature that have previously been ignored in market economies. These can include tax exemptions or green subsidies for sectors or regions that have a positive environmental impact. An example of this would be fiscal transfers from regions that have lower biodiversity to areas that have higher biodiversity.

Example: A popular intervention across many countries has been a tax or set pricing for plastic bags. This involved implementing an economic instrument to impose a cost on an environmentally damaging action, and is often accompanied with a public awareness campaign, that has resulted in a widespread reduction in plastic bag usage and the environmental harm they cause.

Degrowth

In opposition to Green Growth's proposition that it is possible to continue to grow the economy while reducing energy and material use (decoupling), Degrowth argues for a reduction in economic activity to reduce human impacts on nature while providing a more equitable distribution of the outputs of economic activity. As noted by the IPBES (2022) report, the key interventions are, "(i) the adoption of alternative indicators of economic progress, (ii) green and just tax reforms, (iii) subsidy reforms, (iv) work sharing, (v) re-regulating trade, (vi) establish maximum-minimum income ratios, and (vii) secure universal basic needs". The first three of these policy propositions follow the same logic as Green Growth with the shift from measuring and rewarding solely economic activity by including other measure of environmental and social wellbeing and compensating nature positive activities. Where it departs from Green Growth is with regards to work, trade, and inequality. Degrowth suggest that productivity gains should be used to reduce work time as elongated work time increase consumption and pressure on natural resources, this is then accompanied with full employment and job-sharing policies to combat labor market impacts. Degrowth, also, opposes free trade and free capital mobility that allows industries to evade paying for social and environmental impacts and leads to environmentally positive economies to be disadvantaged in international trade. Degrowth does not

only focus on providing an environmentally sustainable economy but, also, a just one by seeking reduced inequality by providing for basic needs with policies such as a universal basic income, housing for all, healthcare for all etc.

Earth Stewardship

The Earth Stewardship approach seeks to change the relationship between humans and nature by including a diversity of values of nature. This is done through increased engagement and participation of people in protected areas and increased social and economic solidarity through education programs. The primary intervention in Earth Stewardship is expanding the understanding of how protected areas contribute to human well-being and socio-environmental justice by including local communities as stewards rather than preservationist policies that exclude all economic activities from protected areas such as in Sub-Saharan Africa in the 1960s and 70s that led to negative social and environmental outcomes. This mainly focuses on the recognition of indigenous peoples and their right to self-determination and territorial rights and the protection of this through regional, national, and international agreements. Current estimates suggest that 11% of the world's forests exist under some form of community ownership or administration and if these areas were recognized it would double the amount of globally protected areas. This needs to be coupled with increased social and economic solidarity through education programs that promote care, respect, reciprocity, and responsibility towards nature. These education programs work by providing a diversity of religious and philosophical traditions, including "Buen vivir" in South America, "ubuntu" in South Africa, and "satoyama" in Japan.

Example: The core principles of "Buen vivir" education programs are: (a) intercultural cooperation, (b) reciprocity, and (c) collective action and solidarity and foster earth stewardship by (i) balancing personal autonomy with community participation, (ii) acknowledging the key roles played by women and the pressures they experience, (iii) teaching values for the preservation of culture and life, (iv) celebrating spirituality that connects humans and nature and heals historical trauma, and (v) connecting different generations (IPBES, 2022).

Nature Protection

The nature protection pathway has the same intended goals as Earth Stewardship to increase the overall number of protected areas and with Degrowth on lessening the impact of consumption on nature but seeks to separate ecological sustainably from social justice. This leads to greater focus on population growth and growth in consumption and related issues such as land use expansion and intensification, habitat fragmentation, climate change, invasive species, over-exploitation and degradation. In response, the key policy intervention is the protection of nature through expanded networks of protected areas to restore the balance between wild areas and human impacted areas.

Example: The Half-Earth theory (Wilson, 2016) calls for half of all land and sea areas to be protected for biodiversity because of the significant impact that humans have on land use. The focus of the protection areas would be on the most biodiverse areas, such as tropical forests and coral reefs, and this could protect more than 80% of species while covering only half the earth.

4.4 Feasibility considerations

4.4.1 Conceptualizing feasibility

In the previous sections, we reviewed and discussed aggregated targets to protect and restore biodiversity, the different actors across segments and geographies of the food and biomass nexus, interventions as means to achieve biodiversity targets, and the plural worldviews and equity considerations that must be taken into account when addressing the complex issue of biodiversity conservation. However, these elements must work in combination and in the right context to successfully enable pathways for transformative change. In this section, we therefore have a closer look at the feasibility aspects that need to be considered to assess which initiatives and combinations thereof are most likely to be successful in different contexts.

The term *feasibility* is very general and needs to be further specified. For this review, the concepts of economic feasibility, technological feasibility, as well as social and political acceptance are particularly relevant. *Economic feasibility* involves the evaluation of costs and cost effectiveness, i.e., the involved costs in

relation to the physical benefits achieved by an intervention (e.g., Euro per ton of CO2 emissions reduced or per river km restored) (Görlach et al., 2005). Considering the environmental feasibility of interventions in specific contexts therefore helps to determine whether they are financially and economically viable in the short and long run. *Technological feasibility* answers the question of whether an intervention can be technically realised and refers to the extent to which the required technology to implement a particular solution is actually available (Skodvin, 2007). As an example, an intervention that requires companies to avoid activities that are harmful to biodiversity might require available technologies for biodiversity monitoring in order to be technologically feasible. We also consider *social and political acceptability,* referring to the adherence of actors to social and political constrains associated with an intervention. This is related to the concept of *political feasibility*, which can be defined as "the relative likelihood that a policy proposal or alternative, and a variety of modifications to that alternative, could be adopted in such a way that a policy problem is solved or mitigated" (Webber, 1986). In the context of environmental policy, Skodvin (2007) defines political feasibility as a function of three main categories of constraint, which are i) the distribution of costs and benefits associated with environmental regulation among target groups ii) the distribution of power among and between target groups and decision-makers; and iii) the institutional setting within which decision-making takes place.

In section 4.3 we introduced a conceptual model to structure interventions along the value chain. In this section, we also use this model as a structure to discuss the aforementioned feasibility aspects of initiatives in relation to actors, geographies, biodiversity targets, and equity considerations. In the following, the reviews and discussions of feasibility aspects will therefore be structured according to the major actor groups in a value chain affected or targeted by the respective initiative in the categories of producer-oriented interventions, intermediate value chain interventions, consumer-oriented interventions and systemic interventions.

4.4.2 Feasibility: production-oriented interventions

Most biodiversity threats linked to food and biomass value-chains in agriculture, forestry, and fisheries accrue at the primary production or resource extraction stage (IPBES, 2019). Production-oriented environmental policy interventions or appropriate safeguards attached to other biodiversity-relevant sectoral interventions would thus theoretically seem to rank among the most effective direct intervention options. However, a number of feasibility constraints often limits their effectiveness in practice.

Starting with the disincentive-based production-oriented intervention options introduced in section 4.3, economic theory suggests that taxes are among the most cost-effective environmental policy instruments, because they can be designed such that the overall costs to society are minimized (Kalkuhl & Edenhofer, 2017). This does usually not apply to land use regulations on private and public lands, such as use restrictions imposed on tenants and land owners or on public protected areas. These regulations tend to apply equally to all land users regardless of their opportunity costs, which can vary substantially in space. Disincentive-based interventions usually require appropriate technological capacities to monitor compliance and an institutional enforcement infrastructure, which is why their application is exclusive to state-authorities. Exceptions include commodity-based private sector moratoria, such as the Brazilian Soy Moratorium, which limit market access to farms that produce soy only on land deforested before a defined cut-off year (Gibbs et al., 2015). Neither taxes nor regulations are popular with producers, which constitutes a political barrier to their application. Many countries have nonetheless formulated quite ambitious environmental legislations to protect and restore the ecosystem services provided by their land and water resources. But, capacity limitations or insufficient funding of the responsible environmental authorities are often the main reason for the poor performance of these intervention options, especially in the biodiversity hotspots of tropical and subtropical forest and marine ecosystems. Importantly, not all relevant biodiversity and other conservation benefits are captured at the national scale, which results in national regulations and tax schemes that are less ambitious than desirable from a global perspective. More ambitious national conservation targets and improved effectiveness of policy implementation thus critically hinge on international cooperation and funding

mechanisms.

Incentive-based conservation interventions at the production side, such as PES and ICDP schemes can also, in principle, be designed as cost-effective and economically efficient interventions. They tend to be more popular among farmers and natural resource users than disincentive-based interventions, but can also be more demanding in terms of economic, institutional, and technological preconditions for effective implementation. For example, for PES to effectively improve conservation outcomes, monetary or in-kind compensations must be sufficient to induce behavioural change among recipients (Börner et al., 2017). Research has also shown that the conditionality of payments is critical for effectiveness, i.e. implementers must be able to suspend compensations if recipients do not comply with the agreed rules of natural resource management. Moreover, stable funding is key for PES to function effectively over extended periods of time. Public PES programs thus need a continuous source of tax revenue or international transfers to maintain large PES programs. This naturally also applies to both civil society and private implementers, who must sustain funding flows from donations or business operations, respectively. Both PES and ICDP-based interventions can usually not operate effectively in isolation and must be aligned with existing natural resource use regulations and tax schemes. Research in some highly biodiverse regions has shown, for example, that PES can most effectively function in combination with protected areas (Sims & Alix-Garcia, 2017). It also needs to be mentioned that the EU may have little influence in some regions where agriculture is managed by the state, e.g., in some coffee production areas, where the government manages yields and cost, so that private sector players have little influence on farmers as incentives are managed elsewhere.

The feasibility of both incentive and disincentive-based production-oriented interventions often critically depends on pre-existing local rules for natural resource use, which can be both formal and informal. Especially when it comes to settings, where natural resources are *de facto* under an open access use regime, local resource users may have established informal rules for resource access and use that may conflict with formal regulations or intentions of PES schemes. In such cases, it may become particularly important to design external interventions in participatory processes.

Similarly, also the enabling intervention options discussed in section 4.3. often come to be necessary preconditions for the effective functioning of disincentive and incentive-based interventions for biodiversity conservation. Neither taxes and regulations nor PES schemes can be effectively operated, when governments fail to guarantee basic property and use rights or when access and use rights to natural resources are ill-defined. In fact, deficiencies in rural tenure systems and law enforcement capacities have been identified among the root causes of the performance gap in production-oriented interventions to conserve natural resources in many highly biodiverse world regions (Pacheco & Meyer, 2022; B. E. Robinson et al., 2018). These deficiencies also impose constraints on many other intervention options discussed in section 4.3.

Building capacity and strengthening the institutional infrastructure for the effective implementation of production-oriented conservation and restoration interventions thus comes to be one of the most important leverage points to reduce biodiversity loss along with interventions to reduce the unintended impacts of other sectoral interventions.

4.4.3 Feasibility: intermediate value chain interventions

Private sector supply-chain initiatives

Analysing feasibility considerations of private sector supply chain initiatives is challenging as they involve a wide range of companies, commodities, supply chains and geographies. In addition, they are diverse in their wording, scope, timelines for implementation and level of transparency, and the availability of evidence on their outcomes is limited. Often, they interact in synergistic or antagonistic ways with public and multi-stakeholder efforts, which makes it difficult to assign responsibility for changes (Lambin et al., 2018).

However, in the context of deforestation, the study of Lambin et al. (2018) revealed that respective policies by companies may not be sufficient to achieve impacts on a broader scale because of leakage effects, a lack of transparency and traceability, selective adoption as well as marginalization of smallholders.

Aspirations of industries and individual companies to end deforestation and the associated loss of biodiversity requires a combination of internal codes of conduct and sectoral standards. Supply chain interventions, when fully implemented, can have measurable impacts on producer behaviour and rates of deforestation in certain supply chains, however, they are often not sufficient to end deforestation and associated biodiversity loss. To increase the effectiveness of private anti-deforestation supply-chain initiatives, mixes with public policies are necessary (Lambin et al. 2018).

Another challenge associated with private sector supply chain initiatives is greenwashing, which can be defined as positive communication about environmental performance despite poor environmental performance (Delmas & Burbano, 2011). This misleading behaviour in which more and more private companies along the supply chain are engaging can have strong negative effects not only on consumer and investor confidence, but on society as a whole (Delmas & Burbano, 2011; Yang et al., 2020).

When considering technological feasibility aspects, especially monitoring technologies and technologies supporting data management are important for the private sector to account for effects on biodiversity along their supply chains (White et al., 2021). However, it can be argued that the full potential of technological solutions for biodiversity conservation has not yet been fully realized (White et al. 2021). Possible reasons include insufficient development of widely applicable tools, e.g., due to lack of commercial incentives, financial support, business models, or markets, and a lack of awareness and technical skills among users, including inappropriate use due to insufficient consideration of constraints or context (Joppa, 2015; Lahoz-Monfort et al., 2019). We are not yet at a stage where global data layers can be dependent upon for remote biodiversity monitoring. Remote sensing technologies will eventually improve field derived data. Currently, we depend on traditional monitoring techniques and citizen science technologies like eBird. Opportunity may lie in building data layers (e.g., GEOBON) and standardising protocols for field monitoring so that comparable and reliable data can be gathered. The insufficient use and application of technologies for biodiversity conservation applies to the private sector despite its long history of fostering technological development and in some cases private companies being pioneers in developing and

trialling new technologies for conservation purposes (White et al. 2021).

Public Sector supply-chain initiatives

Since public sector supply chain initiatives, in contrast to private initiatives, can apply to a much broader and diverse target group, in some cases across nations (e.g., EU regulations), feasibility aspects are even more complex and depend highly on the individual policy. Aspects of political feasibility and societal acceptance play a major role, since policy makers must justify their decisions and policies apply to societal actor groups that need to comply with those policies in order to be implemented successfully. Challenges regarding technological feasibility aspects of biodiversity monitoring and data management apply to the public sector in similar challenging ways as to the private sector.

Governmental action to foster environmentally sustainable supply chains is important for the generation of incentives as well "command-and-control" regulations to adopt practices for biodiversity conservation, to provide the necessary infrastructure and to implement measures to avoid perverse effects on small producers (Lambin et al. 2018). Public policies can be a valuable contributor to reduce deforestation as a complement of private supply chain initiatives since they set the foundations and frameworks for effective environmental governance. As such, they have the potential to enhance the success rate and scale of private initiatives (Lambin et al. 2018). The quality of government regulation can be a major indicator for the effectiveness of sustainability approaches led by companies. Means that governments can use to encourage the implementation of private initiatives encompass the facilitation of information sharing and supply-chain transparency, covering of costs of compliance for small producers, the creation of mechanisms to avoid free-riding, the endorsement and reinforcement of private standards, as well as the threat of stronger public regulations (Tropical Rainforest Alliance, 2023). Instead of fragmented efforts, it is crucial that public and private policies reinforce and complement each other to be effective.

Short food supply chains (SFSCs)

Studies regarding SFSCs in the context of sustainability are predominantly focused on the climate crisis, with rather minor reference to biodiversity loss. Existing studies rely on qualitative data, citing stakeholder opinions on perceived improvements to conserve biodiversity. The study of Brunori et al. (2016) revealed that local food chains appear to preserve agrobiodiversity better compared to long food chains

When looking at the economic feasibility of SFSC in general, doubts about the initiative´s economic relevance stem from the consideration of costs of small producers in comparison to large farms engaging in intensive agriculture. Relevant factors to be considered are cost advantages by economies of scale as well as costs for the case that the local area is unsuitable for a certain production (Canfora, 2016). However, these economic considerations must be balanced with potential social and environmental benefits associated with maintaining local fam activities. SFSCs provide benefits for both consumers and producers, and can be of general public interest (Canfora, 2016). The initiative is in accordance with the goals of "sustainable agriculture", as it contributes to a reduction of CO_2 emissions, reduced transportation cost, the promotion of biodiversity, and implementation of periurban agriculture. In comparison with long supply chains, SFSCs have positive effects on public goods and entail environmental benefits. In addition, they can have a positive effect on consumer´s demand for "green" production (Canfora, 2016).

Reduction in Food Loss and Waste (FLW)

As already pointed out in section 4.3, the challenge for producing developing countries lies in the reduction of food loss, with technological feasibility aspects playing a major role, while the challenge for industrialized nations lies in the reduction of food waste, emphasizing social acceptance. For developing countries, feasible solutions include encouraging small farmers to organize, diversify, and upscale their production and marketing activities. Additionally, investments in infrastructure, transportation, food industries and packaging industries are necessary (Gustavsson et al., 2011). In industrialised nations, feasible solutions for reducing food waste include raising awareness among food industries, retailers, and consumers. Additionally, alternative ways of using safe food that is presently thrown

away must be identified (Gustavsson et al., 2011).

4.4.4 Feasibility: consumption-oriented interventions

Motivating biodiversity-friendly consumer decisions presents numerous challenges and limitations. One significant challenge is the lack of awareness among consumers regarding the impact of their choices on biodiversity. Consumers often prioritize other factors such as price, convenience, and taste over biodiversity-friendly considerations when making their purchasing decisions (Hoek et al., 2017). Furthermore, government policies and regulations may not always support biodiversity-friendly consumer decisions, and subsidies for the production of environmentally harmful products can make them more affordable and attractive to consumers. Additionally, the lack of a clear consensus on what constitutes a biodiversity-friendly product makes it challenging for consumers to identify them.

The gap between consumers perceptions on the biodiversity impact of products and life cycle assessment (LCA) is an important consideration in the agenda to encourage biodiversity friendly consumer choices. The perception of consumers on the environmental impact of different steps in the food chain has also been explored in previous studies. A study by Thomas et al. (2021) investigated the perceptions of 523 French consumers purchasing mostly organic food and found that their perceptions included more than just pollution and emissions, including social (health) and economic (agricultural and other production activities) aspects. However, the study also highlighted that buyers did not understand certain impact categories used in LCA to estimate environmental impacts because of the complex terminology. This finding underscores the need for better communication of LCA results to consumers. A study by Henn et al. (2022) investigated consumer utilization and perception of pulses as a versatile, low-carbon food. The study found that while respondents associated pulses with being healthy and natural, sustainability was not an essential attribute related to the distinction between different types of pulses despite significant differences between for example lentils and chickpeas according to LCA analyses. A potential explanation could be that consumers perceive foods in larger categories (such as “pulses” or “meat”) and assign these categories with attributes (such as “sustainable”) without distinguishing the sustainability of

products within these categories. A choice experiment conducted by Tobler et al. (2011) found that current product information for vegetables is insufficient for judging their environmental friendliness. In contrast to life cycle assessments (LCA), consumers consider transportation distance rather than transportation mode and perceive organic production as very relevant for the environmental friendliness. Furthermore, consumers assess the environmental impact of packaging and conservation as more important than the LCA results show.

Overall, while LCA provides a comprehensive and objective measure of the environmental impact of products, consumers' perceptions of the environmental impact of products often differ. Consumers tend to consider factors such as transportation distance and organic production as more important than LCA results show. To promote sustainable consumption, there is a need for better communication of LCA results to consumers in a way that is easily understandable and informative. This will allow consumers to make informed decisions and promote environmentally friendly consumption.

Conducting experiments and studies on consumer behaviour in the field can be challenging due to several reasons, including collaboration with supermarkets and changes in price tags. Firstly, supermarkets and food producers may not be willing to collaborate due to conflicts of interest. For example, if the study involves changing the price of a product to encourage consumers to make more sustainable choices, wholesalers and food producers may be hesitant to participate as it may negatively impact their sales. Even if collaboration is established, implementing changes in price tags may be difficult due to various logistical challenges. For instance, changing the prices of products across an entire store can be time-consuming and costly. Additionally, there may be resistance from store managers or employees who are hesitant to make changes to established pricing strategies. Furthermore, consumer behaviour is complex and influenced by many factors beyond price, such as taste, convenience, and social norms (Richter et al., 2017). As a result, it can be difficult to isolate the effects of changes in price on consumer behaviour. Moreover, experimental conditions may not always reflect real-world scenarios, which can limit the generalizability of findings (Richter et al., 2018). Another challenge is that significant findings in behaviour change do not necessarily translate into measurable biodiversity effects. As an example, (Veríssimo et al., 2018) found

evidence of impact around human behaviour and perceptions on biodiversity conservation, but no changes in biological outcomes during the 2-year time frame considered in this evaluation. This does not necessarily mean that no biological changes happened as the selection of outcome measures and time period strongly influence the findings, but we need to acknowledge the gap between behaviour change and ecosystems change.

Motivating consumers to make biodiversity-friendly choices can be challenging due to limited knowledge and awareness of the issue among consumers, limited effectiveness of some interventions, and difficulties in achieving significant biological outcomes within a short timeframe. Further research is needed to evaluate the effectiveness of interventions in non-university populations and low- and middle-income countries, which have unique contexts and challenges. To address these challenges and limitations, a multi-faceted approach involving multiple stakeholders such as consumers, producers, and policymakers is required. Consumers need to be informed about the impact of their choices on biodiversity and incentivized to make biodiversity-friendly choices. Producers need to be encouraged to adopt biodiversity-friendly practices, and policies need to be put in place to support and incentivize biodiversity-friendly production and consumption. The success of biodiversity-friendly consumer decisions will ultimately depend on a combination of individual behaviour change and systemic change at the policy and production levels.

In conclusion, conducting experiments and studies on consumer behaviour in the field can be challenging due to conflicts of interest with wholesalers and food producers, logistical challenges of implementing changes in price tags, and the complexity of consumer behaviour. Nevertheless, such studies are essential to understand how to encourage sustainable choices and can help identify effective interventions that balance the interests of all stakeholders involved.

4.4.5 Feasibility: systemic interventions

Green Growth

Many proponents of the Green Growth pathway are advocates due to feasibility considerations because it uses economic instruments, such as pricing, which are already widely accepted by decision makers and society. Also, growth has, historically, been a key driver for the reduction of poverty and the maintenance of this has made this pathway the main focus of governments and international organizations, such as the OECD and the World Bank. This would suggest that this pathway should be considered highly feasible with regards to political and social acceptability but with social movements like the Gillet Jaune in France or the success of the BoerBurgerBeweging (Farmer-Citizen Movement, or BBB) in the Dutch senate elections in 2023, the acceptability of green taxes and the shift towards environmentally sustainable practices are not so clear. This means that the switch to a national accounting system and fiscal policies that consider environmental impacts fully would involve difficult political decisions to be made slowing the implementation of a green economy.

Additionally, while there have been proven successes with interventions such as plastic bag taxes, these interventions have been relatively piecemeal and the transition of an entire country to a green economy is a much larger task. While some products are relatively easily substituted to environmentally friendly alternatives, such as plastic bags, not all are and the existing technical ability to decouple growth from energy and material use is not clear. Hickel & Kallis (2020) argue that there is limited scientific evidence that absolute decoupling is possible and that even if it was possible that, at current trends, keeping to targets of 1.5 °C would be highly unlikely leading to possible overshoots of climate tipping points and their impacts of other environmental crises such as biodiversity loss.

Degrowth

Degrowth policies, unlike green growth policies, have attracted very little governmental or international organization attention until very recently. This is due to the size of the changes envisaged and the diametric opposition to current prevailing economic orthodoxy around growth, the limited involvement from the state in the operations of markets and especially labour market interventions. Key policies such as work time reduction and green job guarantee schemes would have large impacts on levels of consumption and productivity in countries and directly impact government tax raising from incomes. This has meant that they have not been considered as feasible policy options by mainstream political parties in Europe. But the popularity and positive impacts of trials of working time reduction schemes mean that these policies could be more acceptable to the general public than green growth policies (Schor et al., 2023).

As degrowth, as a coherent set of principles and policies, has only been developed over the last decade, there is currently little scientific evidence on the impact of degrowth policies on biodiversity loss. But as the policies directly impact levels of resource consumption, pollution and GHG emissions in high income countries, which are major indirect and direct drivers of biodiversity loss, it is envisioned that it would be an effective policy mix (Otero et al., 2020; Stuart et al., 2022).

Earth Stewardship

Proponents of Earth Stewardship interventions suggest that Earth Stewardship is more feasible than technological solutions, because of time and investment needed to produce them and the long term maintenance required, and economic solutions, because they struggle to value environmental goods but does require the adoption of an earth stewardship value system across large parts of the world (Chapin, Pickett, et al., 2011; Chapin, Power, et al., 2011). This is why the interventions focus on education programmes and the engagement of communities already living nature positive lifestyles. Currently, there is limited uptake in these values systems beyond small scale communities and the scaling up of these values systems would require increased public engagement. Also, upon the subscribing to these values, the construction of specific interventions to engender these beliefs into economic

activities would be necessary.

Nature preservation

Nature Preservation policy interventions are captured in the Kunming-Montreal Global Biodiversity Framework under Target 3 “30 by 30”, which states that at least 30 per cent of all terrestrial, inland water, and of coastal and marine areas, are protected areas by 2030. This does not go as far as Wilson’s half-earth target but was already controversial due to a perceived lack of recognition of the rights of indigenous peoples (Parks & Tsioumani, 2023). This shows that while nature preservation does not have the support of all communities it does have wide support across governments with 200 signatories of the Kunming-Montreal Global Biodiversity Framework. But there are concerns about the effectiveness of such interventions due to protected areas failing to meet their intended goals. This means that strong management and monitoring systems have to be put in place with agreed metrics which are not currently in place. Another concern around efficacy is the importance of non-protected areas in fighting biodiversity loss. If the focus on protected areas were to allow continued degradation on the remaining 70% of terrestrial and marine areas not designated protected areas this would continue to have negative consequences for the reproduction of ecosystem services and biodiversity (Antonelli, 2023).

5. CREATING NEW PATHWAYS

5.1 Overall approach

To generate the RAINFOREST pathways, we rely broadly on the Story-and-simulation approach (Alcamo, 2001), that involves an iterative process between expert-led qualitative storyline design, feedback from stakeholders and quantification with models. There can be large variations in the modalities and intensity of stakeholder participation in such process (IPBES, 2016), ranging from predominantly expert-led exercises with limited stakeholder participation (often applied for large spatial scales), to highly participatory co-design processes (often applied to more localized contexts). The scope, time and resources constraints of the RAINFOREST project makes it challenging to implement a highly participative process. However, recent community-wide efforts such as the Nature Futures framework and the SHAPE project engaged in the development of value-explicit pathway with a more intense level of stakeholder participation than feasible within RAINFOREST project. Building on such efforts for the development of the RAINFOREST pathways not only harnesses their participatory engagement efforts, but also increases the chances for uptake of RAINFOREST in the community through an easy linkage to community-wide scenario framework.

Our approach relies on the following steps:

1) **A new framework focused on environmental justice (section 5.2)**. We propose a new conceptual framework building on environmental justice literature, to provide the foundation for better including different forms of justice – covering a key set of justice considerations – than existing scenario frameworks reviewed in section 2.
2) **Combining value-explicit scenario frameworks (section 5.3).** We connect the new justice framework to existing, value-explicit, complementary scenario frameworks identified in section 2: the Nature Futures NFs and Sustainable Development Pathways SDPs. We do so by comparing the storylines across the NF and SDP frameworks for selected dimensions, and their alignment to the various forms of justice. This allows evaluating the alignment of existing pathways to various forms of justice

and assessing how storylines from the NF and SDP framework might be combined / adjusted into a limited number of pathways that will form the starting point of RAINFOREST pathways.

3) **Drafting the RAINFOREST pathways' narratives (section 5.4).** We combine the narratives from scenario frameworks combined in previous steps with information reviewed in section 4 to refine the narrative elements for the context of the EU food and biomass nexus in terms of aggregated targets, human agency, interventions and feasibility considerations, to indicate prioritization across aggregated targets in each pathway and to assign to each pathway downscaling principles.

It should be mentioned that at this stage, narrative elements related to interventions and feasibility may remain very preliminary. The draft pathways will be revised at a later stage in the project, with three specific objectives in mind: a) refine the intervention and feasibility dimensions of the pathways, based on the insights of WP3 and WP4, b) include considerations related to early stages of target downscaling (WP1), modelling toolbox development (WP2) and pathway quantification (WP3), and c) improve the overall framework based on feedback collected from engagement with project partners, the stakeholder group and advisory board and the broader community.

5.2 A new framework focused on environmental justice

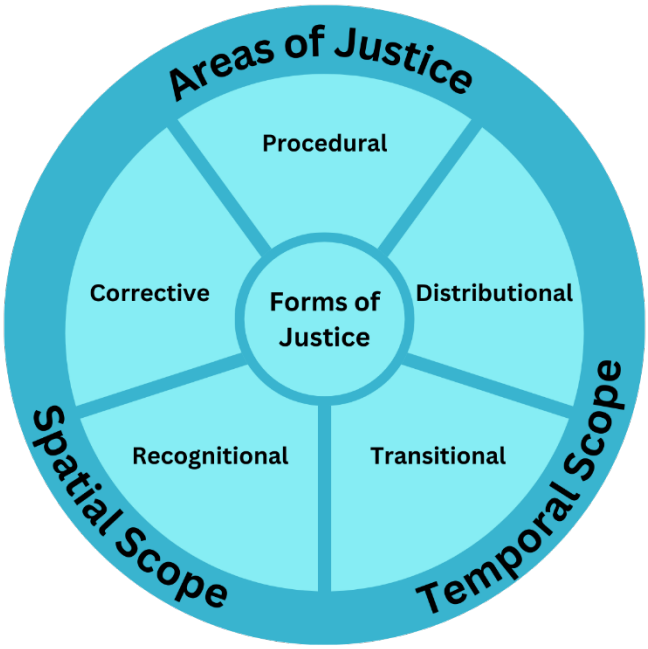


Figure 5. EQU Justice Framework graphic. Source: (Schinko et al., 2023; Zimm et al., 2024)

Biodiversity research and policy exists at a nexus of political, economic and social debates over land and resource use and the allocation of the derived benefits. In this context, understanding different perceptions of justice around interventions and pathways to improve biodiversity has two key benefits. Firstly, to avoid creating greater injustice via biodiversity policy, such as the mistakes of traditional "fortress" conservation, the strict removal of economic activities from areas of natural beauty and high or unique biodiversity, that occurred in the 1960s and 1970s in sub-Saharan Africa that led to injustices for local peoples including forced eviction and denial of rights of passage for migratory routes (Plutynski & Fujita-Lagerqvist, 2016). *Justice for justice's sake*. And, secondly, to improve the viability of policy pathways because the perceived justice – in terms of outcomes as well as decision making processes – of these policies is key to their acceptability. *Justice as a leverage point*. The importance of fairness in policy acceptability has been shown in many environmental policy contexts (Bergquist et al., 2022; Martin et al., 2020; Thaller et al., 2023) including carbon pricing (Maestre-Andrés et al., 2019) and revenue Recycling and compensation schemes as they do not address non-monetary values of stakeholders

(Beck et al., 2016; Leer Jørgensen et al., 2020).

To be able to understand the justice-relevant aspects of research it is necessary to have a framework that supports the appropriate reflection on the impacts and design of research and policies. We have adapted the Justice Framework from Zimm et al. (2024) to support this reflection on the creation of the transformative pathways as part of this project. This framework has 5 stages to identify the justice aspects; the area of justice, the scope of justice, forms of justice; metrics of justice and patterns of justice. The area of justice is the identification of the context in which you are looking to make explicit the justice implications. The scope of justice refers to the spatial and temporal scopes that are being reflected on, respectively, the geographical spread from global to local and the generational spread from historical to future generations. The forms of justice, also sometimes referred to as the dimensions of justice, refer to the different ways in which policies and research can be deemed just. The metrics of justice are the different ways in which these different forms of justice can be measured. And the patterns of justice are the preferences for how different outcomes and processes can be considered just including; utilitarian, egalitarian, sufficientarian, prioritarian and limitarian.

For the application of the framework, it is important to reflect upon the most relevant forms of justice for the research being undertaken. The forms of justice identified in the framework are; distributional, procedural, transitional, recognitional and corrective. Distributional justice refers to the perceived fair manner for sharing or allocating benefits or burdens. Procedural justice centers upon the process under which decisions are made. Transitional justice focuses on the dynamics of the changes that are occurring and the impact this has at different stages on different groups. Recognitional justice reflects upon how different cultural groups reflect, perceive or value the objects being researched and how they may have different types of knowledge. And corrective justice seeks to understand the correct approach to restoration or compensation for an identified injustice.

In the current project, the area of justice identified was transformational pathways for food and biomass value chains towards climate, biodiversity and human wellbeing goals. The geographic scope focuses on the EU both within a global context and between EU member states. The temporal scope defined as from now until 2050

including historical responsibility dependent on context. The forms of justice selected as most relevant were distributional as burden sharing and the downscaling of global and EU targets is a key objective, procedural as the governance and social interventions are another key aspect of the project and recognitional because of the importance of respecting different values towards nature. The patterns of justice will be elaborated upon later in the context of the different pathways because these are value specific but it was necessary to identify the possible range of distributive justice principles as the downscaling of global and EU targets is a key objective of the project.

In order to be transparent about ethical considerations in the pathways and allow us to select the correct pattern of distributive justice for each of the pathways, we identified the most commonly used ethical principles for distributional issues in environmental justice, especially climate justice. We will then as part of the project reconfigure these for the context of biodiversity loss and food and biomass systems.

Table 3. Ethical principles for downscaling global and EU targets and examples of interpretation in the climate context. Source: own compilation.

Pattern of Justice	**Ethical Principle**	**Definition in the Climate context**
N/A	Grandfathering	Grandfathering is based on a sovereignty principle where current resource use is seen as an acquired or 'status quo right'. This approach allocates mitigation costs or carbon budgets based on a country's current share in global environmental pressure .
Utilitarian	Cost Effectiveness	Cost Effectiveness prioritises climate protection schemes that have the least economic costs.
	Progressivity	Prioritizes economic and social progress in mitigation plans for carbon reduction based on technological advances.
Prioritarian	Responsibility	Responsibility approach is where those responsible for GHG emissions bear the burden of reduction and restoration such as polluter pays.
	Capacity	The capacity or ability to pay approach is based on the capability principle where allocation of mitigation costs or carbon budgets is based on a country's GDP per capita.
Sufficientarian / Limitarian	Need	Need takes account of the social requirements of alleviating poverty so exempting the poorest from contributing to climate action because meeting their basic needs has moral priority.
	Subsistence	Distinguishes between subsistence emissions and luxury emissions and suggests that they should be treated differently in reduction schemes.
Egalitarian	EPC	Equal per capita allocation is based on the equality principle where a country's share in the global population designates their allocation of budgets or costs.
	Egalitarian	Actions that reduce inequality are prioritised.

5.3 Combining value-explicit scenario frameworks

Two main value-explicit scenario frameworks have been identified as complementary and relevant to the RAINFOREST pathway specifications: the Nature Futures framework (Durán et al., 2023; L. M. Pereira, Davies, Den Belder, et al., 2020), and the Sustainable Development Pathways (Kriegler et al., 2022). In this section we i) review the narratives of these two frameworks and their complementarities, and ii) map these pathways one onto another and to the main justice dimensions.

5.3.1 The Nature Futures framework

Rather than scenarios themselves, the Nature Futures framework provides a conceptual framework to develop value-explicit scenarios, opening for multiple explorations of the related value perspectives. Yet, 6 illustrative narratives have been developed by Durán et al. (2023) to spur the operationalization of the framework. These span the various combinations of value perspectives proposed by the framework (Nature for Nature NN, Nature for Society NS, Nature for Culture NC – see also *Figure 6* and *Table 4*): Arcology (NN), Sharing through sparing (NC-NS), Optimising Nature (NS), Innovative commons (NS-NC), Reciprocal stewardship (NC), Dynamic natures (NC-NN). Each of the narratives relies on a skeleton developed through iterative stakeholder engagement processes, and is provided with a detailed description for each of 22 themes expected to be important components of social–ecological systems and related to society's governance (economy, governance, cities, communities), society's functioning (infrastructure, energy, transport, water), natural resource management (food, diet, agriculture, fisheries, aquaculture, land management, wellbeing), habitat and biodiversity (megafauna, oceans, biodiversity use) and society's organization (trade, law-rights, education, policy). After an initial draft of each theme, the pathways were further arranged along 3 gradients related to transformative change debates: land sharing vs land sparing, half Earth vs whole Earth, and green growth vs post-growth (see *Figure 6*).

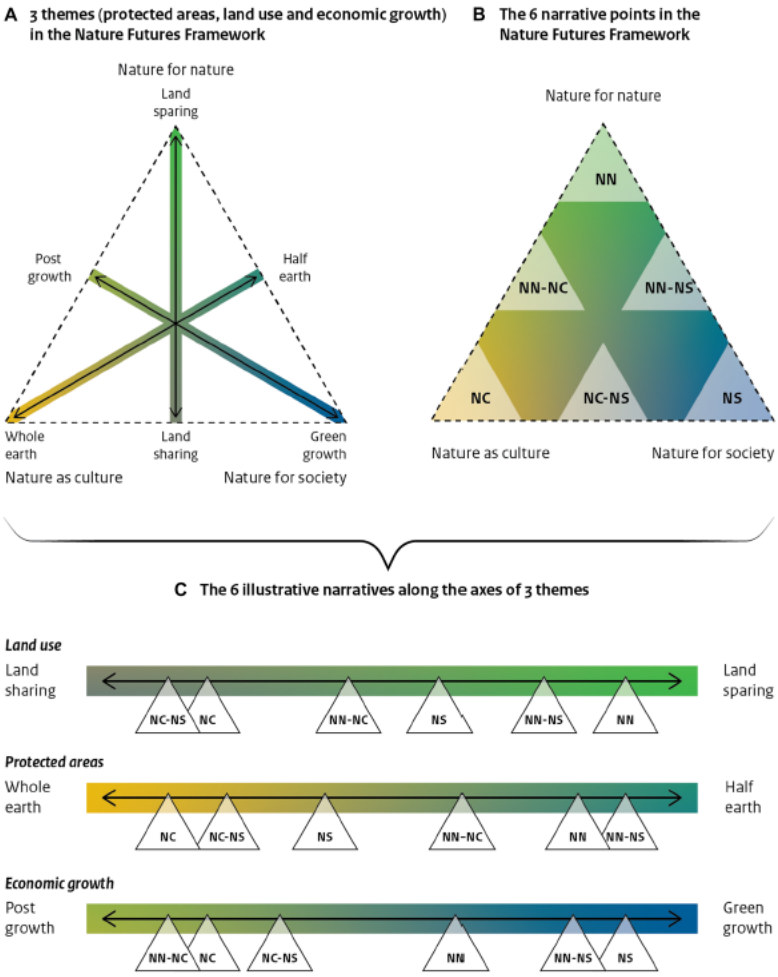


Figure 6. Positioning of the 6 illustrative Nature Future scenarios along the Nature Futures value perspectives and three themes. Source: Durán et al. (2023).

Table 4. Short summary description of each of the 6 illustrative Nature Future narratives. Source: Table 2 of Durán et al. (2023).

Narrative	Short summary	Key words
Arcology (NN)	People respect and value all life on Earth intrinsically. This world is characterized by extreme land sparing, as vast areas of land and sea are strictly protected. People live in dense self-sustaining urban areas designed to minimize the influence of people in the biosphere.	Planetary stewardship, post-growth, smart cities, blue-green infrastructure, protected area, large-scale ecological dynamics, rewilding, self-sufficient settlements
Sharing through Sparing (NN-NS)	People have a fairly strong use orientation towards nature, but also value and protect the self-regulating capacity of the biosphere as biodiversity and natural processes provide the resilience that enables humanity to stay within planetary boundaries. While sparing space for nature, remaining areas are used intensively, but efficiently and sustainably.	Eco-efficiency, green growth, blue-green infrastructure, urban–rural integration, optimized ecosystem services, protected area, engineered ecosystems, rewilding
Optimising Nature (NS)	A highly connected world that shares knowledge and technology to maximise efficient and sustainable utilisation of nature's contributions to people while ensuring maintenance of the key ecosystem functions that support them	Eco-efficiency, green growth, smart cities, urban–rural integration, land sharing, optimised ecosystem services, engineered ecosystems
Innovative Commons (NC-NS)	People have built a world of innovative ecological commons and live in interconnected blue-green cities and rural settlements across land- and seascapes. People use their local and traditional knowledge, and technology, to manage and expand the use of ecosystems and biodiversity also to enhance their culture	Bio-cultural heritage, commons, post-growth, bluegreen infrastructure, urban–rural integration, cultural landscapes, land sharing, optimised ecosystem services
Reciprocal Stewardship (NC)	In this world, values of reciprocity and harmony structure peoples' relationships with nature at all levels of human organisation. Biological and cultural diversity are co-conserved and co-managed across a wide range of interconnected bio-cultural systems	Bio-cultural heritage, stewardship, commons, postgrowth, cultural landscapes, engineered ecosystems, self-sufficient settlements
Dynamic Natures (NC-NN)	Dynamic, connected and biodiverse ecosystems are valued to allow traditional socio-cultural reproduction, spiritual values and connections to be re-established and new ones to be shaped. Society accommodates the dynamism of nature through both traditional and innovative lifestyles that takes into consideration cultural heritage and traditional ecological knowledge	Planetary stewardship, post-growth, urban–rural integration, engineered ecosystems, large-scale ecological dynamics, rewilding, self-sufficient settlements

It should be noted that the framework has been applied to generate EU-focused NF narratives. While restrict the comparison narratives across the NF and SDP frameworks to the NF illustrative pathways, the following applications might be

useful to refine the RAINFOREST pathways for the EU context:

- Dou et al. (2023) generated four scenarios including a baseline and three scenarios exploring how to reach EU biodiversity and pollution reduction targets following the three NF overarching value perspectives (NC, NS and NN). The baseline was following the SSP1 'Taking the Green Road' scenario (combined with a relatively ambitious climate mitigation pathway RCP2p6). The NF scenarios pictured additional action towards explicit policy targets from the EU Green Deal and the KMGBF for protected area expansion, increased restoration, agricultural nitrogen input and pollution reduction, afforestation and green urban area expansion, with part of the related assumptions (location of additional protected areas, forest restoration and afforestation efforts, as well as differences in population trends across cities, peri-urban spaces and cities) being specific to each value perception. The impacts of the various scenarios on land use were quantified using an integrated modeling framework combining the GLOBIOM and CLUEMondo models.
- Fornarini et al. (2023) similarly generated four scenarios that includes a baseline following SSP1 and three NF scenarios exploring how action towards the EU Biodiversity strategy ambition to design of a connected Trans-European Nature Network (TEN-N) might vary along the three core NF value perspectives (NC, NS and NN). On top of a baseline scenario depicting SSP1 (associated with RCP2.6) based on EU climate and biodiversity targets, translated into scenario specific assumptions for 7 topics (protected areas, connectivity and restoration, forests, freshwater ecosystems, agriculture, urban systems, energy).

5.3.2 The Sustainable Development Pathways framework

Within the frame of the SHAPE project, a new set of scenarios was designed to explore alternative, value-explicit pathways to reach the goals of the sustainable development agenda from a comprehensive perspective (e.g., in relation to all 17 Sustainable Development Goals SDGs). The framework includes a definition of the target space for sustainable development (van Vuuren et al., 2022) comprising specific quantitative targets by 2030 and 2050, defined by values for one or more indicators for each of the 17 SDGs (see *Figure 7* and Table 2 in van Vuuren et al.,

2022).

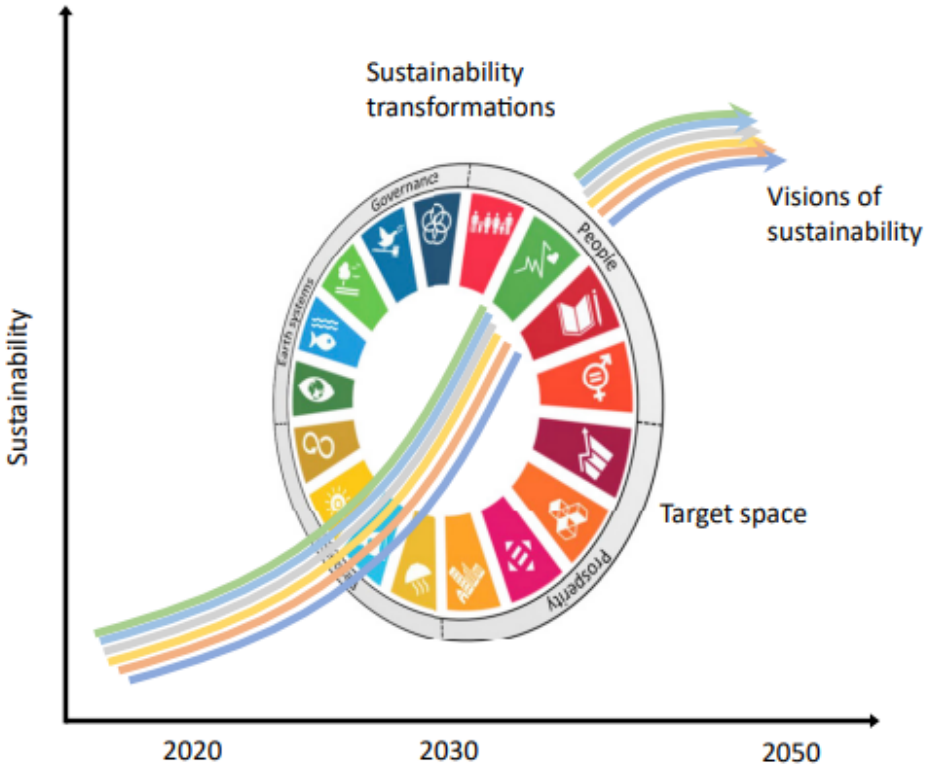


Figure 7. Conceptualization of the sustainable development target space that defines the long-term sustainability vision the SDPs are expected to reach. Source: Figure 1 from van Vuuren et al., 2022.

The SDPs also includes narratives for 5 target-seeking pathways that aim to reach the sustainability target space based on alternative value perspectives about how to get there (Kriegler et al., 2022), related to individual (e.g., human rights), economic (private vs public sector-oriented economies, property rights), societal (liberalism vs collectivism, progressive vs traditional) and human-nature (human-centric vs nature-intrinsic) value dimensions and generated through a participative process. Although the narrative are still preliminary, available material suggests that the 5 narratives (Economy-driven innovation, Resilient communities, Managing the global commons, local solutions, green and social market transitions – see also short description in *Table 5*) have detailed narrative elements for 12 thematic areas ('societal governance', 'global governance', 'economic paradigm, growth, inequality & finance', 'future of work & technological innovations', 'urbanization', 'mobility', 'sustainable production & consumption', 'land & food', 'energy', 'water', 'health & education', 'Nature'), as presented in more details in *Figure 8*.

Table 5. Short description of the SDP narratives (preliminary). Source : Kriegler et al 2022, https://shape-project.org/products/shape_narratives_poster_iamc22.pdf/view.

Narrative	Short description
Economy driven innovation (EI)	In this world, liberal, functional, and global world views become prevalent. Societies embrace innovation, efficiency, global action and equal rights as key elements to depart from current unsustainable trends and drive the transition towards sustainable development.
Resilient communities (RC)	This world develops towards community oriented world views, emphasizing solidarity and wellbeing. Societies emphasize regional diversity, transcend the capitalist economy model and rely on equitable sharing of resources and economic wealth to ensure sustainable development.
Managing the global commons (MC)	In this world, global norms and the perception of global citizenship become prevalent. States and global institutions orchestrate the transition towards sustainable development, including an increased focus on human services and decreased emphasis of material consumption.
Local solutions (LS)	In this world, states become regional centers of authority and pursue regional approaches to sustainable development. They rely on public good provision, demand management and resource efficiency to provide for all within environmental boundaries.
Green and social market transition (GS)	In this world, societies adopt global norms to coordinate the transition towards sustainable development, relying on non-state actors as well as state actors and global institutions. This includes transitioning to a service-oriented and well regulated economy and environmental-friendly technologies.

	Economy-driven innovation	Resilient communities	Managing the global commons	Local solutions	Green & social market transition
Societal Governance	**Economy driven:** key role of market actors/solutions, efficiency	**Society driven:** key role of societal networks, solidarity	**Politically driven:** strong statehood and good governance	**Politically driven:** strong statehood and good governance	**Society driven:** key role of societal networks, solidarity
Global Governance	**Convergent Liberal World**: strong globalization, multilateralism, efficiency	**Divergent Glocality**: weak globalization, polycentric decision making, local action	**Convergent Cosmopolitan Global Society:** strong social globalization based on universal human values, multilateralism, solidarity	**Divergent Glocality**: weak globalization, polycentric decision making, local action	**Convergent Liberal World**: strong globalization, multilateralism, efficiency
Economic Paradigm, Growth, Inequality & Finance	**Innovation driven:** Market economy aligned with societal goals, rapid growth and convergence between regions, social security for those in need	**Solidarity driven:** focus on covering needs, provision of public goods, redistribution of wealth, post-growth future	**Service driven:** focus on wellbeing, valuation of social work, moderate growth, strong convergence between regions, universal access to services	**Solidarity driven:** focus on covering needs, provision of public goods, redistribution of wealth, post-growth future	**Service driven:** focus on wellbeing, valuation of social work, moderate growth, strong convergence between regions, universal access to services
Future of Work & Technological Innovation	**Symbiosis:** rapid digitalization, pervasive human-machine interaction, high technological progress, open data society	**Deceleration:** new digital skepticism, technological progress is slowed to allow societies to adapt organically	**Homecoming**: workplace emphasises human skills and interactions, automation of routine tasks, expansion of human services	**Deceleration:** new digital skepticism, technological progress is slowed to allow societies to adapt organically	**Homecoming**: workplace emphasises human skills and interactions, automation of routine tasks, expansion of human services
Urbanization	**Tech cities:** high urbanization, predominance of metros and large cities, compact urban form.	**Distributed cities:** Settlements centered on local communities. Small to medium cities thrive.	**Green cities:** urban development driven by local institutions and governance, high urbanization.	**Green cities:** urban development driven by local institutions and governance, high urbanization.	**Tech cities:** high urbanization, predominance of metros and large cities, compact urban form.
Mobility	**SciFi Mobility:** autonomous electric vehicles and freight transport, high-speed intercity travel, constant long distance travel due to digital alternatives	**Sustainable Lifestyles:** public and local transport, car sharing, focus on local markets decreases long-distance freight transport	**Green Mobility**: full (direct and indirect) electrification of all transport. Reduced long-distance travel.	**Green Mobility**: full (direct and indirect) electrification of all transport. Reduced long-distance travel.	**SciFi Mobility:** autonomous electric vehicles and freight transport, high-speed intercity travel, constant long distance travel due to digital alternatives
Sustainable Production & Consumption	**A bright High-Tech Future:** "green growth" extrapolation of current trends, large efficiency gains, cradle-to-cradle material usage, heavy use of digital technologies	**Caring for the World**: high degree of self-sufficiency, personal interaction and social participation valued higher than comfort and status, sharing of goods & services	**Sharing the Global Commons:** regional and global institutions regulate fair and sustainable production and consumption.	**Caring for the World**: high degree of self-sufficiency, personal interaction and social participation valued higher than comfort and status, sharing of goods & services	**A bright High-Tech Future:** "green growth" extrapolation of current trends, large efficiency gains, cradle-to-cradle material usage, heavy use of digital technologies
Land & Food	**Sparing:** intensification & efficiency, largely privately driven, landless food production, genetic engineering	**Caring:** strong behavioural change, shift to plant-based diets, low waste. Focus on local & organic agriculture	**Sharing:** mixing managed/natural land, biodiversity-based practices, strong institutions, focus on whole-system efficiency	**Sharing:** mixing managed/natural land, biodiversity-based practices, strong institutions, focus on whole-system efficiency	**Sparing:** intensification & efficiency, largely privately driven, landless food production, genetic engineering
Energy	**Market Supply:** increased supply of clean energy, benefits from economies of scale, globalized markets and centralized distribution networks	**Energy Communities:** reduced energy demand through behavioural change, overcoming producer/consumer split, decentralized energy system	**Flexible Electrification:** interconnected energy systems optimizing supply & demand, high electrification from renewables, focus on end-use efficiency and system flexibility.	**Energy Communities:** reduced energy demand through behavioural change, overcoming producer/consumer split, decentralized energy system	**Flexible Electrification:** interconnected energy systems optimizing supply & demand, high electrification from renewables, focus on end-use efficiency and system flexibility.
Water	**Water Innovation:** well-regulated water markets, increased suppy (incl. desalination) and efficient water use.	**Low Tech:** community based and decentralized water supply and sanitation infrastructure. Reduced demand based on sufficiency, reuse and behavioural change.	**Regional Water Partnerships:** water resources management at basin level, transboundary water institutions. Reduced demand based on sufficiency & recycling.	**Regional Water Partnerships:** water resources management at basin level, transboundary water institutions. Reduced demand based on sufficiency & recycling.	**Regional Water Partnerships:** water resources management at basin level, transboundary water institutions. Reduced demand based on sufficiency & recycling.
Health & Education	**Market-driven innovations:** Education valued as basis for economic and personal freedom, technology driven transfer of knowledge. High tech progress in health system, personalized medicine and health advice.	**Holistic approach**: Education valued as a means to personal development, valuation of local knowledge and lifelong learning. Health system focused on prevention and public health.	**Global programs:** Universal access to health care and education as a human right and means of social development. Focus on combating major global health problems by transfer of technology, knowledge and personnel.	**Holistic approach**: Education valued as a means to personal development, valuation of local knowledge and lifelong learning. Health system focused on prevention and public health.	**Global programs:** Universal access to health care and education as a human right and means of social development. Focus on combating major global health problems by transfer of technology, knowledge and personnel.
Nature (Biodiversity & Ecosystems)	**Symbiosis:** Human centric value of nature. Widespread use of nature adjusted to sustainable levels. Ecosystem health supported in an integrated manner.	**Sufficiency and Co-existence:** Nature has intrinsic value, source of identity for local communities, co-existence of humans and nature, moderate and traditional use of natural resources.	**Global Efficient Safeguarding**: Global nature protection universally valued. Focus on strong institutions and governance, conflict and epidemic prevention. Large areas with no exploitation.	**Sufficiency and Co-existence:** Nature has intrinsic value, source of identity for local communities, co-existence of humans and nature, moderate and traditional use of natural resources.	**Global Efficient Safeguarding**: Global nature protection universally valued. Focus on strong institutions and governance, conflict and epidemic prevention. Large areas with no exploitation.

Figure 8. Preliminary, detailed narrative information of the 5 SDPs. Source : Kriegler et al (2022), https://shape-project.org/products/shape_narratives_poster_iamc22.pdf/view.

5.3.3 Comparing and linking the SDP and NFF frameworks

We will briefly review in this section how the two sets of narratives relate one to another, with the goal to understand a) what are the commonalities and differences in main scenario features, b) to what extent the key dimensions covered by the narratives overlap / complement one another and c) to what extent the individual scenarios can be linked one to one across the scenario frameworks.

The two scenario frameworks share a number of similar features:

- They aim to describe alternative future visions with explanations of how to meet goals for human, nature and climate,
- They also both take a global scale and relatively long-term (e.g., mid-century) perspective,
- They rely on a co-design process, involving participation from a range of stakeholders beyond the scientific community[10].

The two scenario frameworks however differ in a number of points:

- First, while the NF framework aims to generate multiple scenario development applications in multiple contexts and at multiple scales, the SDP framework aims to support one primary scenario instance, to be directly used by the IAM community for global to regional scale analysis (even though it does not preclude extensions, as was done for the SSPs).
- Second, while both frameworks cover a broad range of themes that include major drivers of global change and human-nature relationships (see next paragraph), the illustrative NF narratives focus with more details on human-nature relationships (at the cost of details in other parts of the sustainable agenda), while the SDP focuses on the opposite side.
- Third, the frameworks might also differ (likely in a minor way) in the extent to which they are focusing on the target space vs on the transition from the current state to target space, with a bit slightly more explicit ambition to target the

[10] A description of the stakeholder engagement (including a large visioning workshop in 2017, and several workshops at CBD-COP meetings, IPBES meetings, scientific conferences and expert meetings) in support of the NFF development can be found in Pereira et al. (2020), while a description of the stakeholder engagement (including two large workshops and multiple online seminars) can be found on the project website (https://shape-project.org/stakeholder-dialogue) and relies on the method proposed by Aguiar et al., (2020).

transition in the SDP.

Overall, while there are clear distinctive features across the two scenario frameworks, they share a lot in common and are likely to complement one another, unless they display major inconsistencies in the details of their narratives.

When looking at the range of themes covered in the narrative descriptions, there is a good match despite differences in grouping. Topics related to a) governance, b) the economy, c), urban-rural structuring and mobility, d) education, e) the management of land and water resources and related sectors, f) the relationship to nature, or g) the energy sector are relatively well covered by both frameworks. The NFF illustrative narratives seem to be more specific than the SDP narratives on habitats and biodiversity, as well as on the ocean and freshwater socio-ecological systems, while the opposite is true for topics like work, technology, sustainable production and consumption or inequalities. Individual topics can however be approached differently, with more or less interpretation needed in mapping them one to another.

To understand the possible alignment of the major themes relevant to RAINFOREST – human-nature relationships, economic paradigms, sustainable production and consumption, agriculture and land resource management – between the SDPs and NF framework, we undertook a mapping exercise (see *Table 6* and *Figure 9*).

Based on this mapping exercise, the Economy-driven innovation SDP pathway was found to most closely align with the Sharing through Sparing (NN-NS) pathway, as well as having overlaps with the Optimising Nature (NS) pathway. This is due to the narrative being based on a liberal economic and social worldview where societies view innovation, efficiency and progress as the key aspects of sustainable development. This places the narrative at the green growth end of the instrumental value axis where nature is perceived as being in service of individual welfare functions. On the importance of culture axis it was rated low as the pathway is moves further towards economic globalization and prefers market based solutions to traditional local practices. On the autonomy of nature axis, the pathway was mapped in the midpoint area due to the technological and agribusiness preference rather than multifunctional landscapes and land sharing but also not following large scale

land sparing and rewilding perspective. There is a slight tendency toward more land sparing created by the more efficient precision farming.

The Resilient communities pathway was most closely aligned with the Dynamic Natures (NN-NC) pathway, as well as perhaps in the middle of the triangle. On the instrumental values axis it is aligned on post-growth end and was mapped to a low to medium instrumental value where nature is viewed with values such as stewardship and the importance of non-use values of nature through sustainable production and consumption with high-levels of self-sufficiency and low material use. On the autonomy of nature axis it was also mapped to low to medium due to the preference towards multifunctional landscapes and that management can improve biodiversity. On the importance of culture axis it was mapped to the high to medium end due to the importance of localization and preference for community decision making that would support traditional and local cultural valuations of nature.

The Managing the global commons pathway was also mapped to NN-NS but closer to the middle of the NFF triangle. There is still a strong instrumental value towards nature leading to a high ranking on the related axis due to focus on maintaining ecosystems for the benefit of human need through a global institutional and economic convergence focusing on wellbeing, social work & access to services. This pathway has a balanced approach to the autonomy of nature axis with a preference for mixed landscapes and biodiversity-based practices led by strong institutions and focus systemic management being coupled with global commitment to nature protection through protected areas with limited exploitation. There is also a balanced approach to the nature for culture axis where global governance protects certain traditional practices and conservation techniques in protected areas.

The Local Solutions pathway lies somewhere in the lower left-hand corner of the NFF triangle (NC, NC-NS, NC-NN). This is the pathway with the highest score on the importance of culture axis where nature has a strong cultural value that is seen through the importance of local forms of knowledge and land management practices. This leads to low scores on the autonomy of nature and instrumental value axes with preferences for land sharing with mixed landscapes and a post-growth narrative for meeting needs and redistributing wealth.

The Green and social market transition pathway is another mixed pathway and lies somewhere in the middle of the NFF triangle. On the instrumental axis this pathway leans more towards the green growth end than the post-growth but is less strictly instrumental in its valuation of nature than the EI pathway with a focus on efficiency, material recycling use rate and technology. For the autonomy of nature axis it tends more towards sparing than sharing with greater space given to protected areas. And on the importance of culture axis more half earth than whole earth with a preference for precision farming and intensification and a global perspective on food value chains but still allowing for more local food systems than the EI pathway.

Table 6. Mapping of SDPs (preliminary version) against NFF value perspectives. Source: own compilation.

SDP narrative	Nature for Nature	Nature for Society	Nature as Culture
Economy-driven innovation	Medium to Low	High	Low
Resilient communities	Medium	Medium to Low	Medium
Managing the global commons	Medium	Medium	Medium
Local solutions	Low	Low	High
Green and social market transition	Medium	Medium	Low to Medium

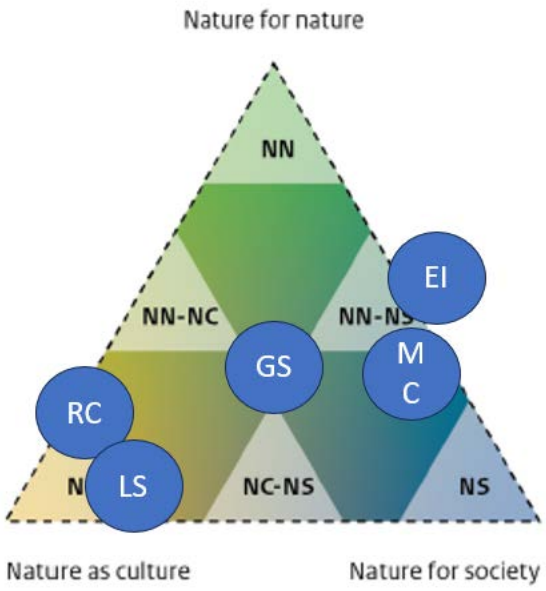


Figure 9. Mapping between the SDPs (preliminary version) and the illustrative NF scenarios (Duran et al 2023). Source: own compilation.

5.3.5 Mapping to the environmental justice narrative

As identified using the justice framework, the three forms of justice being used to differentiate the narratives are; distributional, procedural and recognitional. In each of the forms there are many different perspectives that cannot be covered on a single axis but it is useful to map the narratives on a key aspect of each of the forms of justice that is relevant to the research context. The selected axes are equality in the distribution of nature's contribution to people for the distributional axis, the level of democratic procedures and inclusiveness of decision-making processes for the procedural axis and the level of reflection on marginalized and vulnerable people for the recognitional axis.

As shown in *Figure 10*, the four selected pathways were then placed on each of the axis to show the relative importance of each of the proxies for the respective form of justice.

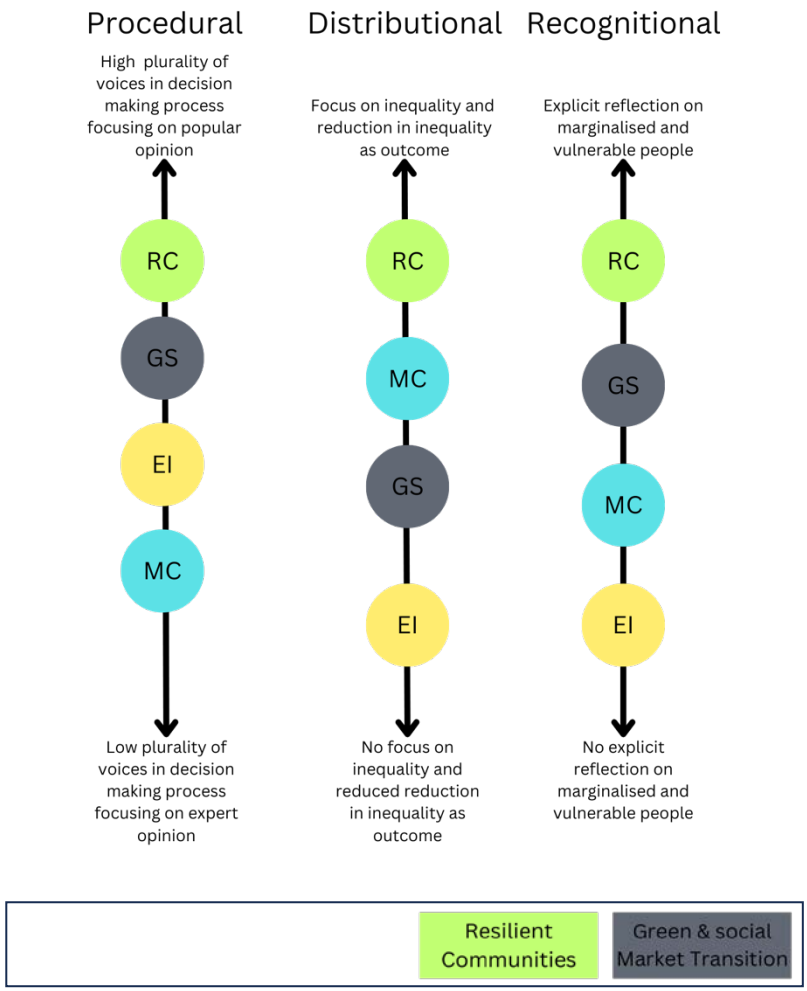


Figure 10. Alignment of selected SDP narrative across the three forms of justice. Source: own compilation

On the procedural axis, the RC pathway has the highest level of plurality in voices as the governance highlighted in this narrative is bottom up and community led which requires large scale popular engagement via local community groups to national citizen assemblies. The EI pathway was placed at a mid-level because peoples' voices are reduced to those of consumers but still does entail a plurality of involvement from consumer groups, industry and business lobbies and government. The GS pathway was placed in between the previous two pathways as it is a balanced approach between a community-led transition and a business-led innovation-based transition. The MC was rated the lowest as it prioritizes top-down and expert led forms of governance that identifies environmental and social priorities to meet. This does not entail a lack of consultation with business and community groups but that these are mediated through centralized government institutions.

On the distributional axis, the RC pathway was rated as the most focused on

inequality reduction. This was due to the adherence of economic degrowth supported by large scale redistributive interventions. The EI pathway was placed lowest on the axis as inequality reduction is not a focus in itself for this narrative because theories of just distribution tend towards conceptualizations such as pareto optimal outcomes that mean that no one is left materially less well-off but may increase inequality. MC was placed at an upper mid-level for inequality reduction because the narrative focuses on priorities such as global governance for poverty eradication but does not go so far as the RC pathway in seeing the reduction of inequality as a key outcome. The GS pathways is placed between the EI and MC pathways because it places a higher importance on social outcomes than EI.

On the recognitional axis, the RC pathway was again placed as the pathway which has the greatest reflection on marginalized and vulnerable people. This pathway is most concerned with the inclusion of traditional and indigenous voices and knowledge in the transition because of the desire to relocalize economic activities. EI was again placed as the lowest ranking of the axis because liberal globalist market ideologies tend to reduce community differences by viewing people as individual consumers not as members of cultural contexts. The MC pathways was ranked as the next lowest because it is the pathway with the most strictly protected areas that can come at a cost to traditional and indigenous communities. The GS pathway is placed between MC and RC because of the more balanced views towards protected areas and human economic activity but still does not go as far as RC in the inclusion of marginalized voices.

5.4 Draft of RAINFOREST pathway narratives

Building on the SDPs and the mapping to the NF scenario framework and the newly developed environmental justice framework, we generated three contrasted pathways that represent different value-explicit pathways. At a later stage, a fourth pathway that tries to provide a more balanced view across contrasted perspectives might be considered.

A short text description of the three pathways is provided:

- Global green innovation: In this world, liberal, functional, and global world views become prevalent. Societies embrace innovation, efficiency, global action (driven by private sector actors supported by state actors) and equal rights (in the sense of ownership, but also light touch welfare state) as key elements to depart from current unsustainable trends and drive the transition towards sustainable development. A highly connected world that shares knowledge and technology to maximize efficient, intensive and sustainable utilization of natural resources while ensuring maintenance of the key ecosystem functions that support nature's contributions to people. Demand might evolve towards innovative sustainable products. Plurality of voices is assumed to be enabled via market mediation of individual choices, and there is moderate emphasis on reducing inequalities and including considerations from vulnerable and marginalized people. Efforts towards global goals are shared based on grandfathering, cost-effectiveness and (potentially) progressivity.
- Needs-based and nature-connected local stewardship: This world develops towards community- oriented world views, emphasizing solidarity and wellbeing. Societies emphasize regional diversity, and move towards a post-growth economy model and rely on equitable sharing of resources and economic wealth to ensure sustainable development. Biological and cultural diversity are co-conserved and co-managed across a wide range of interconnected bio-cultural systems. Land is used extensively with minimal areas devoid of human activity and a strong social connection and geographical proximity between producers and consumers, while the focus on a needs-based society and lifestyle changes supports a reduced footprint on resources. A large plurality of voices is ensured through high reliance on social networks and polycentric decision-making, reducing inequalities is seen as a goal per se and a key lever for achieving other global goals. There is a high recognition of the needs of vulnerable local communities. Efforts towards global goals are shared based on need, capacity, and subsistence.
- Global stewardship towards co-existence: In this world, global norms and the perception of global citizenship become prevalent. States and global institutions orchestrate the transition towards sustainable development, including an increased focus on human services and decreased emphasis on material

consumption. People protect the self-regulating capacity of the biosphere as biodiversity and natural processes provide the resilience that enables humanity to stay within planetary boundaries. People also respect and value all life on Earth intrinsically and, therefore, set aside areas to be undisturbed with low to no human intervention. In addition to sparing space for nature, remaining areas are used with medium intensity and consumption footprint is reduced by a mix of regulation and consumer awareness. Expert-driven decision-making and multilateralism are seen as more efficient than ensuring a plurality of voices in decision-making, poverty and hunger alleviation are pursued as goals per se. There is a medium of recognition of the needs of vulnerable local communities. Efforts towards global goals are shared based on capacity (more or less same as egalitarian) and responsibility.

It should be noted that the RAINFOREST pathways all intend to reach positive futures for nature, climate and people. They should be considered as broadly attempting to reach the sustainable development target space as defined by 2030 and 2050 for the SDPs in terms of specific targets for a range of SDG-related indicators (van Vuuren et al., 2022). They however are also based on human-nature relationships and additional environmental justice elements and might entail variations in the definition of individual targets, different levels of priorities given to various parts of the sustainable development target space, and no guarantee that all targets are met. It should also be noted that the RAINFOREST pathways are focusing on a narrower component of the human and Earth system, with limited focus on some part of the target space (e.g., energy sector beyond the use of biomass, freshwater and marine ecosystems). Some elements that are neither explicitly considered in storylines nor modeled by the RAINFOREST modelling toolbox might have to be drawn from other scenario frameworks: for example, population trends might be driven from a central projection from the SSP framework (e.g., SSP2), while mitigation efforts in the rest of the economy might be drawn from available climate mitigation pathways (e.g., RCP1.9, RCP2.6).

As detailed in *Table 7*, the three RAINFOREST pathways are primarily based on a preliminary version of the Sustainable Development Pathways (SDPs, Kriegler et al., 2022), enriched with value-explicit perspectives on human-nature relations from the illustrative Nature Futures narratives (NFF, Durán et al., 2023) and the scenario

framework for the Trans-European Nature Network (TEN-N, Fornarini et al., 2023) and environmental justice perspectives based on the framework presented in previous sections. Narrative elements are further declined for various human agency dimensions relevant to EU biomass value chains (*Table 8*): geography (with a focus on EU within global scale and variations within EU), agriculture and forestry value chain segments (consumers, producers, intermediates), other sectors (with a distinction between conservation and restoration, finance, energy), and institutions (governments, markets, Indigenous People and Local Communities IPLC). The narratives are further declined in terms of key entry points and priorities in terms of outcome and action targets for nature, climate and human wellbeing at global and EU scale (*Table 9*).

Table 7. Key value-explicit foundations of the RAINFOREST pathways. Source: own compilation.

	Global green innovation	**Needs-based and nature-connected local stewardship**	**Global stewardship towards co-existence**
Relation to Sustainable Development Pathways SDPs	Based on the "Economy driven innovation (EI) towards sustainable development" SDP	Based on the "Resilient communities (RC) achieving sustainable development" SDP	Based on the "Managing the global commons (MC)" SDP
Mapping to Nature Futures framework (NFF illustrative narratives and TEN-N)	Maps closest to the NN-NS 'Sharing through sparing' Nature Futures illustrative pathway, and to the NS TEN-N scenario	Maps closest to the NN-NC 'Dynamic natures' Nature Futures illustrative pathway, and to the NC TEN-N scenario	Originally maps closest to NN-NS 'Sharing through sparing' Nature Futures illustrative pathway, but slightly reworked with some elements of NN 'Archology'; maps closest to the NN TEN-N scenario
Dominant worldviews and environmental justice concepts	Liberal point of view, with individual freedom of choice at the core. Focus on greening to ensure material human wellbeing of future generations with economic instruments, cost-effectiveness and minimal changes to power positions and political systems. Addressing intergenerational justice is seen as important through the lens of ensuring wellbeing of future generations.	Communitarian point of view with equality at the core. Focus on overall reduction in inequality and ensuring a just transition for all through polycentric governance inclusive of a range of views and types of knowledge. Addressing Intragenerational justice through reduction of present-day inequalities is seen as important as intergenerational justice towards future generations.	Managerial point of view with process at the core. Focus on meeting internationally agreed goals and recognizing responsibility through strengthened multilateral and state institutions. Historical responsibility in climate and biodiversity crisis is recognized as an additional component of inter- and intra-generational justice.
Distributive aspect of environmental justice	Preference for utilitarian approach, where those that can maximize environmental and social benefits most efficiently should be allocated the most resources. Cost-effectiveness, progressivity, capacity and grandfathering principles guide effort sharing.	Preference for egalitarian approach, where the outcome is based on need and parity (rather than on benefits derived) and universal measures are preferred to allow everyone equal access to NCPs. Need, capacity and subsistence principles guide effort sharing.	Preference for prioritarian approach, where the meeting of agreed goals such as poverty eradication are more important than efficiency or equality, and supra-national and multilateral bodies have a strong role in targets and implementation. Capacity and responsibility principles guide effort sharing.
Procedural aspect of environmental justice	Medium plurality of voices is enacted through personal choice via consumption decisions, with markets and businesses as key institutions in managing the transition.	High plurality of voices justice is enacted through local and inclusive community decision making that is part of polycentric governance systems with overlapping competencies and responsibilities.	Low plurality of voices follows from expert-led decision making and hierarchical management where business and community input is mediated through political structures
Recognitional aspect of environmental justice	Ownership and individual rights are key, low reflection on marginalized and vulnerable people.	Community and the recognition of different cultures are key, high reflection on marginalized and vulnerable people.	Human rights and international legal systems are key, medium reflection on marginalized and vulnerable people, rights of nature are built into international agreements.

Table 8. Narrative elements for key human agency dimensions in the RAINFOREST pathways. Source: own compilation.

	Global green innovation	**Needs-based and nature-connected local stewardship**	**Global stewardship towards co-existence**
Geographical scope / EU within global	EU is an innovation leader in private sector-led world, with efforts to consolidate competitive and efficient EU biomass value chains, net export position and export innovations to reduce footprints. For the sake of cost effectiveness, conservation and restoration efforts towards sufficient planetary functional integrity are targeted outside of the EU with financial transfers through multilateral institutions.	The EU is consumer-led moral leader and ethical trade partner in world focusing on lifestyle changes and needs, and prioritizes local needs, resilience and autonomy over competitiveness, trade openness and material wellbeing. While there is fiscal support for conservation areas in other regions of the world, the priority is in improving biodiversity across a mixed landscape in the EU itself.	The EU contributes according to its capacity and responsibility in the global context through adjustments in finance, conservation, consumption, trade and production, and promotes improved expert-led global governance and cooperation towards sustainable development.
Geographical scope / within EU	Industry-led transition through market, technological innovation, and regulation. Cost effectiveness and progressivity are preferred principles to allocate efforts within the EU, with limited changes in specialization and landscape gradients across Europe.	Community-led transition through changing lifestyles, improving local resilience and cultural uses of nature. Need, capacity and sufficiency are preferred principles to allocate efforts within the EU, with expected EU-wide transition to extensive farms, forests and landscapes and limited growth in strictly protected areas to protect the most vulnerable ecosystems and species.	Governments-led transition through centrally designed incentives and strict regulations to steer conservation, production and consumption towards patterns compatible with EU contribution to global goals. Efforts are allocated based on EU-MS responsibility and capacity principles, and leading to mixed landscape changes across Europe, including stricter protection and rewilding.
Agriculture and forestry value chain segments / consumers	Consumers are incentivized by labelling and technology-led price reductions to switch to more sustainable preferences towards high value-added sustainable products (e.g., novel proteins, novel plant-based alternatives to animal products, engineered wood products and biomaterials), further regulatory frameworks demand consumers to reduce waste and increase material use rate.	Consumers take an active role by reducing their overall consumption and moving to a high share of plant-based, whole and organic foods and a strong reduction in overconsumption and waste, with an explicit choice to adhere to principles of sufficiency.	Consumers adjust their material consumption as required to meet production and restoration goals through a mix of financial incentives (including choice architecture and message framing), self- and societal-awareness and tighter regulations.
Agriculture and forestry value chain segments / producers	Producers are financially incentivized to adopt technological innovations in efficiency-oriented production methods that maintains or enhances productivity gains while limiting pollution (e.g., precision farming, integrated pest and nutrient management, automated mechanical practices).	Producers consciously and in close connection to consumers move to a mix of extensive practices (e.g., organic agriculture, precision farming, traditional practices) and managed landscapes, with lower productivity.	Producers adopt more sustainable practices required to meet production and restoration goals through a mix of financial incentives, self- and societal-awareness and tighter regulations, and value the stability, fair competition and access to international markets provided by strong international frameworks.
Agriculture and forestry value chain segments / intermediate	Focus on uptake of sustainable practices (e.g. shorter value chains, lower waste and higher recycling) through technological	Focus on shortening and diversifying food value chains, with lower food loss and a weakening of the role of wholesalers,	Focus on coordinated but highly regulated new industry standards with increased traceability, "level-playing field"

	advance and private-led sustainable supply chain standards and incentives.	manufacturers, distributors and retailers.	reduces incentives to offshore environmentally and socially unsustainable practices.
Other sectors / Conservation and restoration	Conservation and restoration efforts target an optimised delivery of NCPs at global (e.g., planetary functional integrity) to local (e.g., high access to pollination, recreational activities) scales, favour biodiversity offsets and restoration compensations, as well as permissive but technology-oriented management of conservation areas.	Conservation and restoration efforts target biocultural diversity (biodiversity but also human cultural diversity and their interconnections) and multifunctional managed ecosystems. Community ownership rights are strengthened and are seen as particularly important, and limited, like-for-like offsetting may be accepted to meet other priorities.	Conservation and restoration efforts target a balance between NCP provision and more intrinsic values of nature, with expert-designed and occasionally excluding efforts compatible with agreed contributions of nations, and no offsetting allowed for highly biodiverse ecosystems.
Other sectors / Energy	A moderate use of biomass, with efforts to minimize related biodiversity and food security impacts, is considered as necessary to support short-term energy transition and long-term negative emissions based on new carbon capture technologies.	Changes in lifestyle and adoption of low impact energy systems allow reducing or eliminating the need for biomass.	Less space for renewable energy production sites due to extended conservation areas is perceived as a challenge, improvement of international energy grit allows better consideration of regional specifications for renewable energy.
Other sectors / Finance	Finance is directed towards private-led technological progress and conservation and restoration efforts, while large international finance for biodiversity is accepted as a need to achieve a cost-effective transition.	Financing of the transition is supported by community credit unions rather than large investment companies, and international finance for biodiversity is limited.	Further development of public and private finance regulation, oriented on transparency and sustainability requirements, together with moderate levels of international finance for biodiversity to ensure effective conservation
Institutions / governments	Governments support the transition via incentivizing sustainable practices and related innovations, as well as selected and moderate disincentivizing of unsustainable practices.	Governments empower the local communities and polycentric decision making, with local direct democracy bodies connected to national citizen assemblies.	Governments invest in multilateral and expert-based decision making, with a shift in power towards EU level and other international or global institutions.
Institutions / markets and trade	Markets are perceived as a central institution, with more open trade and generalized but moderate pricing of externalities and strengthening of environmental provisions in trade agreements	More localized markets and stronger border protections are perceived as needed for the transition, trade might be selectively pursued to support achieving needs	Markets are seen as part of the solution with selected but potentially strong use of price signals, and globalized markets focused on products with a low environmental footprint.
Institutions / IPLCs	Local and indigenous knowledge and practice is seldom valued, IPLC might benefit from some protected areas but do not get granted additional rights on their land.	Local and indigenous knowledge and practice is seen as key in the transition, IPLC benefit from protected areas and get granted additional rights on their land.	Local and indigenous knowledge and practice is seldom valued, IPLC might be granted additional rights in some protected areas but also be excluded in some others

Table 9. Key entry points and priorities in terms of outcome and action targets for nature, climate and human wellbeing. Source: own compilation.

	Global green innovation	**Needs-based and nature-connected local stewardship**	**Global stewardship towards co-existence**
Outcome targets / Biodiversity	The following KMGBF 2050 goals are prioritized: maintaining, enhancing and restoring the integrity, connectivity and resilience of ecosystems, increasing the area of natural ecosystems (part of goal A) and maintaining, enhancing and restoring nature's contribution to people (goal B).	The following KMGBF 2050 goals are prioritized: the abundance of both emblematic and used native wild species is increased to healthy and resilient levels, and the integrity, connectivity and resilience of managed and semi-natural ecosystems are maintained, enhanced (parts of goal A) and biodiversity is sustainably used and managed (part of goal B)	The following KMGBF 2050 goals are prioritized: maintaining, enhancing or restoring the integrity, connectivity and resilience of ecosystems, increasing the area of natural ecosystems, halting human-induced extinction of threatened species, reducing extinction rates and risks, increasing the abundance of native wild species, and maintaining the genetic diversity within populations of wild and domesticated species (GBF goal A)
	In the EU, biodiversity is on a path to recovery by 2030 with a focus on pollinating species recovery, a sustainable level of biomass production, increased carbon removals and resilience to climate change.	In the EU, biodiversity is on a path to recovery by 2030 with a focus on the conservation and restoration of extensive and high cultural value landscapes and a revitalization of rural areas	In the EU, biodiversity is on a path to recovery by 2030 with a focus on high biodiversity and intact ecosystems, with an ambitious effort reflecting historical responsibility.
Outcome targets / Climate	Globally, climate change is limited to well below 2 °C (Paris Agreement), with some overshoot.	Globally, climate change is limited to well below 2 °C (Paris Agreement), with a chance for little to no overshoot due to strong lifestyle changes.	Globally, climate change is limited to well below 2 °C (Paris Agreement), with minimized overshoot and a stronger recognition of common but differentiated responsibility principle.
	In the EU, the current climate objectives (55% GHG emission reduction by 55% by 2030, climate neutrality by 2050) are met, but ambitions do not go beyond this.	In the EU, the current climate objectives (55% GHG emission reduction by 55% by 2030, climate neutrality by 2050) are met, with a chance for faster convergence to climate neutrality due to strong lifestyle changes.	In the EU, efforts are more ambitious than current objectives to limit negative consequences of overshoot for nature and recognize historical responsibility.
Outcome targets / Other planetary boundaries	Humanity largely progresses towards planetary boundaries, but being within the uncertainty zone is accepted as long as delivery of key NCPs is not hampered	Humanity focuses not only on safe but also just planetary boundaries, with a good likelihood chance to return to and stay within planetary boundaries	Humanity largely returns to the save operating space within planetary boundaries. Specific attention is paid to boundaries related to intact ecosystems and biodiversity.
Outcome targets / Human wellbeing targets	Limited reduction of inequality, poverty, hunger, obesity and global burden of disease, as it not seen as a high priority target.	Strong reductions of inequality, including in the distribution of food with improved access to healthy diets and reduced overconsumption.	Intermediate reduction of inequalities compared to the other scenarios, poverty, hunger, obesity and global burden of disease reductions are pursued as goals per se
Action targets / Conservation & restoration, land use and pollution	KMGBF targets 11 (NCPs) & 12 (urban green and blue space) are a strong entry point to the KMGBF implementation, combined with liberal and efficiency-/NCP-focused interpretation of target 1 (focus on halting loss of	KMGBF targets 10 (sustainable land use practices) and 16 (sustainable consumption) are a strong entry point to the KMGBF implementation, combined with a focus on empowering local communities (e.g., target	KMGBF targets 1 (land use planning and halting loss), 2 (increased restoration), 3 (increased protection), 7 (pollution reduction) are a strong entry point to the KMGBF implementation, with an expert-informed, multilaterally agreed and

	areas important for NCPs, offsetting allowed), 2 (limited focus on rehabilitation of managed ecosystems through extensification, restoration to natural state mobilized to achieve net natural ecosystem extent gains and increased delivery of NCPs) and 3 (protection prioritizing natural assets), 7 and 10 (pollution reduction achieved through technology- and efficiency-oriented solutions like precision farming, and achieved globally but not locally), 8 (e.g., reuse part of ag land for bioenergy plantations).	22) and extensification of managed ecosystems (e.g., focus on halting loss and protecting IPLC and culturally important areas in target 1 and 3, on rehabilitation of managed ecosystems in target 2).	state-implemented allocation of restoration and protection efforts and additional measures to limit further losses and reach net gains to the extent of natural ecosystems, and103 incentivize sustainable production and consumptions patterns compatible with these objectives.
	In the EU, 30% protection and 20% restoration targets by 2030 (EU-BS) are met with a liberal and NCP-focused implementation of restoration outside of habitats listed in Annex I of the Habitat directive and strict protection goals. The F2F pollution targets (50% reduction in pesticide and nutrient losses) are met at an aggregated level but not locally.	In the EU, the 2030 EU-BS 30% protection and 20% restoration targets (EU-BS), as well as the F2F pollution targets (50% reduction in pesticide and nutrient losses) are met, and focus lies on the development of multifunctional extensive and high cultural value landscapes.	In the EU, the 2030 EU-BS 30% protection and 20% restoration targets (EU-BS), as well as the F2F pollution targets (50% reduction in pesticide and nutrient losses) are met, implemented in a way that ensures the recovery of both managed and natural ecosystems, and followed by more ambitious action towards 2050.
Action targets / Sustainable consumption, production and trade	Strong and technology- and efficiency-focused emphasis on KMGBF target 10 (sustainable land use practices) with some progress on target 16 (sustainable consumption, towards a decoupling of material consumption). Large reliance on trade (including the maintenance of some level of feed proteins to the EU) but also strengthening of sustainability chapters in trade agreements, reflecting increased private-led standards and preferences for global effort sharing.	Strong and voluntary emphasis on KMGBF targets 16 (sustainable consumption, with a reduction of luxury consumption and waste, transition to planetary health diets) and 10 (sustainable land use practices, towards diverse extensive practices), with efforts to reduce imported environmental impacts and trade dependency except where necessary to ensure reductions in undernourishment.	Balanced efforts on KMGBF target 16 (sustainable consumption) and 10 (sustainable production), with state interventions to shape consumer preferences and production practices in line with responsibility-based allocation of efforts sharing and spare space for nature. Trade is mobilized towards overall global “whole system efficiency”, but also regulated to reduce imported environmental impacts.

6. NEXT STEPS

This deliverable provides the foundations and a first draft of the RAINFOREST pathways, focusing on new, just, viable and actionable targets and pathways able to halt or reverse the ongoing global biodiversity decline through transformative change in the EU food and biomass nexus between climate action, production, trade, consumption, and human behaviour. After reviewing the state of the art of available pathways, the need to incorporate plural worldviews and equity considerations, and additional ingredients to the pathway design (relevant policy- and science-driven aggregated targets, human agency considerations, interventions and feasibility considerations), we combine a novel framework for environmental justice with two recent large-scale value-explicit scenario frameworks (the SDPs and the NF illustrative narratives) to propose a draft of three RAINFOREST pathways. By bridging key emerging value-explicit scenario frameworks and complement them with a more explicit focus on environmental justice, the RAINFOREST pathways are expected fill an important gap and to have a potential for large uptake.

The pathway narratives described in this report should be viewed as preliminary, and several improvements could be useful. For example, there might be a margin for improving the consistency within individual pathways (i.e., across various narrative elements for a given pathway), as well as the contrast across pathways (e.g., across various pathways for a given narrative element). There could also be value in creating one additional pathway, for example a pathway that tries to balance the current three contrasted pathways. The narrative elements could also be amended to make them relevant to a wider context: e.g., marine and freshwater ecosystems, better inclusion of key elements for equity like alternative ways of knowing and IPLCs, more in-depth coverage of some sectors (e.g., energy, conservation and restoration) or even inclusion of others (e.g., fisheries, tourism, etc.) and of the interventions that could occur for each actor in each pathway (e.g., with a focus on feasibility), etc. Similarly, the pathways could be refined for more local contexts, with more intense participatory process. While we plan to improve some of these aspects within the frame of the RAINFOREST, other improvements might need further efforts and the involvement of additional researchers and stakeholders. For example, the current draft narratives focus heavily on terrestrial ecosystems: while we might

try to improve the coverage of freshwater ecosystems within RAINFOREST, covering the marine ecosystems would be more challenging.

Within the frame of the RAINFOREST project, the following applications will guide further improvements to narratives and complement them with quantification efforts:

i. Downscaling of aggregated outcome and action targets (e.g., biodiversity, climate, conservation, restoration, land use extent, land use intensity, pollution reduction, production, consumption) to different regions, sectors and value chain segments. The focus will be on translating the distributive justice principles of each pathway into alternative sets of disaggregated action and outcome targets.

ii. Quantitative assessment of the pathways using the RAINFOREST modelling toolbox (combining the land use component of an integrated assessment model, a biodiversity model, LCIA databases and an environmentally-extended MRIO) in terms of outcomes for nature, climate, and people.

iii. RAINFOREST's set of case-studies will be contextualized with the pathway narratives to highlight and discuss specific trade-offs and potential synergies in the food and biomass nexus. Potentially this might also lead to adjustments in the pathways themselves, in particular on feasibility aspects.

The draft of the RAINFOREST pathways is expected to be improved and finalized by fall 2024 through the following steps:

- Further interactions with the RAINFOREST partners and stakeholder reference group on the draft storylines and considerations emerging from the case studies (e.g., on feasibility aspects), through a co-design process.
- Early insights from the quantitative applications (target downscaling and pathway quantification with the toolbox).
- A broad engagement with the community through the solicitation and welcoming of comments the draft pathway narratives, discussion with on-going closely related scientific projects and posters and presentations at various conferences (e.g., at the 2024 World Biodiversity Forum in Switzerland, the 15th Conference of the European Society for Ecological Economics in Spain, and 2024 Open Science

Meeting from the Global Land Project in Mexico). This might allow for enlarging the expertise contributing to the pathway design beyond the RAINFOREST partners.

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