

1 Perspective paper

2 **Adding forests to the water-energy-food nexus**

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18 **Preface**

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

26 **Main text**

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

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

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

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

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

69         Among the many frameworks or paradigms proposed to promote sustainable development,  
70 the Water-Energy-Food Nexus (WEF-Nexus) is gaining attention because of its potential to help  
71 understand synergies and trade-offs in an interdisciplinary way<sup>13</sup>. This framework is designed to  
72 improve understanding and quantification of supply and demand of natural resources, economic  
73 flows and social structures that affect water, energy, and food securities<sup>14</sup>. Since its launch at the UN  
74 2011 Bonn Conference<sup>15</sup>, important advances have been made in both the theoretical foundations  
75 and practical deployment of the WEF-Nexus approach to assess and hopefully resolve complex  
76 socio-ecological problems<sup>16</sup>. Work has highlighted the utility of WEF-Nexus framework for  
77 assessing and accounting for people's vulnerabilities to both natural and socioeconomic hazards and

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

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

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

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

112 Forest and landscape restoration can, evidently, improve the resilience of socio-ecological  
113 systems<sup>23</sup>. Replenishing forests where they have been cleared or degraded can increase the capacity  
114 of socio-ecological systems to cope with the risks of climate change (SDG-13). Many international  
115 agreements and tree planting initiatives aim to strengthen forest restoration worldwide<sup>24</sup>. Examples  
116 include: Aichi Target 15; Convention on Biological Diversity (CDB - Decision XI/16); Objective  
117 3(b)(i) of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), and the  
118 Decade on Ecosystem Restoration 2021-2030 (United Nations). One global initiative, the Bonn  
119 Challenge, denotes pledges of up to 170 million hectares of lands destined for restoration activities,  
120 but only 18% of these targets have been achieved, mainly due to insufficient funding and economic  
121 incentives or poor governance mechanisms<sup>25</sup>.

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

130 the UN thematic decade on ecosystem restoration (2021-2030). This period coincides with national-  
131 level implementation of action plans for achieving SDGs<sup>26</sup>.

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

139

#### 140 **Water, energy, food and forest securities**

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

156

157 *Water security and forests*

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

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

180         The impacts of forest restoration on water yields remain uncertain, but a few systematic  
181 reviews have assessed them and showed that increasing tree cover can reduce water yields<sup>35</sup>. But



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

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

208 safe water supply. Undoubtedly, aiming the resilience of currently degraded socio-ecological  
209 landscapes through forest restoration must play an important role in achieving water security for all.  
210

### 211 *Energy security and forests*

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

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

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

241

#### 242 *Food security and forests*

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

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

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

273

#### 274 *Forest security matters*

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

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

293

#### 294 **Keystone principles of WEF-Nexus**

##### 295 *Mainstreaming forest restoration*

296 Tree planting has become something of a “holy grail” for environmentalists and land managers. In  
297 2015, post-COP 21, the Paris Agreement put reforestation for carbon mitigation at the centre of the  
298 global climate change agenda, and a few ‘Trillion Trees’ initiatives were launched recently,  
299 including in 2020 by the World Economic Forum<sup>26</sup>. Increasing the planet's tree cover through  
300 restoration was considered a reliable tool for mitigating and adapting to climate change<sup>66</sup>. The  
301 benefits of FLR go beyond carbon sequestration and can include land management, soil protection  
302 and biodiversity conservation<sup>67</sup>. Given these myriad benefits, regrowing forests became an attractive  
303 policy discourse for achieving sustainability and livelihoods goals in human-managed landscapes.  
304 These mixed-use landscapes now prevail worldwide and demand interventions to recover or keep  
305 their long-term capacity to provide services and goods<sup>68</sup>. Some reforestation approaches like  
306 agroforestry, maximize multiple benefits within the same area, while other approaches such as  
307 exotic tree plantings, silvopastures and riparian forests must be carefully distributed across  
308 deforested and degraded landscapes in order to achieve the social and ecological conditions for  
309 creating heterogeneous, multipurpose landscapes.

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

312 policy agendas (Table 2)<sup>7,11</sup>. Important advances have been made toward understanding the  
313 economics of planting and regrowing trees in terms of spatial prioritization<sup>10</sup>, opportunity costs<sup>69</sup>,  
314 trade-offs<sup>70</sup> and job generation<sup>71</sup>. 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<sup>26</sup>. 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<sup>72</sup>.  
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<sup>73</sup>. 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-rcn.org/>). Ensuring that local communities – including marginalized social groups - have equitable  
332 access to forest resources, as that forest management is participatory, is key to making forest  
333 restoration a long-term enterprise based on people's needs and wills<sup>74</sup>. In the same way, the WEF-  
334 Nexus approach must adopt participatory schemes to map both challenges and opportunities for  
335 local communities to align decisions with their WEF-securities<sup>75</sup>.

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

353

#### 354 *Nature-based solutions*

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

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

371

## 372 **Conclusions**

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



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

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400

401 **Author contributions**

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

405

406 **Competing interests**

407 Authors declare no competing interests

408 **Figure legends**

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

414

415

416 **Tables**

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

<b>Key principles</b>	<b>Applied to Forest and Landscape Restoration (FLR)</b>	<b>Applied to Water, Energy and Food Securities (WEF-Nexus)</b>
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 interlinked. 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 through 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 environmental 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.

<b>Type of security</b>	<b>Definition</b>	<b>Potential role of forest restoration</b>	<b>Broad scale programs and/or institutions</b>
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

423

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

<b>Intervention or project/Country</b>	<b>Description</b>	<b>Securities attended</b>
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 <sup>81</sup> .	Forest; Water; Energy; Food
Farmer-managed natural regeneration / Niger and Burkina Faso	Combat desertification through 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 <sup>82</sup> .	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 <sup>83</sup> .	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 <sup>84</sup> .	Forest; Water
Community-managed agroforests / Brazil	Local rural communities involvement in forest management and agroforestry systems, centred on harvesting fruits of the palm <i>Euterpe edulis</i> Mart. (Arecaceae), an endemic, threatened species, improving livelihoods by supplying market valuable and culturally important plants <sup>58</sup> .	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 <sup>62</sup> .	Forest; Water; Food

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