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# Agroforestry as part of climate change response

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**Abstract.** Three concepts of agroforestry interact with three aspects of climate change, linking local to global scales. Scientific knowledge can contribute to public policy development in four distinct phases: grasp, commit, operationalize and innovate. This contribution highlights three ways agroforestry can be part of a climate change response: adapt to increased risks and uncertainties, facilitate an energy transition (while capturing and storing carbon), and restoring landscape multifunctionality to allow current human resource appropriation to become sustainable, fitting sustainable development goals within planetary boundaries.

## 1. Introduction

Climate change is a symptom of excessive human resource appropriation, exceeding planetary boundaries. Yet, the 17 Sustainable Development Goals (SDG) articulate ambitions for considerable further resource availability for a still growing human population, and leave dealing with climate change to 'goal 13' implementation, rather than making it central to all other issues. The latest IPCC [1] report reconfirmed that the commitment made in the UNFCCC Paris Agreement, to keep global warming as close to 1.5$^{o}$ C as feasible is not a luxury, but a must, if the world is to avoid unknown territories of positive feedback loops and run-away change in oceanic and atmospheric circulation that will drastically change climates as we know them. The consensus among the global scientists, however, is not enough to change global policies, as science is seen as 'one among many voices'. A deeper understanding of the way knowledge links to action is essential for a science that aspires not only to be 'credible' (academic quality standards of consistency and reproducibility), but also 'salient' (relevant for public policy development) and 'legitimate' (aligned with public, rather than private, agenda's). Linking knowledge and action requires 'boundary work' [2], and an understanding of how policy attention issue cycles work [3] (Figure 1).

Four stages in such cycles require different types of knowledge:

- Grasp: understanding an issue, knowing how it can be studied in its interactions with others, agreeing on ways to measure and monitor its change
- Commit: starting with a 'denial' phase, the importance of an issue and credibility of its science can lead to public policy commitments when there is enough stakeholder pressure
- Operationalize: when 'blaming others' is no longer sufficient, the commitments must lead to 'ability to act' using the full range of policy instruments
- Innovate: although it seems attractive to 'prescribe' solutions, the real policy challenge is to maximize the space to innovate and find better solutions is 'wisdom of crowds'

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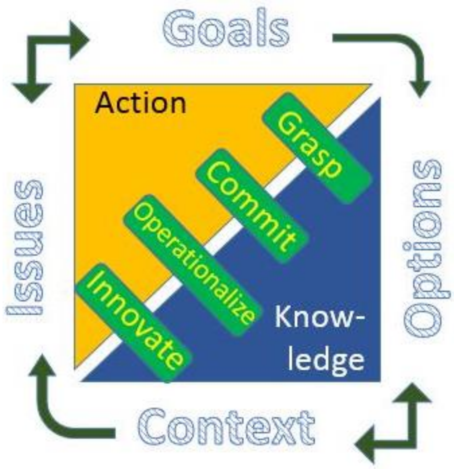


**Figure 1.** Four knowledge-to-action chains, representing different stages of (policy attention) issue cycles (“Grasp”, “Commit”, “Operationalize”, and “Innovate”) linking knowledge of options in context to issues of public concern and politically legitimized goals [3]

The SDGs, to which world leaders committed themselves in 2015, provides a framework for relations between scales and sectors. A silo-based sectoral approach, in which agriculture, forestry, climate change, biodiversity conservation, water management, energy supply, devolution of governance and reduction of inequity are seen as separate targets is not going to deliver on the promises made. A coherent approach to all land uses (including agriculture and forestry) is needed. As recently proposed, a reinvented agroforestry agenda, aiming for policy coherence across the land use sectors, could be a major step forward [4]. A tree architecture is not only a convenient communication tool for suggesting policy coherence (Figure 2), wiser use of trees will also have to be a key part of SDG operationalization and innovation, to match the commitments made, especially because water is one of the primary challenges in matching human ambitions with planetary boundaries [5].

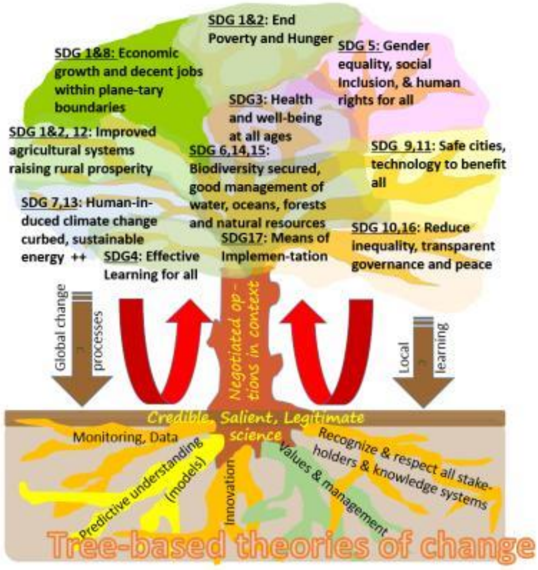


**Figure 2.** Representation of the connections between the 17 Sustainable Development Goals (SDGs) and the generation of global and local knowledge needed to provide negotiated solutions for transforming lives and landscapes that meet all the goals [6]

The SDGs will require a reconciliation between three challenges: 1) increased human resource appropriation to meet demand for goods and services from agriculture, forestry and other land uses, 2) the need for resource conservation, 3) redistribution of power and benefits (Figure 3).

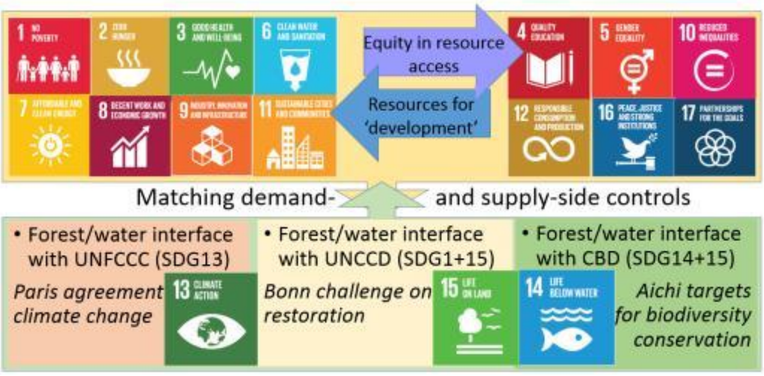


**Figure 3.** Three groups among the SDGs, using the relationship between forest and water as example

The focus in this presentation will be on the hypothesis that reinvented forms of agroforestry can be a major part of an effective climate change policy. We will first unpack the terms 'agroforestry' and 'climate change' across three scales (micro, meso and macro) and then discuss three main SDG issues that together define the climate change agenda.

## 2. Agroforestry concepts at micro-, meso- and macro scales

More than 40% of global agricultural lands have at least 10% tree cover [7], suggesting the landscape- (or meso) level AF2 concept is more widespread than the intimate-interactions concept of AF1 at micro-level. At the start of its 5th decennium [8] agroforestry has evolved from a science of primarily biophysical interactions between trees, soils and crops [9], above- or below ground [10], to one that explicitly recognizes its context of a changing climate [11], while more effectively connecting farm, landscape and policy scales in their socio-economic-policy dimensions. In addressing the footprint of food, existing efficiency gaps require land use options that are more efficient than monocultures [12], such as intercropping and agroforestry.

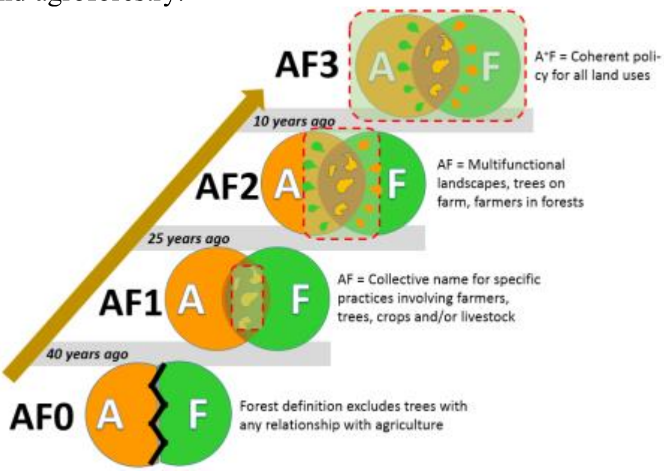


**Figure 4.** Three interpretations of agroforestry in their historical context [13]

The degree to which people and trees can co-adapt [14] and the way tree cover transitions relate to food security [15] are examples at the mesoscale that are relevant for more macro policy interests. As are studies of the relevance of agroforestry for SDGs, for example, focused on Africa [16]. Agroforestry is important for multiple dimensions of food security [17].

Agroforestry dealing with issues at landscape scale have to interact with multiple knowledge systems as well as multiple stakes and require appraisal methods such as those compiled in the Negotiation Support Toolkit [18]. Aiming for 'Climate Smart' landscapes [19] research has identified 'Coinvestment in Environmental Stewardship [20] as a viable concept for aligning rules, incentives and motivation. At the macro (AF3) level the Indian agroforestry policy [21] and inclusion of agroforestry in the agricultural policies of the European Union [22] have been the first examples of explicitly harmonizing rules for agriculture and forestry.

## 3. Climate change: three aspects at micro, meso and macro scales

Climate change can similarly be understood at the micro, meso and macro level (Figure5).

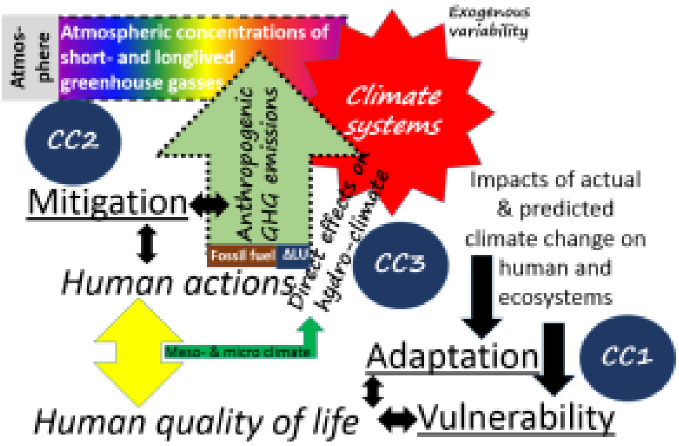


**Figure 5.** Logical loop between human actions, atmospheric concentrations of greenhouse gasses, global climate systems (shaping temperature, windspeeds and precipitation) and the impacts on ecosystems that affect humans [23]; the two main issues of climate change policy, Adaptation (CC1) and Mitigation (CC2) are complemented by direct effects of land cover on the hydroclimate [24]

Microclimate studies are making a come-back [25] after two decades dominated by global climate change studies that assumed that data collected at synoptic weather stations (away from trees and their effects on temperature, wind speed, humidity) represent the only 'ground truth'. Buffering, reducing variability, is a key concept in microclimate studies (Figure 6).

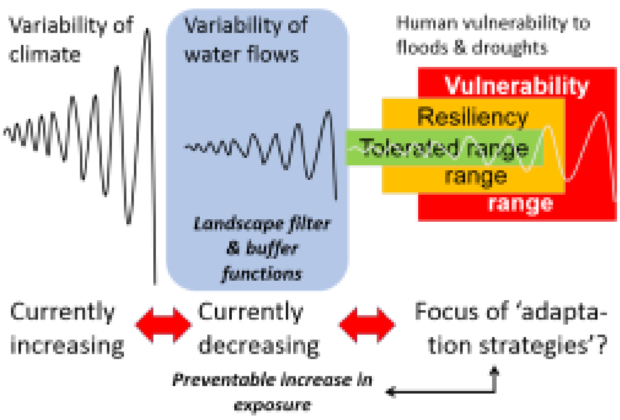


**Figure 6.** Buffering, defined as reduction of external variability, is a key concept in reducing human vulnerability [26]

Although climate policy long maintained a strong segregation between 'mitigation' (reducing greenhouse gas emissions) and 'adaptation' (dealing with the consequences of climate change), in the land use sectors such segregation is dysfunctional, as 'climate smart' land uses such as agroforestry operate at the interface of the two policy domains (Figure 7).

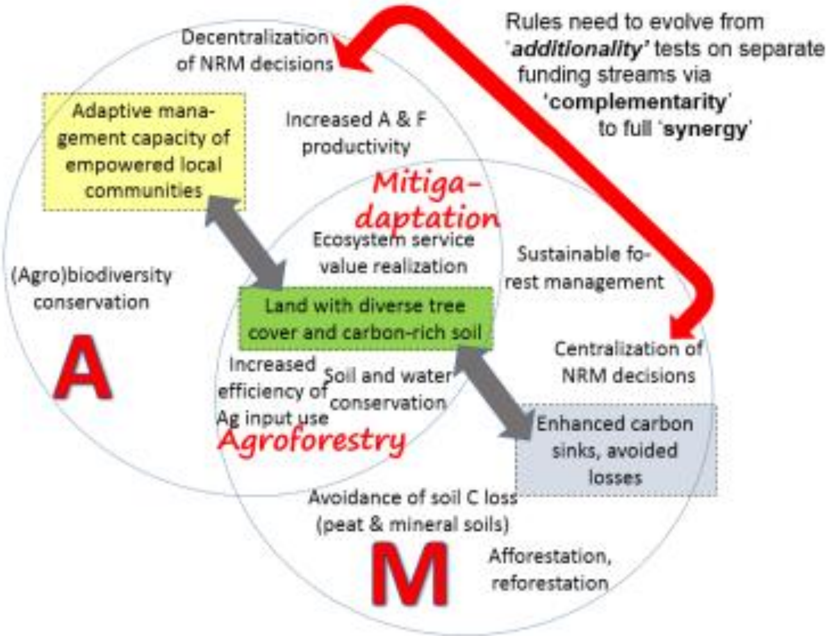


**Figure 7.** Mitigadaptation as interface of climate change mitigation and adaption [27]

Progress has been made in identifying water as key elements of the global climate system (Figure 8). Water vapor and clouds have a direct effect on temperature, as we all know, but its interactions with land cover have for long been only weakly represented in global climate models.

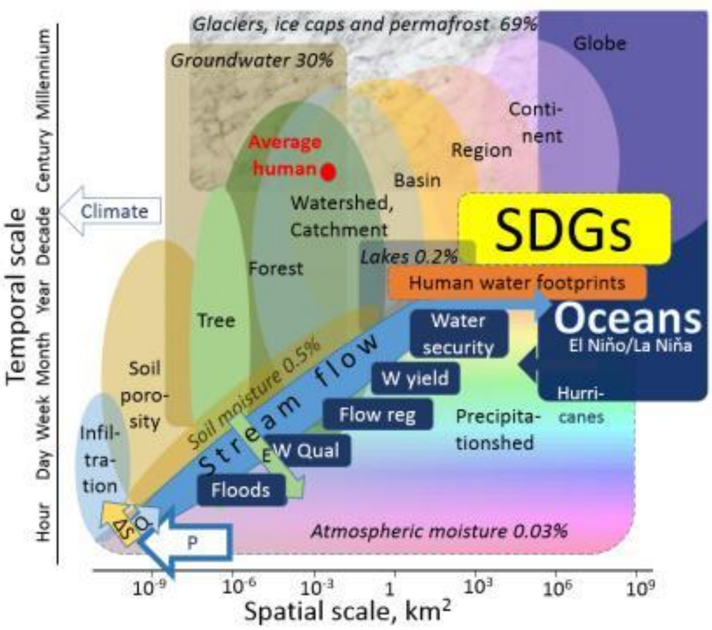


**Figure 8.** Representation of water stocks and flows across spatial and temporal scales, with the key terms of a water balance (P = precipitation, Q = streamflow, E = Evapotranspiration and ΔS as change in soil water storage)indicated, as well as some 'watershed functions' [28]

Public perceptions of a direct and positive relationship between forests and all aspects of the water balance have been challenged by the science of blue-green water competition that suggests that forests and trees use more water than other vegetation (Table 1, Figure 9). The further paradigm shift to the current 'full hydrological cycle' concepts has to lead to a more nuanced perspective on location-specific net effects on water availability. Rainfall recycling over land is now understood to be responsible for more than half of the precipitation on which vegetation depends.

**Table 1**. Three forest-water paradigms in relation to (samples of illustrative) local perceptions, policy implications and scientific evidence

| Paradigm/Slogan / key concept | Local perceptions | Policy implications | Scientific evidence |
|---|---|---|---|
| **I. 'Paradise lost'** / 'No forest, No water' / Forest landscapes buffer and regulate river flows and provide water of a directly usable quality | o Forest conversion induces floods<br>o Forest conversion induces droughts<br>o Tree-planting reverses these trends, including a return of downhill spring flow (at least sometimes…)<br>o Recognizing indigenous and local community control over forests secures water supplies | • Forest protection is key, but regulated logging can reconcile economic and ecological concerns as long as land remains 'forest'<br>• Headwater forest protection secures water-based ecosystem services for downstream people<br>• Costly river flow monitoring can be replaced by easier to obtain 'forest cover' data and policy targets<br>• Synergy with biodiversity agendas can lead to cost sharing for forest protection | ▪ Flood effects are most evident at small (below regional) scale<br>▪ Downstream drought effect depends on balance of infiltration and seasonal water use<br>▪ Key effects depend on the soil rather than trees as such<br>▪ Reforestation has mixed effects, soil macroporosity recovery can take decades<br>▪ Recognition of local rights needs to be complemented by active management |
| **II. 'Bluewater competition'** / 'Less forest, More water' / Additional green water use by forests and plantations, relative to other land covers, is traded off against blue water yield | o *Eucalyptus* trees are disturbing local water supply<br>o Elsewhere forestry-managed *Pinus* or invasive exotics are doing the same<br>o Such problems disappear if local communities own and benefit from the trees | • Water engineering is more relevant than forest management in securing water availability for humans<br>• A water-use tax for fast-growing tree plantations (as pioneered in South Africa)<br>• Support for removing invasive exotics along rivers<br>• Carbon-focused tree planting in drylands is a risk<br>• Regulating forest stand density and production cycles can optimize river flow<br>• Water footprints quantify the way available water is partitioned and define 'water shortage' | ▪ There is a wide range of forests and forest types, differing in water demand<br>▪ Fast-growing trees use more water per unit space and time, but can be efficient per unit wood produced<br>▪ There is a wide range of water demands in 'non-forest' land use types, and the increasing presence of trees in agricultural and urban contexts, blurring the forest/non-forest distinction<br>▪ Leaf Area Index (LAI) is a pretty good 'proxy' for blue water yield, given precipitation data |

| | | | |
|---|---|---|---|
| **III. 'Full hydrological cycle'** / 'Down-wind re-cycling matters' / The intensity of hydrological cycles depends on land cover and shapes water availability | ○ Trees are cool<br>○ Deforestation affects local climate<br>○ Deforestation affects rainfall patterns<br>○ Tree planting can increase rainfall | • Managing a cycle goes beyond partitioning a fixed budget<br>• Geographic context matters more than were realized previously<br>• Urban parks provide for key human needs; increasing urban tree cover helps to reduce (fossil) energy use for air conditioning<br>• 'Water tower' landscapes deserve attention at downstream / downwind interface<br>• Cross-boundary atmospheric flows and precipitation sheds deserve negotiations of rights<br>• 'Green rainfall infrastructure' deserves empirical tests | ▪ Evapotranspiration (tree water use) is directly linked to local cooling<br>▪ Atmospheric residence times of moisture (~8 days) plus prevailing winds define location-specific recycling<br>▪ Globally at least half of precipitation is 'short' rather than 'long' cycle<br>▪ Atmospheric teleconnections matter in the Amazon basin, Africa and parts of Asia<br>▪ Biotic triggers of rainfall are a science frontier |

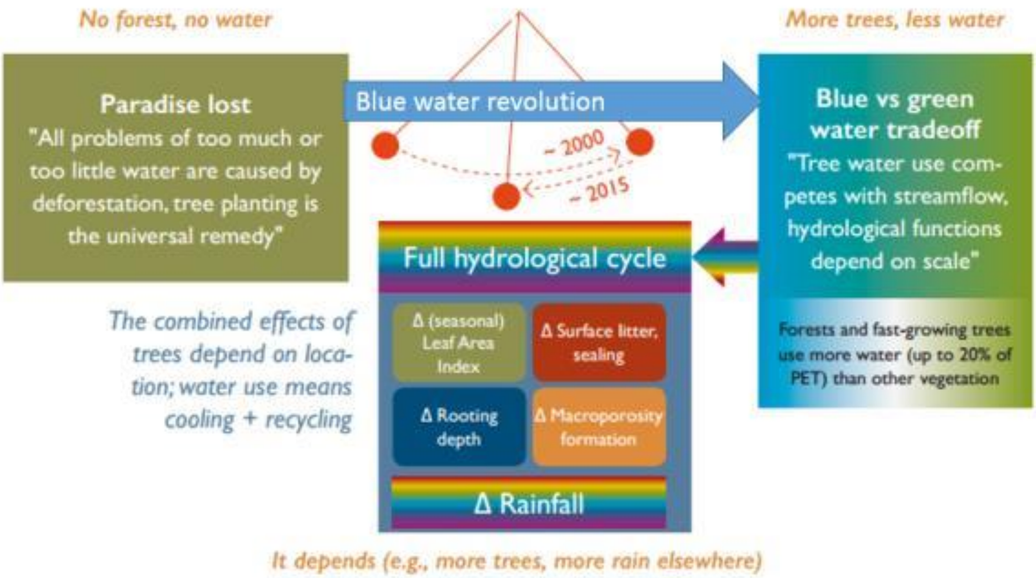


**Figure 9.** Three paradigms that represent a public understanding of climate-forest-water relations [29]

Location specificity of the way vegetation interacts with atmospheric moisture and wind speeds can be summarized in the mean atmospheric residence time of moisture (around 8 days) [30] and wind speeds that imply distances covered in that period ranging from around 200 to 20,000 km (Figure 10).

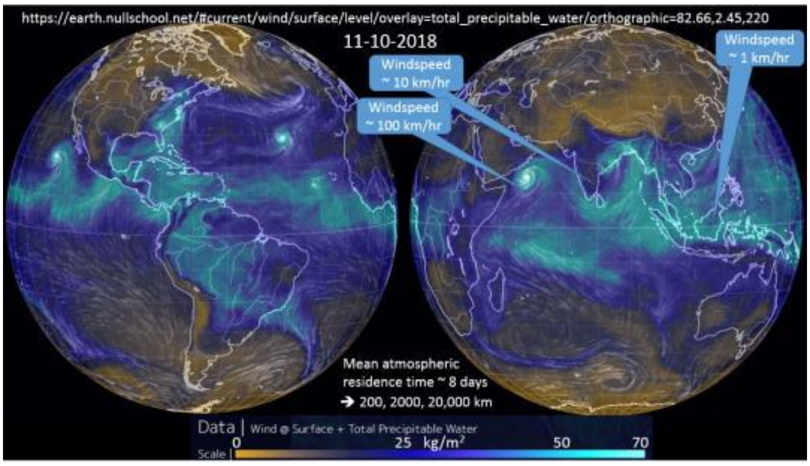


**Figure 10.** Snapshot of atmospheric humidity and moisture transport that is available in the public domain

Where rainfall recycling has been most intensively studied for the Amazon basin, similar relations in Africa may affect more people (e.g. Blue Nile rainfall is linked to regional context and recycling [31]). Although in Indonesia marine influences on climate are strong, low wind speeds over Borneo determine high degrees of rainfall recycling and sensitivity of rainfall to forest loss [32]. Elsewhere the ‘water tower’ configuration [33] has been identified as a hot spot for conflict, as economic opportunities for profitable land uses (e.g. temperate vegetables, Arabica coffee) clash with downstream interests in a regular and clean water supply. Part of the water towers includes cloud forest, where active capture of atmospheric moisture can be lost after deforestation [34].

## 4. Implications

At the interface of micro-, meso- and macro-scales agroforestry is relevant for three main aspects of current climate policy (Figure 11).


**Figure 11.** Three climate policy issues for which agroforestry has partial solutions to offer

## 5. Adapt or fossilize

Biologists have studied adaptation both as a description of a match between architecture plus function and environment (‘being adapted’) and as a process of continuous change in phenotype and genotypes due to differential survival and reproduction (‘survival of the fittest’). Staying the same is not an option for long-term survival. The term adaptation in climate change literature refers to ‘adjustment’, but may still be seen as a one-off change, rather than as a continuous process. It requires that many types of information and analysis come together (Figure 12). The microclimatic buffering by trees in the landscape needs to be factored into current efforts that primarily seek genotypic change in crops and livestock.

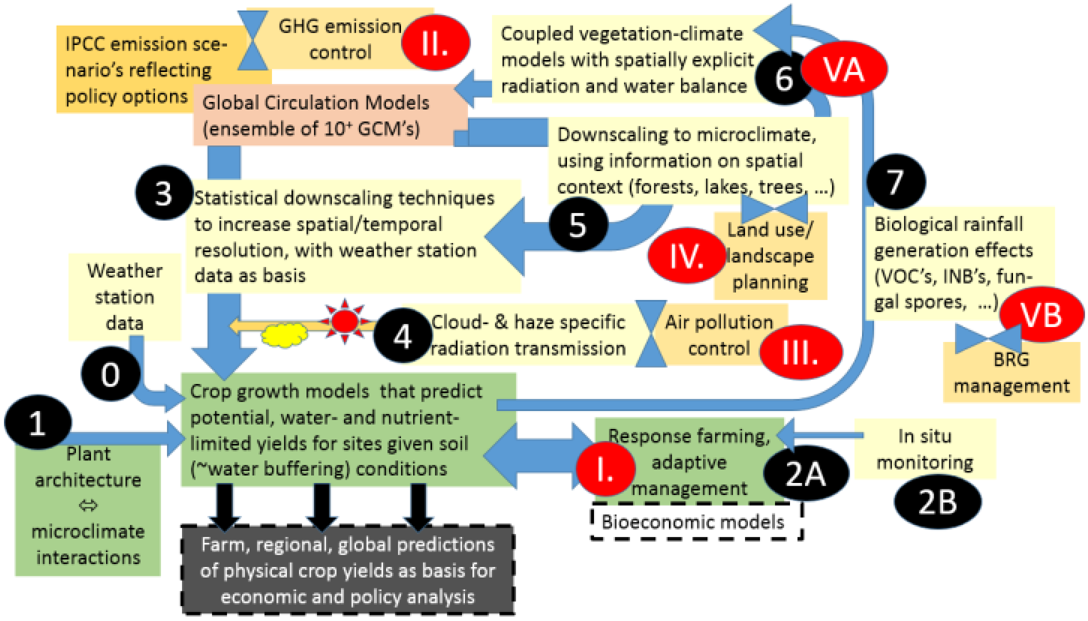


**Figure 12.** Steps involved in assessing the degree of adaptedness of current agricultural systems interacting with climate and the options for further change ('adaptation')

Global climate change forms a challenge for a balanced below- and aboveground response of trees [35]. Young trees respond primarily to longest dry spell in growing season, from year two onwards they may respond to overall water balance [36]. $N_2$ fixing legumes are a source of $N_2O$ emissions [37].

A recent analysis of options for keeping the food system within environmental limits concluded that [38]**: "…**staying within the planetary boundaries of the food system requires a combination of measures: GHG emissions cannot be sufficiently mitigated without dietary changes towards more plant-based diets; cropland and Bluewater use are best addressed by improvements in technologies and management that close yield gaps and increase water-use efficiency; and reducing nitrogen and phosphorus application will require a combination of measures to stay below the mean values of the planetary boundaries, including dietary change, reductions in food loss and waste, improvements in technologies and management that increase use efficiencies for nitrogen and recycling rates for phosphorus, and efforts in global socioeconomic development."

## 6. Defossilize human energy systems

Weaning humanity of its dependency on fossil fuels (whether coal, liquid fuels or gas) is the primary issue of climate change mitigation. Land use with trees supports the sustainable use of hydropower (reducing siltation of reservoirs and sediment loads of streams), while biomass-based energy (traditionally mostly as firewood and charcoal) has a new future, especially in use for electricity generating plants. There still are, however, inconsistencies and gaps in the global accounting of emissions linked to land use (Figure 13).

Partly because the nation-based policies to bring greenhouse gas emissions under control are so slow and tedious, global citizens take responsibility for their footprints and demand 'deforestation-free' products (Figure 14), triggering responses in the value chains such as those for oil palm [39] and cacao [40] (Figure 14). It is not clear under which condition certification is only 'shifting blame' and where it contributes to resolving issues [41].

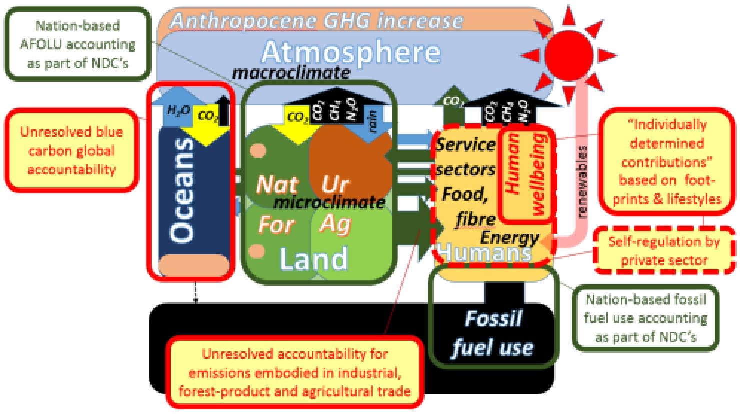


**Figure 13.** Major elements in the global accounting of greenhouse gas emissions [42]

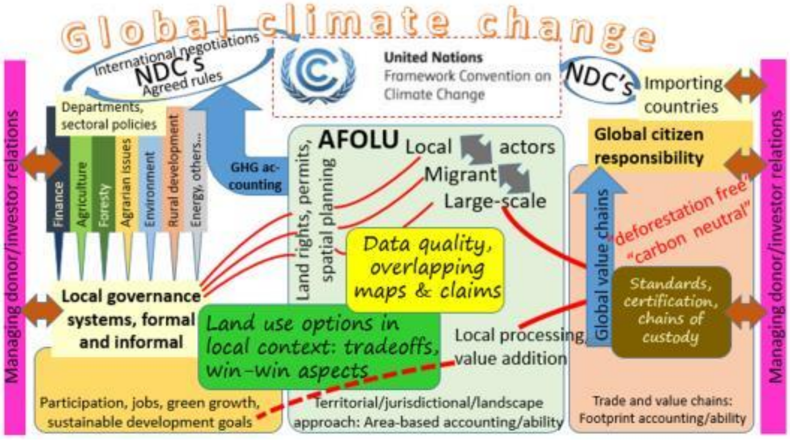


**Figure 14.** Complementarity between territorial (nation-based) accounting of net greenhouse gas emissions and the actions of global citizens to take responsibility for their footprints by preferring 'deforestation-free' products from accountable value chains [43]

Of specific interest to Indonesia are the substantial contributions to total emissions from the destruction of peatlands, where the products of 10,000 years or more of photosynthesis have accumulated [44]. Recent studies have made clear that smallholder agroforestry emissions on peatlands are also substantial [45]. There is a clear need for broadening current paludiculture options [46], while peatland land use scenarios need to take local actor perspectives into account [47].

## 7. Restore landscape multifunctionality

Large areas of 'degraded' land, often still under the control of forest authorities, are not productive. In Indonesia, the Imperata grasslands are an example of such, although many former Imperata areas have successfully been reclaimed for agroforestry and tree crops, especially on Java and (subsequently) Sumatra when land pressure increased. Supported by high-level policies such as the Bonn challenge, 'restoration' efforts are needed when soil and vegetation conditions make use of inputs for 'sustainable intensification' ineffective (Figure 15).

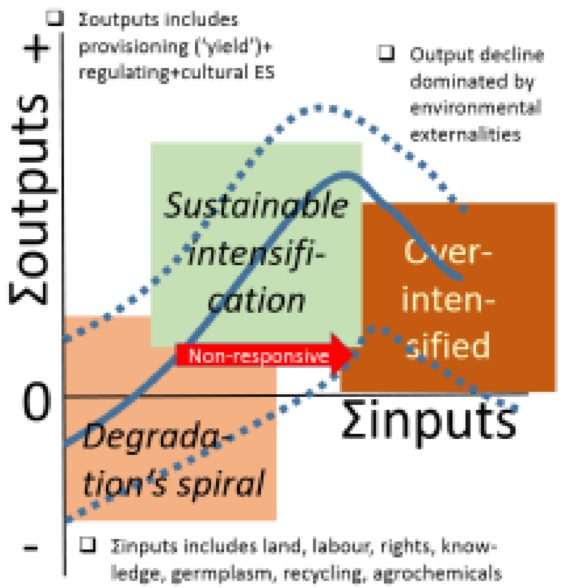


**Figure 15.** The restoration agenda on land that currently is a downwards degradation spiral and that requires special efforts to get back to a 'sustainable intensification' domain in which input use pays off by efficient plant production systems, avoiding overintensification

Location-specificity of adaptations needs to be understood in a restoration-conservation context [48]. Especially at the urban-rural interface restoration of multifunctionality of landscapes can be key to a hydrological function that can buffer increased rainfall variability and help in avoiding floods and drought. The 'flow persistence' metric [49] can serve as a performance metric, as it is directly linked to the way peak precipitation translates to peak flows (Figure 16).

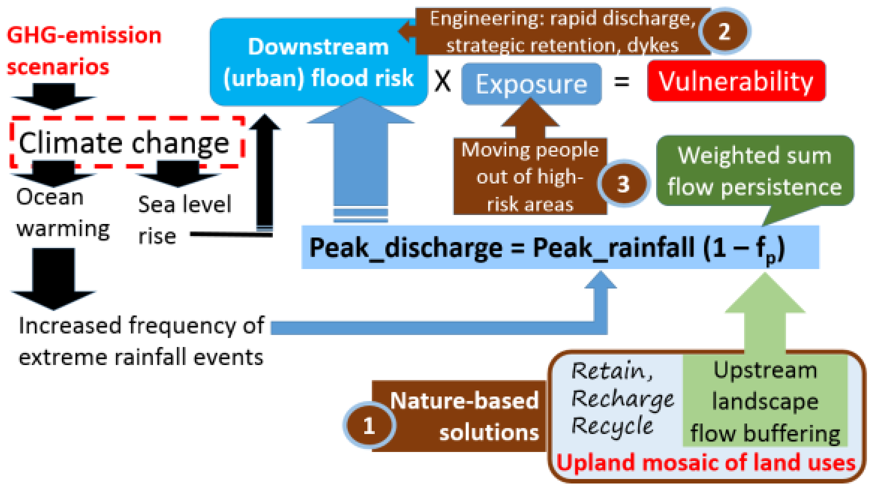


**Figure 16.** The logical relationship between climate change, land use change, engineering interventions and flood risk in urban areas as basis of human vulnerability ($f_p$ = flow persistence metric)

Bringing the sectoral institutions for Agriculture and Forestry together is more easily said than done [50]. A number of bottlenecks in the spheres of regulation, incentives and knowledge/motivation currently constrain 'Green growth' in Indonesia [51], requiring a comprehensive approach. Current 'community forestry' solutions in Indonesia don't yet achieve the stated 'fairness' targets [52]. Of the four knowledge-to-action chains of figure 1 the options for continued innovation, 'Sustainability' [53], are the most challenging, but ultimately most important aspect.

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