Perspective paper

Adding forests to the water-energy-food nexus

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Preface

Forest and landscape restoration (FLR) is a promising strategy for improving water, energy and food securities (WEF-Nexus). We advocate that 'forest security' should form a fourth, foundational dimension of a novel water, energy, food and forest security nexus (WEFF-Nexus) framework. Key principles of this new framework support an integrated role of forests in sustainable development, and engagement of local communities in nature-based solutions, particularly in the Global South. We believe that this new approach can help to accelerate the pace and magnitude of changes needed for achieving the United Nations Sustainable Development Goals.

Main text

Safeguarding biodiversity and promoting a sustainable and equitable sharing of the planet's natural resources is one of humanity's major challenges[1]. Forests are irreplaceable for maintaining biodiversity and provide crucial direct and indirect benefits to people[2]. Unfortunately, high rates of deforestation and land degradation are transforming landscapes to the extent that they require environmental protection to slow these processes and restoration interventions to support flows of ecosystem services[3]. Severely degraded landscapes have low conservation value and reduced capacity to support human well-being now or in the future[4]. Additionally, three-quarters of poor people worldwide live in rural areas[5]. Managing these altered landscapes to maintain agricultural productivity as well as diverse ecosystem services that support sustainable livelihoods often presents a "wicked problem" – i.e. trade-offs are common[6].

Forest and landscape restoration (FLR) has emerged as a socio-ecological approach to expand restoration objectives and restore landscape characteristics such as productivity, resilience, and sustainability[7]. However, FLR demands complex multidisciplinary approaches based on reliable, coherent conceptual frameworks[8]. Understanding, foreseeing, and minimizing trade-offs is crucial to achieve so-called 'win-win' outcomes for the environment and societies[7]. One possible solution lies in building a holistic framework that recognizes the role of forests as paramount for ecosystem functionality and human well-being. This framework for guiding policy interventions would not eliminate trade-offs but should, ideally, help to recognize, anticipate, and minimize them[9].

Much forest restoration research focuses on targeting priority areas for increasing forest cover based on biophysical and socioeconomic features of landscapes. For instance, Banks-Leite and colleagues[10] used biodiversity conservation thresholds to map and prioritize areas for strategically restoring the Brazilian Atlantic Forest and proposed that re-purposing only 6.5% of the existing agricultural subsidy for that region would support cost-effective restoration on private lands. Another comprehensive study[7] calculated a restoration opportunity score for all tropical

rainforests by mapping restoration benefits based on biodiversity conservation, climate change mitigation and adaptation, and water security. Also, Strassburg and colleagues[11] incorporated both ecological and economic efficiency to show that cost-effectiveness of FLR increases eight-fold when planned systematically, compared with non-systematic baseline restoration efforts in Brazil's Atlantic Forest region.

Despite the relevance of these analyses to inform priority areas, they privilege the cost-effectiveness of restoration, rather than engaging with the needs, values and preferences of affected social groups. Understanding the complex linkages between ecological and societal change demands more integrative approaches that incorporate interactions among local people needs, opportunities for agricultural sector and biodiversity conservation. Whereas restoring forests to exclusively deliver environmental benefits is costly and reduces direct benefits to farmers[12], harnessing agroforestry to integrate the production of food, firewood, and other forest goods helps to transform forest restoration into an economically-viable, scalable land use. Resolving some of the socio-economic bottlenecks of forest restoration (e.g., avoiding rural unemployment by creating local jobs within the restoration supply chain) is crucial to mainstream it as one of the mechanisms for achieving the United Nations Sustainable Development Goals (hereafter SDGs), especially those directly linked to forests, during the upcoming UN Decade of Ecosystem Restoration (2021-2030).

Among the many frameworks or paradigms proposed to promote sustainable development, the Water-Energy-Food Nexus (WEF-Nexus) is gaining attention because of its potential to help understand synergies and trade-offs in an interdisciplinary way[13]. This framework is designed to improve understanding and quantification of supply and demand of natural resources, economic flows and social structures that affect water, energy, and food securities[14]. Since its launch at the UN 2011 Bonn Conference[15], important advances have been made in both the theoretical foundations and practical deployment of the WEF-Nexus approach to assess and hopefully resolve complex socio-ecological problems[16]. Work has highlighted the utility of WEF-Nexus framework for assessing and accounting for people's vulnerabilities to both natural and socioeconomic hazards and

how it can contribute to achieving SDGs[17]. Compared to other integrative approaches such as Integrated Water Resource Management[18], WEF-Nexus has attracted more attention because it involves multiple sectors, all affected by the current climate emergency[13]. The "perfect storm" predicted by Sir John Beddington (a former UK Government Chief Scientist) foresaw that by 2030 the demands for water, food and energy will be the main challenges for a growing global population. This warning still echoes in academia and governmental sectors that have adopted WEF-Nexus as a promising framework for mitigating against, and adapting to, this challenging uncertain future. We think, however, that achieving WEF securities requires more than addressing supply/demand dynamics, but needs to focus on how to sustain and restore the forest ecosystems that support the provisioning of such natural resources. Security can be progressively defined as the fair access to quality resources in satisfying quantities, for all people, which can be impacted by governance, institutions, and power relationships[14,19,20].

We argue that bridging the gap between WEF-Nexus and FLR approaches and policy agendas could help accelerate the pace of the kinds of socio-environmental transformations needed to achieve SDGs. Large-scale FLR programs should, ideally, help countries and sub-national regions to meet SDG targets and guarantee water, energy, and food security through sustainable development. The goals to end poverty (SDG-1), zero hunger (SDG-2), deliver clean water and sanitation (SDG-6), affordable clean energy (SDG-7), and life on land (SDG-15) can be achieved faster if the promising policy intervention strategies from different ministerial remits can dialogue and create partnerships (SDG-17) in order to strengthen synergies and align agendas. For instance, if a nation's environmental and agricultural policies are complimentary, rather than antagonistic[21]. However, scholars are only beginning to understand the many possible and complex interactions among the 169 SDG targets.

Among the interactions between SDGs (both trade-offs and synergies), some present strong positive correlations such as ending poverty (SDG-1), and ensuring health and well-being (SDG-3) and water (SDG-6), all tending to follow advances in most of the SDGs[22]. On the other hand,

ensuring responsible consumption and production (SDG-12) seems to negatively interact with other SDGs, including those directly related to forests, water, energy and food [i.e. the WEF-Nexus] (SDGs 2;6;7 and 15)[22]. Forest restoration initiatives can help to overcome these trade-offs and potentialize the sinergies. FLR programs aim to increase tree cover, improve the resilience of managed ecosystems, and safeguard biodiversity in the hope that healthy landscapes provide a balance of functions that support sustainable livelihoods[3,7,8]. This goal resonates with the WEF-Nexus focus on integrating water, energy and food securities, which all depend on the capabilities of human societies to organize themselves in order to manage natural resources.

Forest and landscape restoration can, evidently, improve the resilience of socio-ecological systems[23]. Replenishing forests where they have been cleared or degraded can increase the capacity of socio-ecological systems to cope with the risks of climate change (SDG-13). Many international agreements and tree planting initiatives aim to strengthen forest restoration worldwide[24]. Examples include: Aichi Target 15; Convention on Biological Diversity (CDB - Decision XI/16); Objective 3(b)(i) of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), and the Decade on Ecosystem Restoration 2021-2030 (United Nations). One global initiative, the Bonn Challenge, denotes pledges of up to 170 million hectares of lands destined for restoration activities, but only 18% of these targets have been achieved, mainly due to insufficient funding and economic incentives or poor governance mechanisms[25].

This scenario of under-funding may change because, to date, over 60 national and sub-national commitments to restore degraded and deforested landscapes by 2030 were made to the Bonn Challenge, and several other reforestation programs were included through National Determined Contributions to the Paris Climate Agreement. Tree planting in general was prominent in the 2020 Davos' World Economic Forum, posited as helping national economies to mitigate climate change, and many investors and business-people have declared their support for tree planting initiatives. Expectations are high that the political and financial support for forest restoration based on tree planting and natural regeneration approaches will be boosted soon, during

the UN thematic decade on ecosystem restoration (2021-2030). This period coincides with national-level implementation of action plans for achieving SDGs[26].

Here, we present a novel framework for mainstreaming forest restoration into the WEF-Nexus approach that may help societies to meet SDGs. Our aim is to demonstrate the benefits of restoring degraded and deforested landscapes as a way to achieve water, energy and food securities, from landscape to regional scales. Because almost any intervention aiming to support livelihoods relies on decision-making processes around land-use, our integrated approach can address the shortcomings of stand-alone FLR and WEF-Nexus frameworks while emphasizing the best principles of these frameworks.

Water, energy, food and forest securities

We propose a hybrid framework, called WEFF-Nexus (the nexus among water, energy, food and forest security), which highlights the foundational role of forests in achieving water, energy and food security (Table 1; Fig. 1). This merging of WEF-Nexus and FLR involves, conceptually, adding "forests" (both planted and natural) as an inter-connected meta-dimension of the classic WEF-Nexus triangle (Table 1; Fig. 1). Below we summarize the role of forests in promoting water, energy and food securities. Our presentation is not comprehensive, given that we exclude non-forest ecosystems from our perspective and most of the examples cited are focused on tropical regions due to our research experience. However, the rationale behind our arguments can be applied to other ecosystems and forest biomes. It's worth stating that we do not use the term "security" as a synonym of availability or balanced supply/demand dynamics but instead as representative of broad societal access to resources, thus taking in account social and economic determinants of security[14]. Access can be defined as "the ability to derive benefits from things"[20] which expands the notion of security as going beyond property, thus including diverse socioeconomic and socio-ecological relationships (e.g., allowing for community management of natural resources, for example) that determine how people benefit from natural resources[20].

Water security and forests

Water scarcity can reflect ecological or socioeconomic constraints and is worsening globally, with a cascade of consequences for both livelihoods and ecosystem health[27]. The depletion of freshwater resources has many causes, but is coupled to deforestation locally and globally. Restoring forests can contribute to reversing this trend[28]. Planting or regenerating forests are key strategies to protect and recover degraded watersheds[29]; however, maintaining or increasing forest cover within watersheds tend to compete with land uses that provide more immediate economic returns, such as pastures or crops[30]. Longer-term decision-making that accounts for externalities such as floods, soil erosion, and reduced water quality should show stronger net-benefits of restoring forests, yet the restoration of ecosystems usually has lagged responses in the provisioning of ecosystem services such as carbon storage, water regulation, and biodiversity recovery[31].

These trade-offs are typical of water management challenges but can be overcome through effective policy. Landscape planning must consider the long-term social and economic benefits of managed tree cover that is expected to exceed the immediate costs (including foregone opportunities) of conservation or restoration[30]. In Brazil, for example, the Native Vegetation Protection Law (NVPL) of 2012 established a legal environment that regulates land occupancy and made conservation set-asides a recognized land-use that need to be restored as a legal requirement aiming to protect water springs and riparian zones for the common good[32]. This legal instrument provided a huge opportunity for forest restoration, because 21 million hectares need to be restored on private land in that country in order for farmers follow the law and access agricultural credit[33]. An assessment of degraded watersheds the Rio Doce, Brazil, estimated that recovery of 716,000 hectares of forest is: a) economically feasible; b) could meet 6% of national restoration commitments; c) improve water quality; and d) improve resilience to both drought and floods [34].

The impacts of forest restoration on water yields remain uncertain, but a few systematic reviews have assessed them and showed that increasing tree cover can reduce water yields[35]. But

this is not necessarily a major limitation of FLR, as reforestation approaches like agroforestry establish low densities of trees, in order to allow the integration of pastures or crops to the system, with consequent lower evapotranspiration and reduced impacts on water yield[36]. Because water use is principally local, water balance has mostly been calculated at the catchment scale, resulting in apparently negative effects of forest cover on water yields calculation because forest reduces water runoff[35]. However, evapotranspiration is a trans-boundary process that contributes with most of the rainfall in regions such as Southeastern Brazil and Northern Argentina and Uruguay[37]. FLR focuses on landscapes and benefits of restoration at landscape scale and provides a strong argument for protecting the continental movements of water as a direct result of forest metabolism[38].

Water security – as we conceptualize it - also includes water quality and fair access to water resources. Water quality is improved when native vegetation is present across the catchment area. Across the tropics, many ongoing payments for ecosystem services (PES) schemes are based around improving water quality through the restoration of degraded water springs and riversides[39,40]. Increasing catchment-level forest cover can also reduce the economic costs of water treatment. For example, avoiding 1% conversion of native forest to non-forest land uses decreases the costs of water treatment by 1.16% in Malaysian catchments[41]. These “forest-to-water” services help to find the (needed) money for restoration through PES schemes that generate restoration jobs and transfer economic resources to landowners that both conserve and restore watersheds[42]. The economics of forest-water relationships is developing rapidly as evidence accumulates and win-win schemes based on water-restoration relationships are increasingly easy to communicate to a general audience[35]. This is due to the popularization of examples such as the “flying rivers” generated through evapotranspiration from Amazonian forests that transfer rain down south into Brazil’s soybean belt [43]. To support water security and provide water in quantity and quality for human well-being, FLR should be developed as a foundational step for improving future water provision and equitable access to those living in forest biomes. Water security goes beyond the technical problem of reducing water scarcity and should be viewed as a socio-political problem of ensuring access to

safe water supply. Undoubtedly, aiming the resilience of currently degraded socio-ecological landscapes through forest restoration must play an important role in achieving water security for all.

Energy security and forests

Nearly 2.5 billion people depend on fuelwood to attend their basic needs for cooking and heating[44]. Native forests and woodlands are the main sources of this enormous amount of biomass, which is consumed mostly by poor households in the Global South[44]. Fuelwood demand represents a continuous source of degradation to natural ecosystems that may deplete other ecosystem services provided by forests, especially biodiversity safeguarding and carbon storage[45]. Biomass burning accounts for over 70% of all renewable energy consumed globally[46]. The consumption of fuelwood is expected to respond for 42% of the primary energy sources in the year 2035 in sub-Saharan Africa[47]. Under this scenario, FLR emerges as one of the main tools to deal with the growing fuelwood challenge.

The Food and Agriculture Organization (FAO) regards forests as "nature's powerhouses" and crucial for meeting the SDG's on sustainable energy sources because fuelwood is affordable and mainly important in the Global South[48]. Around half of the global wood production is used by the wood-energy sector, which employs almost 900 million people on a part or full-part basis, mostly in low and middle income countries[48]. Supporting the sustainable production of fuelwood in tree-covered, human-modified landscapes through forest restoration or commercial tree plantations should help to reduce the degradation of native forests and improve the resilience of managed ecosystems[46]. Another role for forests in enhancing energy security is supporting hydropower generation because tree cover reduces local soil erosion and siltation, which is a major problem for hydropower dams[49]. Finally, as forests can regrow, any human activity relying on wood-energy can contribute to carbon-neutrality if transparent and accurate measures of carbon dynamics of all types of forests (primary, managed, or planted) are adopted across different economic sectors that adopt such source of energy[50].

Summarizing, we argue that FLR should be adopted as a key strategy for achieving energy security, particularly in the topical Global South, where there is a greater reliance on biomass energy and alternative energy sources are less likely to substitute fuelwood in the short-to-medium term[51]. Nevertheless, discourses on forest restoration rarely explore potential benefits for providing sustainable energy sources, which could be integrated into agroforestry approaches that provide both food and the energy to cook it. FLR can provide multiple benefits based on diverse ecosystem services supply, and providing energy security is among the most promising ones[26].

Food security and forests

Food insecurity is mainly caused by insufficient reliable access to food rather than food shortages[52]. Inequitable land distribution is part of this problem because many poor people lack access to arable lands, and instead live in marginal degraded landscapes or their access to food supplies from forests is diminished by property rights[53]. Worldwide, over 2 billion hectares of land are both deforested and unproductive[46], failing to provide food for people or to safeguard biodiversity (both native and agrobodiversity). We strongly support calls for cost-effective techniques to allow restoration of degraded landscapes which can meet multiple demands, especially food production[54]. Moreover, when forest restoration promotes the recovery of biodiversity, it ultimately improves pollinator communities and natural enemies of agricultural pests, increasing food production in neighboring rural areas[55]. Returning degraded lands to a functional state means that forests must help people to have equitable opportunities to grow, harvest or purchase food. This should be among the main goals for any restoration initiative. Of course achieving these goals relies on good governance and effective, diverse institutions[56]. Sustainably producing food for people under a changing climate depends on ecosystem services that can only be delivered by functional landscapes[57].

Hundreds of millions of poor people depend on forests for income through the harvesting of non-timber forest products[58]. Wild-meat is an important source of nutrients for poor people living in rural areas, especially in west Africa and Amazonia[59,60]. Beyond being a source of wild-meat, forests

are used as rangelands and help to feed millions of people[61]. Multi-functionality (the ability to deliver several benefits for nature and sustain livelihoods) is, increasingly, a desired feature of working, biodiversity-friendly landscapes. In this sense, restoration can play a crucial role in diversifying land uses through the implementation of productive agroforestry systems, including silvopasture[62]. Diversifying food production and planting trees in degraded lands could also improve food sovereignty and boost economic and social returns from currently unproductive landscapes[63]. Making restored forests productive would help to offset conservation and restoration costs and also improve food security for local communities[64]. Therefore, regrowing forests in degraded landscapes is key to establishing a sustainable system of production based on forest goods and services that help societies to achieve or regain food sovereignty. The integration of trees in productive landscapes would be a smart and effective way to make a better use of the inherent biophysical features of deforested and degraded landscapes, in which trees maximize the ecological efficiency of natural resources use.

Forest security matters

Forests can be defined, quantified, qualified (i.e. whether natural, mature, secondary or planted), monitored and managed as well as any other natural resource. The benefits of forests for people can be assessed both globally and locally through their interconnections with water, food and energy securities as well as for their role in climate mitigation and adaptation. Forest security encompasses the protection and the ability to recognize and generate broad, equitable benefits from both existing natural forests and planted ones wherever they can help to create better landscapes for people and nature[30]. Forests matter because they also cool the planet and are a major component of nature-based solutions to fight and adapt to the climate emergency[24]. There have been several recent attempts to assess other urgent problems of the humanity through the lens of WEF-Nexus framework. Climate-related issues are currently central to any major analytical sustainability framework, and it not surprising to see attempts to make climate a fourth node of WEF-Nexus. A

recent effort focuses on climate vulnerability and proposes that balancing the WEF securities requires a fourth pillar, social-ecological security[65]. This modified framework, based on case study research in the Brazilian semi-arid region, represents an important advance in expanding WEF-Nexus but remains detached from forest policy agendas. Whereas water, energy and food are resources, climate is a systemic planetary condition and social-ecological security is an abstract multivariate meta-dimension. Conversely, forests can be seen as a natural resource and their integration with WEF securities, livelihoods and climate is heuristically straightforward.

Keystone principles of WEFF-Nexus

Mainstreaming forest restoration

Tree planting has become something of a "holy grail" for environmentalists and land managers. In 2015, post-COP 21, the Paris Agreement put reforestation for carbon mitigation at the centre of the global climate change agenda, and a few 'Trillion Trees' initiatives were launched recently, including in 2020 by the World Economic Forum[26]. Increasing the planet's tree cover through restoration was considered a reliable tool for mitigating and adapting to climate change[66]. The benefits of FLR go beyond carbon sequestration and can include land management, soil protection and biodiversity conservation[67]. Given these myriad benefits, regrowing forests became an attractive policy discourse for achieving sustainability and livelihoods goals in human-managed landscapes. These mixed-use landscapes now prevail worldwide and demand interventions to recover or keep their long-term capacity to provide services and goods[68]. Some reforestation approaches like agroforestry, maximize multiple benefits within the same area, while other approaches such as exotic tree plantings, silvopastures and riparian forests must be carefully distributed across deforested and degraded landscapes in order to achieve the social and ecological conditions for creating heterogeneous, multipurpose landscapes.

Forest and landscape restoration thinking has been developed by a diverse global community of researchers and practitioners, yet it has moved beyond academia, and begun to shape

312 policy agendas (Table 2)[7,11]. Important advances have been made toward understanding the
313 economics of planting and regrowing trees in terms of spatial prioritization[10], opportunity costs[69],
314 trade-offs[70] and job generation[71]. Forest restoration as a global movement has reached a level of
315 maturity to the point that also enables self-criticism and recognition of limitations[26]. This
316 knowledge now allows interested parties to estimate costs and benefits, map stakeholders, maximize
317 economic and social returns, and reduce undesirable consequences of restoration initiatives.
318 Drawing on these FLR advances can help to accelerate policies towards the SDG's, ensure WEF
319 securities and avoid unintentional perverse outcomes of simplistic actions and planning (Table 2).
320

321 *Empowering local communities*

322 Both FLR and WEF-Nexus approaches rightly take the role of local communities seriously and
323 consider them crucial for achieving sustainable use of natural resources. Large-scale policy
324 programs such as Forest and Farm Facility (FAO) recognize that local people must be the main
325 decision-makers and beneficiaries of restoration in order to ensure progress towards the SDGs[72].
326 Admittedly, however, FLR and WEF-Nexus underplay social differences and tend to homogenize
327 diverse actors and local governance institutions. This is problematic because inter-group and intra-
328 group inequities hinder collective action to manage forests[73]. Many examples with important lessons
329 on how FLR promote empowerment of local communities can be found within scientific and gray
330 literature (Table 3). Also, principles and guidelines regarding the roles of local people in restoration
331 are outlined on the website of the People and Restoration in the Tropics Network (https://partners-
332 rcn.org/). Ensuring that local communities – including marginalized social groups - have equitable
333 access to forest resources, as that forest management is participatory, is key to making forest
334 restoration a long-term enterprise based on people's needs and wills[74]. In the same way, the WEF-
335 Nexus approach must adopt participatory schemes to map both challenges and opportunities for
336 local communities to align decisions with their WEF-securities[75].

In order to ensure social accountability, water, energy, food and forest securities should be: 1) mapped; 2) quantified; 3) ordered in terms of importance; and, 4) used as feedback for project design and implementation[75]. The role of local communities in this accountability process is to participate in the decision-making processes around recognizing, interpreting and resolving the trade-offs which inevitably emerge among WEFF securities to help achieve a fair distribution of environmental goods and bads (in other words, seeking environmental justice). Local voices must be heard and communities need to be engaged partners with the power to decide how and where widespread degraded lands can be turned into biodiversity-friendly landscapes through agroforestry or instead, to produce wood for many purposes (e.g., fuel, fiber, pulp, timber) or set aside for biodiversity conservation.(see examples in Table 3). Developing institutions for collective, effective management of natural resources requires the promotion of social capital, organization, leadership and autonomy[76]. To have a long-term chance of success, the restoration of degraded lands must be anchored in a bottom-up process that accounts for the needs and values of rural communities which are sufficiently empowered to influence political decisions and resolve disputes. Communities must therefore work alongside, or when necessary, push back against, different scales of government and non-local institutions.

Nature-based solutions

Currently, technological solutions to global challenges are privileged over other forms of social transformation. However, emerging technologies tend to be inaccessible to poor rural communities, who depend instead on natural capital for attending food, energy and water needs. Fortunately, however, nature-based solutions are gaining traction as an efficient, affordable and multi-beneficial alternative to technological innovation (e.g., agricultural mechanization, dams)[77]. Nature-based solutions rest on ethical principles including benefit-sharing between people and the nature of sustainable management of both degraded and natural areas[78]. Restoration is an important nature-based solution through approaches that recover degraded natural systems (e.g., ecosystem-based

adaptation, climate adaptation services, etc.)[78]. We therefore argue for adopting forest restoration as a guiding principle aiming to improve water, energy and food security. Forest restoration can strengthen a community's self-sufficiency (e.g. in food or building materials), and helps facilitate access to alternative markets such as certified organics. Finally, global-scale forest policy initiatives such as REDD+ and the Bonn Challenge encourage the protection of existing forest-related ecosystem services and the recovery of degraded forested ecosystems through forest restoration. Nature-based solutions could thus be used as a 'toolbox' to boost water, energy and food securities through forest restoration[79].

Conclusions

We propose the careful integration of FLR into the WEF-Nexus framework. This ambitious, novel approach for achieving water, energy, food *and* forest securities can, we argue, facilitate better policy-making and action in areas that once supported native forest ecosystems. Our starting point is that forests should be treated as a natural resource whose security must be guaranteed for, and be accessible to, diverse social groups. In this sense, forest security (in forested ecosystems) is foundational for sustainable livelihoods and accelerating progress towards the SDGs. Restored forest rarely substitute natural forest habitats and the ecosystem services they provide, but can certainly help to alleviate pressure on old-growth forests. Forest restoration has gained momentum and related benefits must now be expanded far beyond helping nature. Bringing back forest to degraded landscapes is a chance to materialize "political forests" – an emerging idea that recognizes these landscapes as dynamic territories which are produced through politics (i.e. speaking to political ecology)[80]. Accordingly, forests must not be seen as purely natural entities but as continually being (re)created. Forests are strongly related to politics and culture as well as holding material significance for different sectors of society[80]. Moreover, we believe that recognizing the histories, values and desires of marginalized social groups in forested regions will help progress towards achieving broader development goals. The community-centric approach that we advocate

would help to incorporate a currently degraded or deforested landscape's social and ecological components; essential for effective and long-lasting restoration[24]. We hope that the interdisciplinary nature of WEFF-Nexus can enhance communication with, and maximize influence on, policy-makers working within and beyond the state.

393 **References**

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Author contributions

FPLM conceived the original idea and wrote the outline of the perspective. FPLM, LP, RLC and PB conceived tables, figures and work on writing and revisions. SP, AM, JF, GG and PM contributed to content development, writing and revisions.

Competing interests

Authors declare no competing interests

Figure lengends

Figure 1. **Water-energy-food-forest nexus – WEFF-Nexus.** The left panel (a) shows people's livelihoods representing the balance between trade-offs and synergies among each of the four securities. The right panel (b) represents the unfolding of the left one and shows all two-way interactions among securities. We highlight examples of how forests, both natural and restored, can improve water, energy and food security.

Tables

Table 1. How key principles of Forest and Landscape Restoration are put in practice in restoration interventions and how they can improve Water, Energy and Food securities. Table modified from Chazdon et al. (2020).

Key principles	Applied to Forest and Landscape Restoration (FLR)	Applied to Water, Energy and Food Securities (WEF-Nexus)
Focus on landscapes	FLR takes place within and across landscapes representing mosaics of interacting land uses and management practices.	WEF securities are better assessed from a landscape perspective as trade-offs and synergies are likely to operate mainly at the landscape scale.
Participatory governance	FLR actively engages stakeholders at different scales, including vulnerable groups, in planning and decision-making regarding land use, restoration goals and strategies, implementation methods, benefit sharing and monitoring.	Diverse and comprehensive group of stakeholders are likely to provide a better picture on the challenges and opportunities when pursuing WEF securities, anticipate trade-offs to be avoided and boost synergies.
Multifunctional landscapes for multiple benefits	FLR interventions aim to restore multiple ecological, social, and economic functions across a landscape and generate a range of ecosystem goods and services that benefit multiple stakeholder groups.	WEF securities, by definition, must be addressed simultaneously as they are interliked. Landscapes must ideally be able to offer guarantee as many securities as possible.
Prioritize natural ecosystems	FLR does not lead to the conversion or destruction of natural forests or other ecosystems. It enhances the conservation, recovery, and sustainable management of forests and other ecosystems.	WEF securities must rely on ecosystem services delivered by native biomes and prioritize nature-based solutions that emphasize how livelihoods depend on healthy ecosystems.
Adaptive management	FLR uses a variety of approaches that are adapted to the local social, cultural, economic, and ecological values, needs, and landscape history. It draws on latest science and best practice, and traditional and indigenous knowledge to enhance adaptive management	Long-term WEF securities must promote the adaptive management of the landscapes though diverse and adaptable institutions that promote responsive governance arrangements
Long-term resilience	FLR seeks to enhance the resilience of the landscape and its stakeholders over the medium and long-term. Restoration approaches should be adjusted over time to reflect enviornmenyal and societal changes to be integrated into management plans.	WEF securities must be guaranteed in the long run via improving resilience of the socio-ecological systems in face of future environmental changes, economic shocks and societal transformation.

421 Table 2. Definition of water-energy-food (WEF) securities, the diverse potential role of restoration

422 program to achieve securities, and large-scale restoration programs that can help to meet the goals.

Type of security	**Definition**	**Potential role of forest restoration**	**Broad scale programs and/ or institutions**
Water security	Access to water in adequate quantity and acceptable quality for human consumption, agriculture, power generation and livestock	Restore and protect watersheds; keep large-scale water balance; improve local people power on decision-making	International Water Resource Management - IWRM; Watershed restoration programs (USA).
Energy security	Fair access to sustainable and affordable sources of energy that guarantees human welfare	Fuelwood; biofuels; guarantee water supply for hydropower	International Energy Agency - IEA
Food security	Transportation, storage and distribution of good quality, environmentally friendly and affordable food	Diversify agriculture with agroforestry; reduce food imports; soil remediation, restore degraded lands; increase pollination and pest control	World Agroforestry – ICRAF; Center for International Forestry Research – CIFOR; FAO Forest and Farm Facility

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Table 3. Forest and Landscape Restoration projects and large-scale interventions in developing countries indicating the securities attended according to our proposed water, energy, food and forest securities framework (WEFF-Nexus). A common feature of all projects/interventions is that they mainstream forest restoration, aiming forest security that allows for the adoption of nature-based solutions that promote empowerment of local communities.

Intervention or project/Country	**Description**	**Securities attended**
HASHI/ Tanzania	Grazing exclosures were established in 833 villages to control desertification and restore native woodlands. Trees and catchment conservation improved water quality, provided fodder for cattle, and fuelwood [81].	Forest; Water; Energy; Food
Farmer-managed natural regeneration / Niger and Burkina Faso	Combat desertification thorugh increased tree cover on farms using exclosures. Farmers select the best rootstocks to grow into mature trees, which they nurture through thinning and pruning. These practices provide fuelwood, fodder, and improve crop yields and water retention in soils[82].	Forest; Water; Energy; Food
Community-based forest management and rehabilitation/ Nepal	Local communities restore and manage degraded forests to get access to forest products. The watershed is largely recovered due to forest management and natural regeneration processes and supports livelihoods, wildlife, tourism, and crop irrigation[83].	Forest; Water; Energy; Fores; Food
The Water Conservation Program/ Brazil	Over the first 10 years, the program coordinated restoration activities that increased native forest cover by 60% through contracts of payment for ecosystem services with landowners, and established long-term collaborations among government agencies, civil society, and landowners [84].	Forest; Water
Community-managed agroforests / Brazil	Local rural communities involvement in forest management and agroforestry systems, centred on harvesting fruits of the palm *Euterpe edulis* Mart. (Arecaceae), an endemic, threatened species, improving livelihoods by supplying market valuable and culturally important plants [58].	Forest; Food
Mainstreaming Sustainable Cattle Ranching/ Colombia	The program reached more than 2800 ranchers and transformed more than 50,000 hectares of formerly degraded pastures into silvopastoral systems, helping to protect over 12,000 hectares of existing and recovering forests [62].	Forest; Water; Food