Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in Environmental Sustainability

SDG synergy between agriculture and forestry in the food, energy, water and income nexus: reinventing agroforestry?☆

Meine van Noordwijk[1,2], Lalisa A Duguma[1], Sonya Dewi[1], Beria Leimona[1], Delia C Catacutan[1], Betha Lusiana[1], Ingrid Öborn[1], Kurniatun Hairiah[3] and Peter A Minang[1]

Among the Sustainable Development Goals (SDGs) three broad groups coexist: first, articulating demand for further human resource appropriation, second, sustaining the resource base, and third, redistributing power and benefits. Agriculture and forestry jointly interact with all three. The SDG portfolio calls for integrated land use management. Technological alternatives shift the value of various types of land use (forests, trees and agricultural practices) as source of 'ecosystem services'. At the interface of agriculture and forestry the 40-year old term agroforestry has described technologies (AF1) and an approach to multifunctional landscape management (AF2). A broadened Land Equivalence Ratio (LER) as performance metric indicates efficiency. Agroforestry also is an opportunity to transcend barriers between agriculture and forestry as separate policy domains (AF3). Synergy between policy domains can progress from recognized tradeoffs and accepted coexistence, via common implementation frames, to space for shared innovation. Further institutional space for integral 'all-land-uses' approaches is needed.

Addresses
[1] World Agroforestry Centre (ICRAF), Kenya
[2] Plant Production Systems, Wageningen University and Research, Netherlands
[3] Brawijaya University, Malang, Indonesia

Corresponding author:
van Noordwijk, Meine (m.vannoordwijk@cgiar.org)

Current Opinion in Environmental Sustainability 2018, **34**:33–42

This review comes from a themed issue on **Sustainability science**

Edited by **Ken E Giller**, **Ira Martina Drupady**, **Lorenza B Fontana** & **Johan A Oldekop**

For a complete overview see the Issue

Available online 10th October 2018

Received: 05 February 2018; Accepted: 23 September 2018

https://doi.org/10.1016/j.cosust.2018.09.003

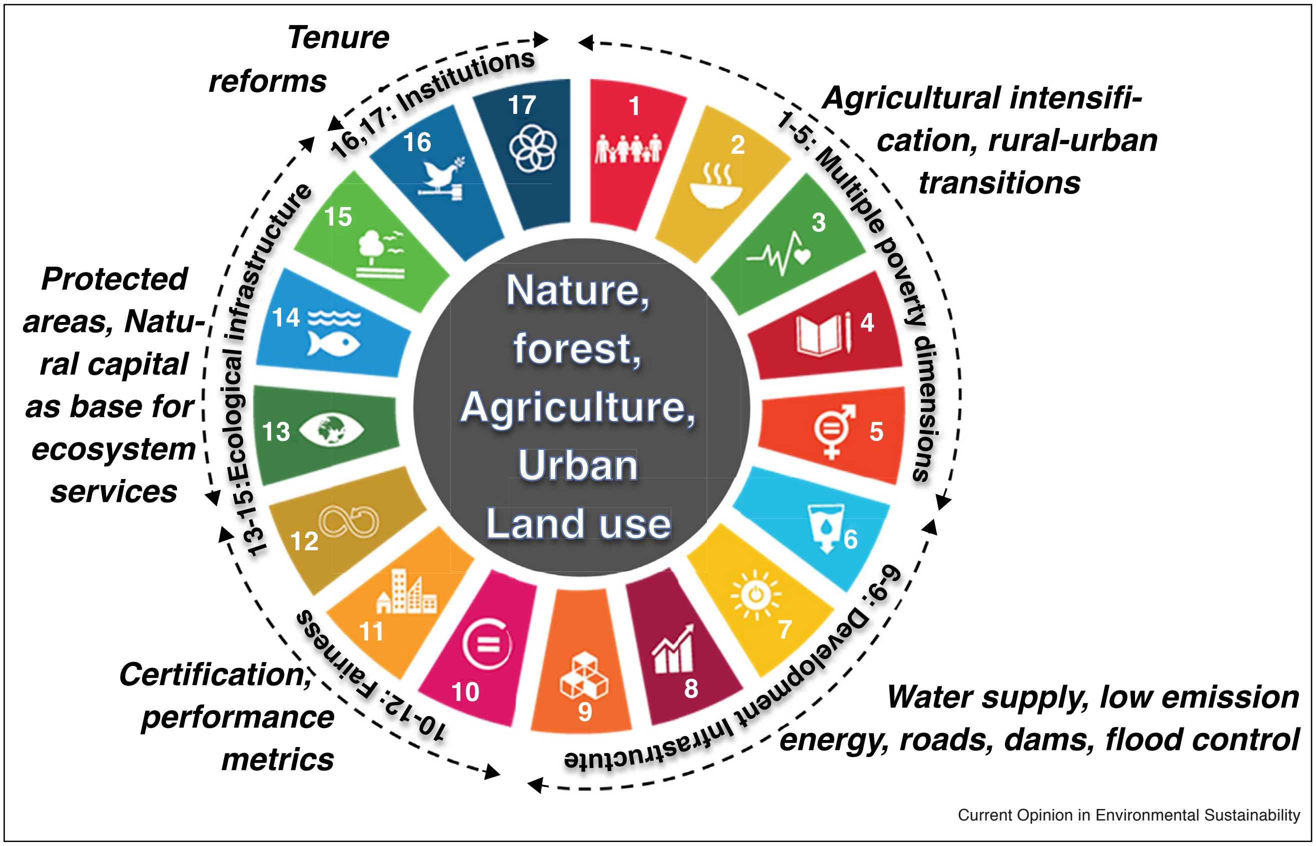
"The existence of large numbers of people in the fragile ecosystems of the developing world, and the fact that these ecosystems occupy the greater proportion of the land of the developing economies, suggest that means must be devised which will assist in increasing the productivity of these ecosystems while at the same time either rehabilitating them or arresting the process of degradation. Agroforestry is a system of land management which seems to be suitable for these ecologically brittle areas. It combines the protective characteristics of forestry with the productive attributes of both forestry and agriculture. It conserves and produces." (King) [1]

Introduction

The formulation of Millennium Development Goals, precursor to current Sustainable Development Goals (SDGs) brought the ending of poverty and the need for environmental sustainability on the same 'goal' level in high-level discourse [2]. It allowed multifunctional land uses, such as agroforestry, to gain wider support [3]. With the SDG agenda[4] of the United Nations, agreed upon by 193 countries in September 2015, the debate has shifted from 'willingness' to 'ability to act'. Because the human brain is challenged when a list contains more than 3–5 items, there have been many attempts to group the 17 SDGs [4,5]. One way (Figure 1) is to recognize five groups: first, SDG 1-5 deal with multiple dimensions of poverty (food, income, health, education, gender), second, SDG 6-9 with development infrastructure (water, energy), third, SDG 10-12 with the fairness-efficiency balance, fourth, SDG 13-15 with ecological infrastructure, and fifth, SDG 16 and 17 with institutions. A further grouping sees a group of goals that articulate increased demand for resources (including food, energy, water) [6], a group that tries to maintain the resource base and a group modifying access to resources, power and benefit distribution (including gender and youth-based distinctions beyond homogeneous household perspectives) [7]. Despite critique on the goals ('By attempting to cover all

☆ Celebrating 40 years since the establishment of the International Centre for Research in AgroForestry
[4] http://www.un.org/sustainabledevelopment/development-agenda/.

Figure 1



Land use can be seen as a key connecting issue for all 17 SDGs, with tradeoffs between increasing demand, shifting benefit distribution, and compromised supply of ecosystem services.

that is good and desirable in society, these targets have ended up as vague, weak, or meaningless') [8] and comments from the science community [9•] that were only very partially taken to heart, they are still the most legitimate attempt at global governance so far, deserving efforts to try and make it work [10].

Progress within each of these SDG groups probably requires efforts that are at least compatible with goals in the other groups (being neutral to or with modest tradeoffs), while providing the focus and clarity needed to address a specific target. Having 17 single-goal implementing policies is not efficient; the Tinbergen rule about the need for the number of policy instruments to match the number of goals [11•] can be softened where goals in practice (at least in a given local context) align. Central to all groups of SDGs is 'land use' as a meeting point for material and immaterial needs. Sustainable land use as target has been debated since long ago [12,13], but could still be the key to progress (Figure 1). It connects the need for further human appropriation of resources, the efficiency with which existing land is used for achieving agricultural and forest production of goods and services, and the rights and governance agenda of who decides, controls and benefits.

The debate on planetary boundaries [14,15] as next step beyond limits to growth [16] has connected current human resource appropriation to a 'carrying capacity' perspective on what the energy, water, nutrient, pollutant and further cycles can afford. Similar to earlier carrying capacity debates [17], the agility of humankind to adapt and modify technology can shift the hard limits proposed. There are, however limits to adaptation [5,18] and current progress may be hindered by a fall back to earlier 'denial' phases by important stakeholders in the debate. The planetary boundaries concept, just as the earlier limits to growth may be most useful if it is a self-unfulfilling prophecy that triggers a just-in-time human adaptive response. Smarter technologies, however, need to go hand in hand with efforts to contain current global environmental change by enhanced and sustained agility [19,20], once goals have been set.

The various SDGs have from their start and political platform in the discussion, been associated with existing sectoral perspectives. SDG2 for example is seen as the domain of 'agriculture' and SDG15 of 'forestry'. It seems logical to relate SDG2 on 'Zero hunger' primarily to agriculture. However, current understanding of the multiple dimensions of food security (adequacy of supply, economic and physical access by all, absence of factors restricting utilization, stability and sovereignty [21]), has opened up to wider perspectives [22]. The concept of 'outsourcing' of staple foods (but not of other elements of healthy diets) in tropical forest margins [23], has pointed at rural income security as basis of food security. A wide range of forest and tree crop products can be a basis for income and thus food security. In many countries, food insecurity and undernutrition are not the result of a lack of availability of food but are related to unequal distribution of resources and unequal access to healthy natural resources, productive inputs, credit, social protection and information. Lack of clean water (SDG6) or energy to cook (SDG7) link forests and trees to underachievement of SDG2. Efforts to achieve food security and nutrition thus require dealing with challenges in production, distribution, pricing and information, access to healthy land and water. However, it also deals with problems of insufficient health care and education, inadequate sanitary systems, or factors such as economic decline and climate change impacts on production and distribution [24]. Rural societies need to deal with all SDGs, rather than SDG2 alone, just as they deal with agriculture, forestry and everything in between.

Three agroforestry concepts

Agriculture and forestry have a long history as separate and often antagonistic sectors [25], but reality in the landscapes shows a much smoother continuum. In the four decades of its existence [1], agroforestry as a concept has been understood and defined by reference to various system scales of interest: plot-level practices [26], soils [27], development goals [28] or climate change [29]. Where earlier definitions of agroforestry (Figure 2) focused on the technology of plot-level integration of trees [30] (AF1), subsequent landscape interpretations have embraced a much larger share of the natural resource management and rights agenda [31,32] (AF2), leading to current perspectives on removing the conceptual and institutional barriers between agriculture and forestry (AF3) [33]. The relationship between the two has largely been analysed as competition for space in a zero-sum (land-sparing) game [34], but the existence of other 'planetary boundaries' than space as such, including the causation of climate change, may urge for a reanalysis [35,36] of the underlying discourses. The latter are shared, structured ways of speaking, thinking, interpreting, and representing things in the world [37], and represent one of the highest level 'leverage points' identified by systems analysis [38]: from parameter settings to the dynamic structure of feedback loops, their strengths and time-lags, to differential information access, goal setting, paradigms and self-organization. Publicly held paradigms and existing segregated institutions are key bottlenecks to SDG attainment.

The SDGs call for new alignments across sectors that don't have a history of smooth cooperation in many countries [39,40], including agriculture and forestry as part of natural resource management. The opportunities for a coherent SDG approach to 'all land uses' across the full spectrum of human use intensity and measurable tree cover, will be bounded by the degree of success in overcoming institutional divides. A seven-point scale has been proposed to describe interactions between goals [41•], ranging from 'Cancelling' (−3) through 'Neutral' (0) to 'Indivisible' (+3), which can be applied to agroforestry at the agriculture/forestry interface as a contribution to climate change adaptation with co-benefits for mitigation within SDG 13, while addressing food, energy and water issues of SDGs 2, 7, 6 along with human health (SDG3) and healthy terrestrial ecosystems (SDG15), while never losing economic progress (SDG1) out of sight. An earlier analysis described how the way adaptation and mitigation dimensions of the global climate change debate can move from competing silo's towards complementarity and further to synergy [42] and took stock of current practice in developing countries in this regards [43].

Following earlier agroforestry reviews of food security and climate change in Africa [44,45], water and climate change adaptation in Indonesia [46], nitrogen fixation as SDG friend or foe [47], and multifunctional agriculture [48•], the rest of this review focuses on the need for a comprehensive 'land use' SDG agenda, transcending existing sectoral views on agriculture and forestry. Four steps in such a process of enhancing synergy can be coupled to the four knowledge-to-action chains [5] that relate understanding of 'public concern' issues to willingness to act, ability to act and capacity to innovate:

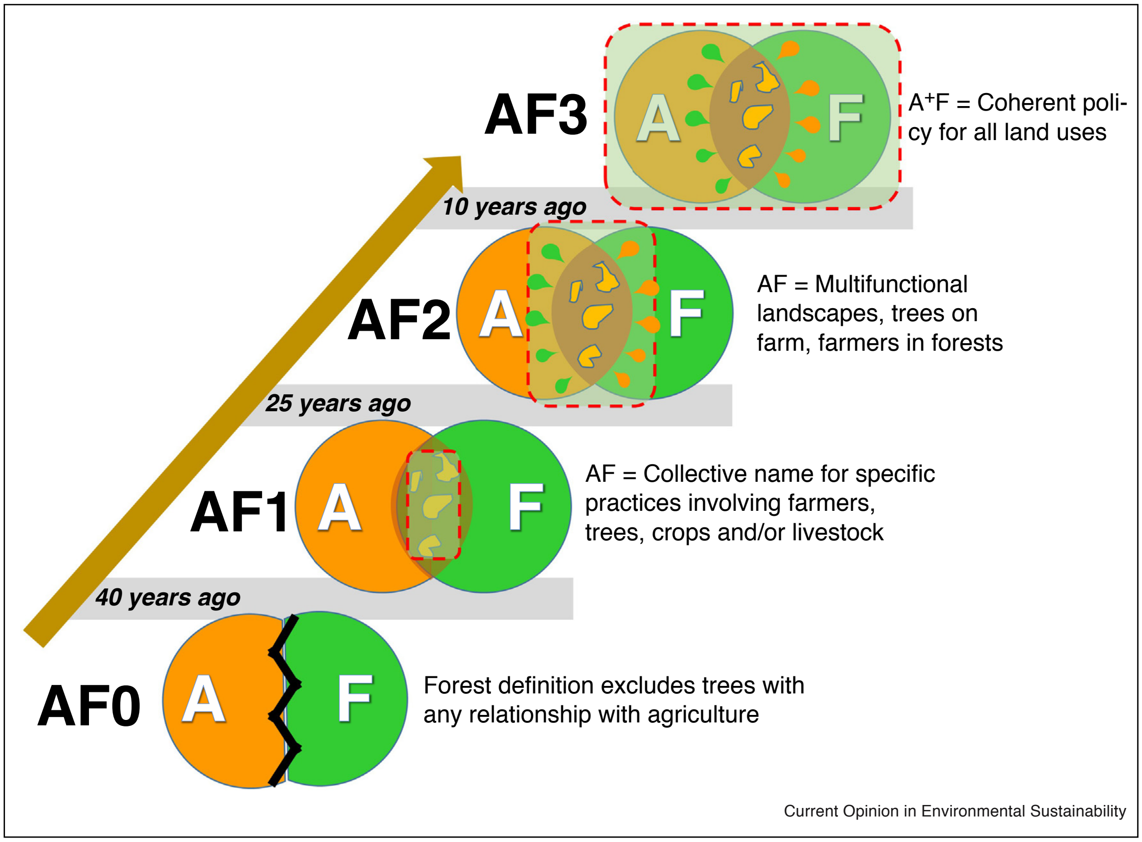
1 Science-based understanding of prioritized issues and their tradeoffs,
2 Willingness to act on ambitious goals,
3 Ability to act across goals with common programs, funding and institutions,
4 Shared monitoring, evaluation, support for innovation.

Progress in resolving issues of public concern can be constrained by any of these four chains [5].

Science-based understanding of prioritized issues and their tradeoffs

Increased demand for food and healthier diets, renewable energy and reliable clean water, as part of the SDG portfolio, all imply claims on land. Increased functionality

Figure 2



Venn diagrams of the evolving agroforestry (AF) concepts as relationship between agriculture (A) and forestry (F), which initially were perceived as having no interface (AF0); specific land use practices in the intersection formed the first agroforestry concept (AF1), followed by a multifunctional landscape perspective on the intersection (AF2) and the union ($A^{+}F3$) that can be the domain for policy and regulation [83].

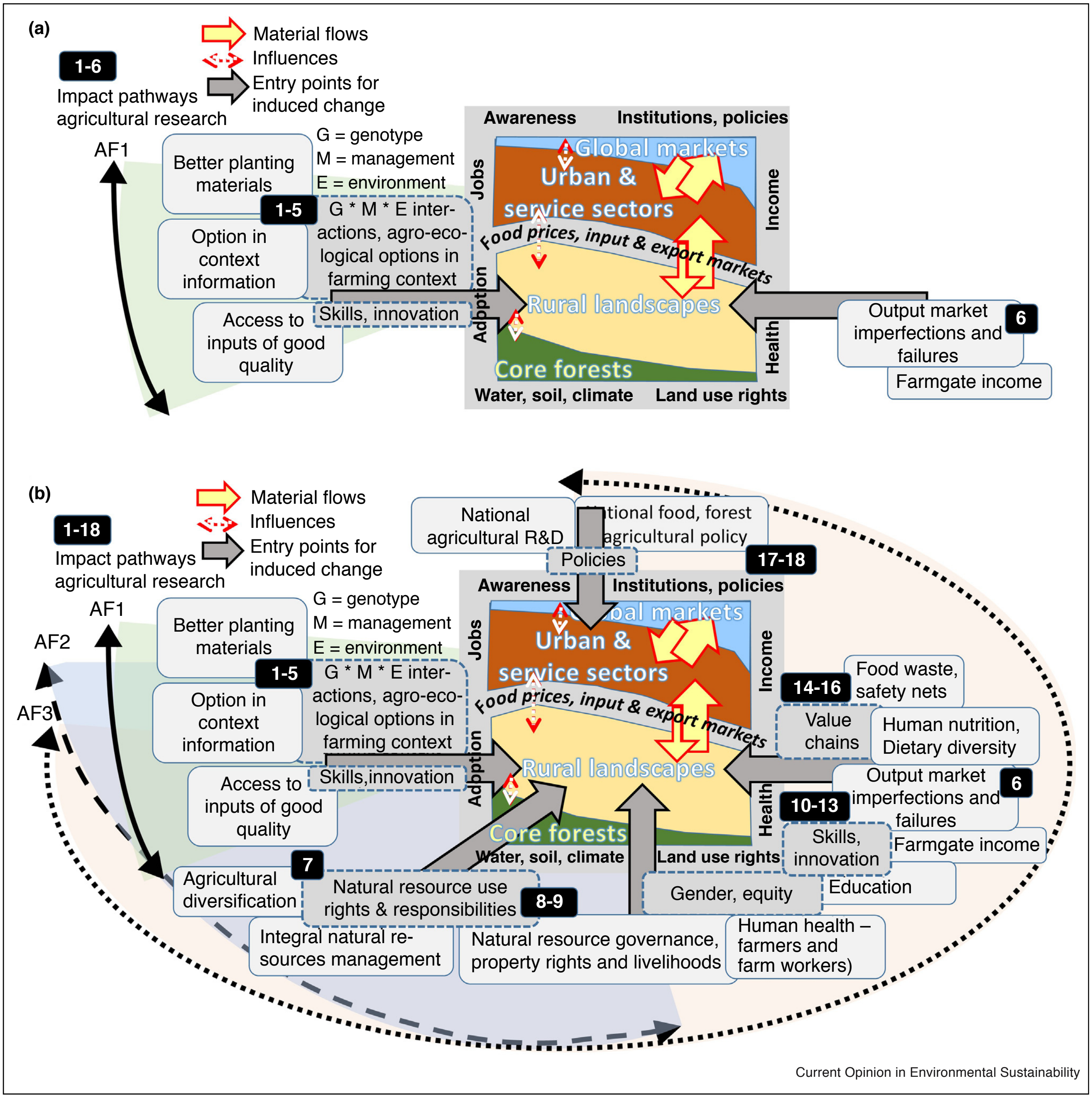
per unit land is needed to reconcile footprints and available space. Intensification (greater use of inputs and energy per unit land to obtain more output) has been the main strategy in agriculture and production forestry to reduce competition for land with other societal functions. In trying to close 'yield gaps', however, a common pathway to intensification has widened other 'efficiency gaps' [49]. In a major review of the diversity of impact pathways by which (international) agricultural research can increase rural prosperity [50•], 18 pathways were identified. The first five describe the traditional core area of such research in the Genotype × Environment × Management interactions of high-yielding germplasm and associated input markets (Figure 3a). The next eight broader issues of natural resource management, property rights, gender, skills and value chains, and the last five policies relating to health, safety nets, food waste and international trade (Figure 3b). The three interpretations of agroforestry of Figure 2 relate to the first five (AF1), the first nine (AF2) and the full set (AF3).

Current understanding of the complexity of the forest-rural and rural-urban interfaces of land use thus gives space for new discourses on how land use as an integral concept can be managed, in line with societal priorities. This is especially relevant in developing countries before and around their demographic and economic transition where more than half of the population and economy is urban. With current projections Africa is the only continent where rural populations are expected to still show absolute increases[5], elsewhere rural population densities are expected to be stable or on the decline [51]. This transition has consequences for an increasing space for forests, but tree densities in densely populated (peri-urban or suburban) subcatchments of the tropics, are higher than those for purely agricultural ones [52]. Evidence for a global increase in trees outside forest [53] can be seen in this light.

Recent debate [54,55] has focussed on the relevance of a diversity of conceptual frameworks [56], beyond what the Millennium Ecosystems Assessment [57] promoted, especially in connection with the 'payments' concept [58,59]. The new language promoted by the IPBES

[5] https://data.worldbank.org/indicator/SP.RUR.TOTL.ZG.

Figure 3

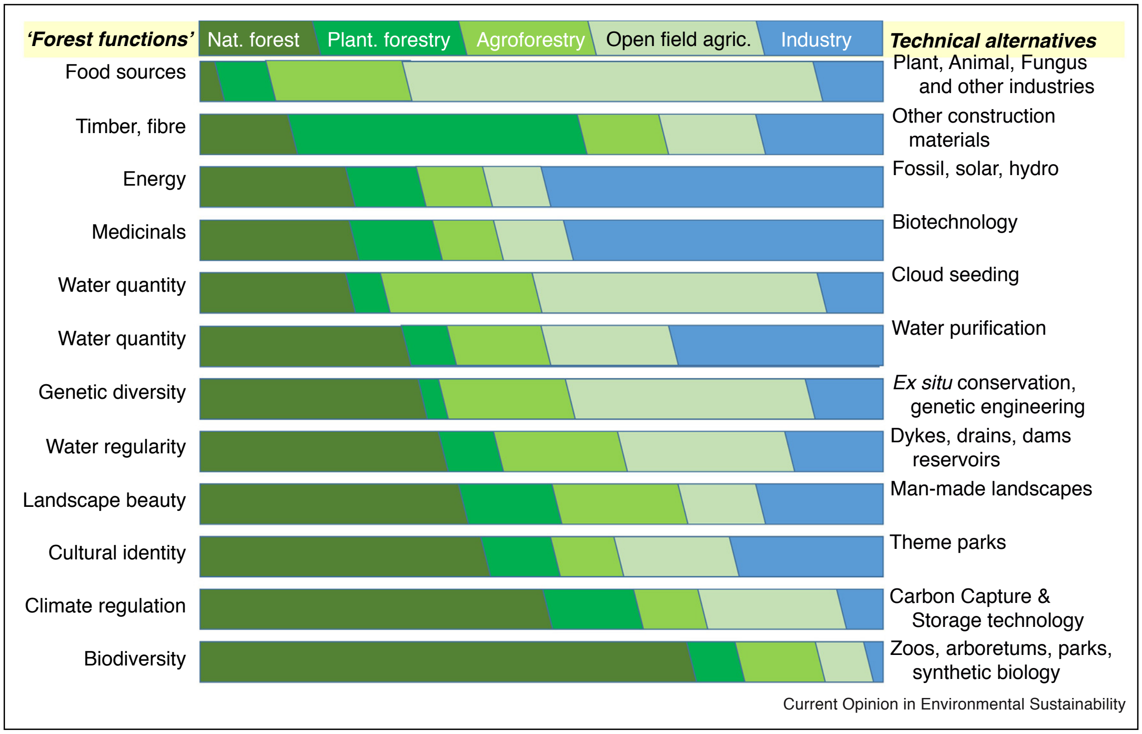


Systems perspective on aspects of agriculture, rural development and national economies, with multiple impact pathways for agricultural research; **(a)** Focused on the initial strength of international agricultural research; **(b)** With the current agenda [51]; three interpretations of agroforestry are indicated as AF1, AF2 and AF3 [33].

assessment [60] of 'nature's contributions to people' expresses the same degree of anthropocentricity as the 'ecosystem services' it tries to replace, assuming a 'free and prior informed consent' on the other side of human resource appropriation[6]. While the terminology debate may have relevance for part of the audience, a more empirical approach may see that many of the functions, services or contributions of 'wild' nature are taken over by more 'domesticated' land uses and/or non-land-based technology (Figure 4). A further quantification of these relations will undoubtedly lead to a refinement of the options and context-specificity of the various substitution

[6] http://science.sciencemag.org/content/359/6373/270/tab-e-lettersss.

Figure 4



Conceptualization of the degree to which a range of 'forest functions' are provided by natural forests, plantation forestry, agroforestry, open-field agriculture or industry, with an indication of the technical alternatives that can substitute for 'contributions from nature' to match human needs.

processes, but a first mental step is to see land uses as a continuum open to empirical exploration, rather than as forest-agriculture dichotomy.

The continuum can be described by a single metric: the degree to which land use in its current form achieves the goals set, relative to other ways of achieving these. The Land Equivalent Ratio (LER) concept, so far focussed on productivity, can be expanded to do so. The conventional LER concept (Eq. (1)) that is central to AF1, can for AF2 be expanded to a multi-functionality land equivalent ratio (LERM, Eq. (2)).

$$LER = \sum_i P_i / P_{i,ref} \quad (1)$$

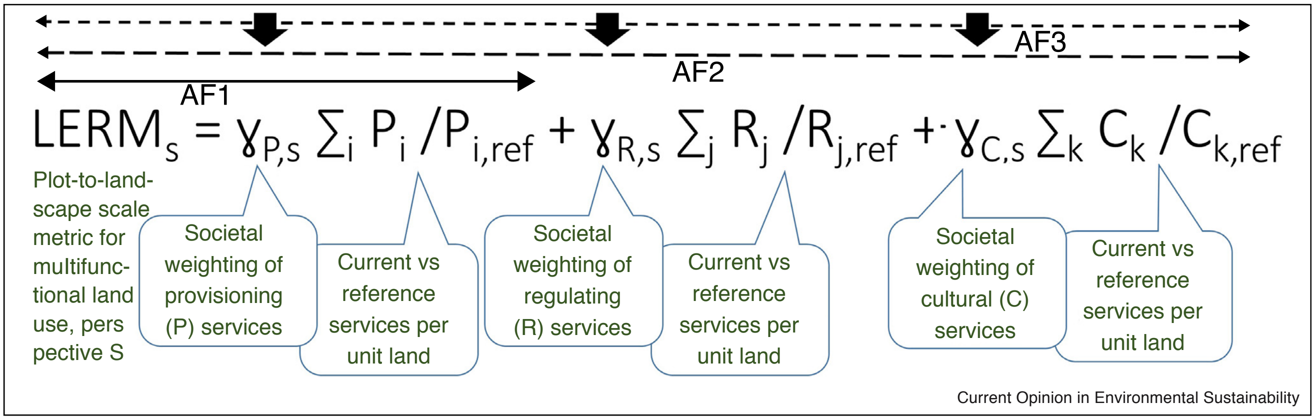
$$LERM = \gamma_{P,S} \sum_i P_i/P_{i,ref} + \gamma_{R,S} \sum_j R_j/R_{j,ref} + \gamma_{C,S} \sum_k C_k/C_{k,ref} \quad (2)$$

Where P_i, R_j and C_k represent the attainment (in any metric of choice, per unit area) of a range of provisioning (P), regulating (R) and Cultural (C) services provided by a landscape, $P_{i,ref}$, $R_{j,ref}$ and $C_{k,ref}$ the attainment (in the same metric) of such services in a landscape optimized for that specific service (often a 'monoculture') and $\gamma_{P,S}$, $\gamma_{R,S}$ and $\gamma_{C,S}$ the weighting functions for the importance of the three groups of ecosystem services from perspective S. Full representation of all weighting factors γ_S may in fact represent the AF3 concept (Figure 5). A comprehensive analysis of properties of alternative cropping systems was recently completed for cacao [61], quantifying various tradeoffs.

Willingness to act on ambitious goals

Research on land use, especially that on tropical forest margins, has quantified tradeoffs between production (local income) and conservation (global wellbeing) goals [62–64] and clarified the need for policy instruments to align land use choices across scales by internalizing externalities. Although the SDGs do not provide a hierarchy among the 17 goals, domestic policy platforms for the various goals have not (yet) converged as much as the international agreements suggest. Within countries and governments a strong preference for 'development' over 'sustainability' dimensions can still be observed. The same may be true where international organizations, and parts thereof, that have so far focussed on single goals, now face new challenges to achieve a higher level of coordination and integration [65,66]. Although accepted as goal by all countries, the effective integration of the gender agenda on land use and natural resource management remains a challenge [67,68]. Complementarity between international, national and local policies needs to be met in raising the 'ability to act'.

Figure 5



Land Equivalent Ratio for Multifunctionality (LERM) as landscape (AF2) extension of the plot-level (AF1) productivity LER; if $LERM_s > 1$ the mixed system, from perspective s and its weighting parameters ɣ, spares land relative to a segregated mosaic of monofunctional reference land uses.

Ability to act across goals with common programs, funding and institutions

The historical institutional divides between 'mitigation' and adaptation', as well as between 'forestry' and 'agriculture' remain a barrier for effective SDG attainment, as project proposals have to target one of the two as goal, as basis for eligibility for international or national funding [69]. An analysis of 201 project design documents from adaptation funds, mitigation instruments, and project standards found that 37% of the documents explicitly mentioned a contribution to the other objective [70], though often as unsubstantiated co-benefit. The drive to integrate climate change mitigation and adaptation includes urban areas [71], 'climate smart' landscapes [72].

Despite challenges in its operationalization, an integrated landscape approach [73–75] still appears to be the best way of coherently targeting the Sustainable Development Goals (SDGs) through new forms of collaboration between stakeholders (which can include scientists) based on long-term commitments [76]. It requires a perspective on land use that integrates beyond what has currently been mainstreamed in 'green economy' policies, both at the national and subnational level. Local governance systems, linked with existing jurisdictions, have to reconcile compliance with national rules, especially where forests are concerned, and local interests that more directly align with agriculture. Beyond land use planning, clear performance metrics for landscape functions and systems for monitoring and evaluation of achievements are essential to a culture of innovation.

Shared monitoring, evaluation, innovation

Once institutional constraints to synergy have been addressed, innovation and co-learning can take place. Non-state actors have played essential roles in moving forward debates where national governments are entrenched, such as in the debate on oil palm [77,78].

Multi-sectoral platforms are processes which often become institutionalized bodies drawing together multiple stakeholder representatives from different sectors to make decisions. They are convened to harness the benefits of collaboration in tackling planning problems that span more than one sectoral jurisdiction and therefore require a co-ordinated response in policy formulation and implementation. Examples include platforms to address planning issues around climate change, food security, biodiversity conservation, timber legality and so on—many of which have nested processes from international level right down to local level. A key question, however, is whether 'certification' can avoid prescribing 'solutions' and create space for goal-oriented innovation [79]. With the history of forests as part of the landscape that were to be protected from local, innovative resource use, it is particularly challenging to frame space for further agroforestry innovation in its polycentric governance context, avoiding the temptation to overdefine and overregulate at the highest level. Jurisdictional certification might address the above problems. The approach taken by the Common Agricultural Policy of the European Union [80•], leaving specifics on what agroforestry is or can be to be further defined at country level is a step in the right direction. Similarly, the Indian agroforestry policy focussed on removing institutional hurdles between agriculture and forestry, rather than on creating agroforestry as a segregated policy domain [81].

Discussion

From our review of science-based understanding (chain 1) we found strong support for a 'continuum' understanding of 'land use, rather than a dichotomy of forests and agriculture as sectors. Tradeoffs between functions are important for the SDG portfolio as a whole; the multifunctionality version of the Land Equivalent Ratio can guide a search for synergy and complementarity. Where willingness to act on ambitious goals (chain 2) is secured for the SDG portfolio at a high level, the ability to act across goals (chain 3) with common programs, funding and institutions is in many cases still a bottleneck. Shared monitoring, evaluation and support for innovation (chain 4) will be essential to allow the synergy options to become reality. The innovation and boundary work literature [65,82] suggests concrete steps to move to a higher level of integration:

1 **Resources**: It is important that there is an allocation of financial and human resources to encourage the integration of forestry and agriculture, potentially to reemerge as 'agroforestry' (AF3). Donors could also give integration more space in their resources allocation processes and calls for proposals.
2 **Time**: Policy formulation and implementation issues are often slow processes which require deliberation at multiple scales in the form of consultation and learning. The growing quest for evidence in the policy spaces will require clarity on what difference integration can bring to the wider goal of achieving the SDGs in an effective and efficient way.
3 **Institutional space**: creating a space or a unit within the existing frameworks without complicating the management hierarchy can promote efforts to integration.
4 **Performance indicators**: existing key indicators across the SDG spectrum will be the direct test of integrated land use perspectives, but only if institutional agendas can be contained.
5 **Integrating scenarios** in local development planning for SDGs need to build on existing land use systems, regardless of their current 'agriculture' or 'forestry' labels. At national and global levels bottom-up and top-down models need to be reconciled in view of planetary boundaries and limits to adaptation.

In conclusion, the SDG portfolio can indeed trigger a major step towards more holistic land use perspectives at the agriculture-forestry interface and can, if used well, trigger institutional change to enhance dynamic sustainability.

Acknowledgements

The underlying research was carried out as part of the Forests, Trees and Agroforestry (FTA) research program of the CGIAR. We appreciate the critical reviews and helpful suggestions an earlier draft received.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest

1. King KFS: *Concepts of Agroforestry*. Nairobi, Kenya: International Council for Research in Agroforestry; 1978 http://www.worldagroforestry.org/downloads/Publications/PDFS/01_Concepts_of_agroforestryv1.pdf.

2. Garrity DP: **Agroforestry and the achievement of the Millennium Development Goals**. *New Vistas in Agroforestry*. Netherlands: Springer; 2004, 5-17.

3. Vandermeer J, van Noordwijk M, Anderson J, Ong CK, Perfecto I: **Global change and multi-species agroecosystems: concepts and issues**. *Agric Ecosyst Environ* 1998, **67**:1-22.

4. Reyers B, Stafford-Smith M, Erb KH, Scholes RJ, Selomane O: **Essential variables help to focus sustainable development goals monitoring**. *Curr Opin Environ Sustain* 2017, **26**:97-105.

5. Nilsson M, Griggs D, Visbeck M: **Map the interactions between sustainable development goals**. *Nature* 2016, **534**:320-323.

6. Jägermeyr J, Pastor A, Biemans H, Gerten D: **Reconciling irrigated food production with environmental flows for Sustainable Development Goals implementation**. *Nat Commun* 2017, **8**:15900.

7. Hajer M, Nilsson M, Raworth K, Bakker P, Berkhout F, de Boer Y, Rockström J, Ludwig K, Kok M: **Beyond cockpit-ism: four insights to enhance the transformative potential of the sustainable development goals**. *Sustainability* 2015, **7**:1651-1660.

8. Holden E, Linnerud K, Banister D: **The imperatives of sustainable development**. *Sustain Dev* 2017, **25**:213-226.

9. • ICSU, ISSC Review of the Sustainable Development Goals: *The Science Perspective*. Paris: International Council for Science (ICSU); 2015.

A thorough analysis of the proposed targets for each of the 17 SDGs, that had limited effect on the final text agreed on by government leaders.

10. Deacon B: **Assessing the SDGs from the point of view of global social governance**. *J Int Comp Soc Policy* 2016, **32**:116-130.

11. • van Noordwijk M: **Integrated natural resource management as a pathway to poverty reduction: innovating practices, institutions and policies**. *Agric Syst* 2017 https://doi.org/10.1016.j.agsy.2017.10.008e.

Framing four knowledge-to-action chains as jointly determining progress along issue cycles, from understanding to effective solutions.

12. Barr N, Cary J: *Greening a Brown Land: The Australian Search for Sustainable Land Use*. MacMillan Education Australia Pty Ltd.; 1992.

13. DeFries R, Rosenzweig RC: **Toward a whole-landscape approach for sustainable land use in the tropics**. *Proc Natl Acad Sci U S A* 2010, **107**:19627-19632.

14. Rockström J, Steffen W, Noone K, Persson Å, Chapin FS III, Lambin E, Lenton TM, Scheffer M, Folke C, Schellnhuber HJ *et al.*: **Planetary boundaries: exploring the safe operating space for humanity**. *Ecol Soc* 2009, **14**.

15. Rockström J, Falkenmark M, Allan T, Folke C, Gordon L, Jägerskog A, Kummu M, Lannerstad M *et al.*: **The unfolding water drama in the Anthropocene: towards a resilience-based perspective on water for global sustainability**. *Ecohydrology* 2014, **7**:1249-1261.

16. Meadows DH, Meadows DL, Randers J: *Limits to Growth*. New York: Universe Books; 1972.

17. Rees WE: **Revisiting carrying capacity: area-based indicators of sustainability**. *Popul Environ* 1996, **17**:195-215.

18. Dow K, Berkhout F, Preston BL, Klein RJ, Midgley G, Shaw MR: **Limits to adaptation**. *Nat Clim Change* 2013, **3**:305-307.

19. Verchot LV, van Noordwijk M, Kandji S, Tomich TP, Ong CK, Albrecht A, Mackensen J, Bantilan C, Anupama KV, Palm CA: **Climate change: linking adaptation and mitigation through agroforestry**. *Mitig Adapt Strateg Glob Change* 2007, **12**:901-918.

20. Jackson L, van Noordwijk M, Bengtsson J, Foster W, Lipper L, Pulleman M, Said M, Snaddon J, Vodouhe R: **Biodiversity and agricultural sustainagility: from assessment to adaptive management**. *Curr Opin Environ Sustain* 2010, **2**:80-87.

21. Altieri MA, Funes-Monzote FR, Petersen P: **Agroecologically efficient agricultural systems for smallholder farmers: contributions to food sovereignty**. *Agron Sustain Dev* 2012, **32**:1-13.

22. Jemal O, Callo-Concha D, van Noordwijk M: **Local agroforestry practices for food and nutrition security of smallholder farm households in Southwestern Ethiopia**. *Sustainability* 2018, **10**:2722.

23. van Noordwijk M, Bizard V, Wangpakapattanawong P, Tata HL, Villamor GB, Leimona B: **Tree cover transitions and food security in Southeast Asia**. *Glob Food Secur* 2014, **3**:200-208.

24. FAO, WFP, IFAD: *The State of Food Insecurity in the World*. Rome: FAO; 2012.

25. Williams M: *Deforesting the Earth: from Prehistory to Global Crisis*. Chicago (USA): University of Chicago Press; 2003.

26. Nair PKR: **Directions in tropical agroforestry research: past, present, and future**. *Agrofor Syst* 1998, **38**:223-245.

27. Sanchez PA: **Science in agroforestry**. *Agrofor Syst* 1995, **30**:5-55.

28. Garrity DP: **Agroforestry and the achievement of the Millennium Development Goals**. *Agrof Syst* 2004, **61**:5-17.

29. van Noordwijk M, Hoang MH, Neufeldt H, Öborn I, Yatich T: *How Trees and People Can Co-Adapt to Climate Change: Reducing Vulnerability Through Multifunctional Agroforestry Landscapes*. Nairobi, Kenya: World Agroforestry Centre (ICRAF); 2011.

30. Coe R, Sinclair F, Barrios E: **Scaling up agroforestry requires research 'in' rather than 'for' development**. *Curr Opin Environ Sustain* 2014, **6**:73-77.

31. Minang PA, van Noordwijk M, Freeman OE, Mbow C, de Leeuw J, Catacutan D (Eds): *Climate-Smart Landscapes: Multifunctionality In Practice*. Nairobi, Kenya: World Agroforestry Centre (ICRAF); 2015. 404 pp.

32. Freeman OE, Duguma LA, Minang PA: **Operationalizing the integrated landscape approach in practice**. *Ecol Soc* 2015, **20**:24.

33. Catacutan DC, van Noordwijk M, Nguyen TH, Öborn I, Mercado AR: *Agroforestry: Contribution to Food Security and Climate-Change Adaptation and Mitigation in Southeast Asia*. Bogor, Indonesia: World Agroforestry Centre (ICRAF); 2017.

34. Mertz O, Mertens CF: **Land sparing and land sharing policies in developing countries–drivers and linkages to scientific debates**. *World Dev* 2017, **98**:523-535.

35. Liu J, Dou Y, Batistella M, Challies E, Connor T, Friis C, Millington JD, Parish E, Romulo CL, Silva RFB, Triezenberg H: **Spillover systems in a telecoupled Anthropocene: typology, methods, and governance for global sustainability**. *Curr Opin Environ Sustain* 2018, **33**:58-69.

36. Luskin MS, Lee JS, Edwards DP, Gibson L, Potts MD: **Study context shapes recommendations of land-sparing and sharing; a quantitative review**. *Glob Food Secur* 2017 http://dx.doi.org/10.1016/j.gfs.2017.08.002.

37. Dryzek JS: *The Politics of the Earth: Environmental Discourses*. Oxford, UK: Oxford University Press; 2013.

38. Meadows D: **Leverage points: places to intervene in a system**. *Solut Sustain Desirable Fut* 1999, **1**:41-49.

39. Griggs D, Stafford-Smith M, Gaffney O, Rockström J, Öhman MC, Shyamsundar P, Steffen W, Glaser G, Kanie N, Noble I: **Sustainable development goals for people and planet**. *Nature* 2013, **495**:305-307.

40. Stafford-Smith M, Griggs D, Gaffney O, Ullah F, Reyers B, Kanie N, Stigson B, Shrivastava P, Leach M, O'Connell D: **Integration: the key to implementing the Sustainable Development Goals**. *Sustain Sci* 2017, **12**:911-919.

41. • Nilsson M, Griggs D, Visbeck M, Ringler C: *A Draft Framework for Understanding SDG Interactions*. Paris: International Council for Science (ICSU); 2016 https://www.icsu.org/cms/2017/05/SDG-interactions-working-paper.pdf.

Introduced a seven-point scale for interactions between SDGs: cancelling, counteracting, constraining, consistent, enabling, reinforcing, indivisible.

42. Duguma LA, Minang PA, van Noordwijk M: **Climate change mitigation and adaptation in the land use sector: from complementarity to synergy**. *Environ Manage* 2014, **54**:420-432.

43. Duguma LA, Wambugu SW, Minang PA, van Noordwijk M: **A systematic analysis of enabling conditions for synergy between climate change mitigation and adaptation measures in developing countries**. *Environ Sci Policy* 2014, **42**:138-148.

44. Mbow C, van Noordwijk M, Luedeling E, Neufeldt H, Minang PA, Kowero G: **Agroforestry solutions to address food security and climate change challenges in Africa**. *Curr Opin Environ Sustain* 2014, **6**:61-67.

45. Mbow C, van Noordwijk M, Prabhu R, Simons AJ: **Knowledge gaps and research needs concerning agroforestry's contribution to sustainable development goals in Africa**. *Curr Opin Environ Sustain* 2014, **6**:162-170.

46. van Noordwijk M, Kim YS, Leimona B, Hairiah K, Fisher LA: **Metrics of water security, adaptive capacity, and agroforestry in Indonesia**. *Curr Opin Environ Sustain* 2016, **21**:1-8.

47. Rosenstock TS, Tully KL, Arias-Navarro C, Neufeldt H, Butterbach-Bahl K, Verchot LV: **Agroforestry with N2-fixing trees: sustainable development's friend or foe?** *Curr Opin Environ Sustain* 2014, **6**:15-21.

48. • Leakey R: **A strong plea for a more functional integration of trees into agriculture.**. *Multifunctional Agriculture: Achieving Sustainable Development in Africa*. Academic Press; 2017.

49. van Noordwijk M, Brussaard L: **Minimizing the ecological footprint of food: closing yield and efficiency gaps simultaneously?** *Curr Opin Environ Sustain* 2014, **8**:62-70.

50. • Tomich TP, Lidder P, Coley M, Gollin D, Meinzen-Dick R, Webb P, Carberry P: **Food and agricultural innovation pathways for prosperity**. *Agric Syst* 2018 http://dx.doi.org/10.1016/j.agsy.2018.01.002.

Introduces and compares a set of 18 impact pathways by which international agricultural research can contribute to poverty reduction.

51. Thomas AR, Fulkerson GM: **Urbanormativity and the spatial demography of suburbia: a response to Meyer and Graybill**. *Urban Geogr* 2017, **38**:164-169.

52. Dewi S, van Noordwijk M, Zulkarnain MT, Dwiputra A, Prabhu R *et al.*: **Tropical forest-transition landscapes: a portfolio for studying people, tree crops and agro-ecological change in context**. *Int J Biodiv Sci Ecosyst Serv Manage* 2017, **13**:312-329.

53. Zomer RJ, Neufeldt H, Xu J, Ahrends A, Bossio D, Trabucco A, van Noordwijk M, Wang M: **Global tree cover and biomass carbon on agricultural land: the contribution of agroforestry to global and national carbon budgets**. *Sci Rep* 2016, **6**:29987.

54. Berbe's-Bla'zquez M, Gonza'lez JA, Pascual U: **Towards an ecosystem services approach that addresses social power relations**. *Curr Opin Environ Sustain* 2016, **19**:134-143.

55. Díaz S, Pascual U, Stenseke M, Martín-López B, Watson RT, Molnár Z, Hill R, Chan KM, Baste IA, Brauman KA, Polasky S: **Assessing nature's contributions to people**. *Science* 2018, **359**:270-272.

56. Tomich TP, Argumedo A, Baste I, Camac E, Filer C, Garcia K, Garbach K, Geist HJ, Izac AMN, Lebel L *et al.*: **Conceptual frameworks for ecosystem assessment: their development, ownership, and use**. In *Ecosystems and Human Well-Being—A Manual for Assessment Practitioners.* Edited by Ash N, Blanco H, Brown C, Garcia K, Henrichs T, Lucas N, Raudsepp-Hearne C, Simpson RD, Scholes R, Tomich TP, Vira B, Zurek M. Washington, DC: Island Press; 2010:71-114.

57. Millennium Ecosystem Assessment: *Ecosystems And Human Well-Being: General Synthesis*. Washington, DC: Island Press; 2005.

58. Muradian R, Corbera E, Pascual U, Kosoy N, May PH: **Reconciling theory and practice: an alternative conceptual framework for understanding payments for environmental services**. *Ecol Econ* 2010, **69**:1202-1208.

59. van Noordwijk M, Leimona B, Jindal R, Villamor GB, Vardhan M, Namirembe S, Catacutan D, Kerr J, Minang PA, Tomich TP:

Payments for environmental services: evolution towards efficient and fair incentives for multifunctional landscapes. *Annu Rev Environ Resour* 2012, **37**:389-420.

60. Pascual U, Balvanera P, Díaz S, Pataki G, Roth E, Stenseke M, Maris V: **Valuing nature's contributions to people: the IPBES approach**. *Curr Opin Environ Sustain* 2017, **26**:7-16.

61. Blaser WJ, Oppong J, Hart SP, Landolt J, Yeboah E, Six J: **Climate-smart sustainable agriculture in low-to-intermediate shade agroforests**. *Nat Sustain* 2018 https://www.nature.com/articles/s41893-018-0062-8.

62. Tomich TP, van Noordwijk M, Vosti SA, Witcover J: **Agricultural development with rainforest conservation: methods for seeking best bet alternatives to slash-and-burn, with applications to Brazil and Indonesia**. *Agric Econ* 1998, **19**:159-174.

63. van Noordwijk M, Tomich TP, Verbist B: **Negotiation support models for integrated natural resource management in tropical forest margins**. *Conserv Ecol* 2001, **5**:21.

64. Clark WC, Tomich TP, van Noordwijk M, Guston D, Catacutan D, Dickson NM, McNie E: **Boundary work for sustainable development: natural resource management at the Consultative Group on International Agricultural Research (CGIAR)**. *Proc Natl Acad Sci U S A* 2016, **113**:4615-4622.

65. Macqueen D, Zapata J, Campbell J, Baral S, Camara K, Chavez L, Grouwels S, Kafeero F, Kamara E, Rametsteiner E, Rodas O: *Multi-Sectoral Platforms For Planning And Implementation-How They Might Better Serve Forest And Farm Producers. FFF Working Paper 2*. Rome, Italy: FAO; 2014.

66. Neely C, Bourne M, Chesterman S, Kouplevatskaya-Buttoud I, Bojic D, Vallée D: *Implementing 2030 Agenda for Food and Agriculture: Accelerating Impact through Cross-Sectoral Coordination at the Country Level*. Rome: FAO; 2017.

67. Villamor GB, van Noordwijk M, Djanibekov U, Chiong-Javier ME, Catacutan D: **Gender differences in land-use decisions: shaping multi-functional landscapes?** *Curr Opin Environ Sustain* 2014, **6**:128-133.

68. Meinzen-Dick R, Quisumbing A, Doss C, Theis S: **Women's land rights as a pathway to poverty reduction: framework and review of available evidence**. *Agric Syst* 2017.

69. Carter S, Arts B, Giller KE, Soto Golcher C, Kok K, de Koning J, van Noordwijk M, Reidsma P, Rufino MC, Salvini G *et al.*: **Climate-smart land use requires local solutions, transdisciplinary research, policy coherence and transparency**. *Carbon Manage* 2018 http://dx.doi.org/10.1080/17583004.2018.1457907.

70. Kongsager R, Locatelli B, Chazarin F: **Addressing climate change mitigation and adaptation together: a global assessment of agriculture and forestry projects**. *Environ Manage* 2016, **57**:271-282.

71. Solecki W, Seto KC, Balk D, Bigio A, Boone CG, Creutzig F, Fragkias M, Lwasa S, Marcotullio P, Romero-Lankao P, Zwickel T: **A conceptual framework for an urban areas typology to integrate climate change mitigation and adaptation**. *Urban Clim* 2015, **14**:116-137.

72. Wambugu SW, Chomba SW, Atela J: **Institutional arrangements for climate-smart landscapes**. *Climate-Smart Landscapes: Multifunctionality in Practice*. Nairobi, Kenya: World Agroforestry Centre (ICRAF); 2015, 257-274.

73. Sayer JA, Margules C, Boedhihartono AK, Sunderland TCH, Langston JD, Reed J, Riggs R, Buck LE, Campbell BM, Kusters K *et al.*: **Measuring the effectiveness of landscape approaches to conservation and development**. *Sustain Sci* 2017, **12**:465-476.

74. Kusters K, Buck L, de Graaf M, Minang PA, van Oosten C, Zagt R: **Participatory planning, monitoring and evaluation of multi-stakeholder platforms in integrated landscape initiatives**. *Environ Manage* 2017 http://dx.doi.org/10.1007/s00267-017-0847.

75. Reed J, van Vianen J, Deakin EL, Barlow J, Sunderland TCH: **Integrated landscape approaches to managing social and environmental issues in the tropics: learning from the past to guide the future**. *Glob Change Biol* 2016, **22**:2540-2554.

76. Bürgi M, Ali P, Chowdhury A, Heinimann A, Hett C, Kienast F, Mondal MK, Upreti BR, Verburg PH: **Integrated landscape approach: closing the gap between theory and application**. *Sustainability* 2017, **9**:1371.

77. van Noordwijk M, Pacheco P, Slingerland M, Dewi S, Khasanah SN: *Palm oil expansion in tropical forest margins or sustainability of production? Focal issues of regulations and private standards. Working paper 274*. Bogor, Indonesia: World Agroforestry Centre (ICRAF); 2017 http://dx.doi.org/10.5716/WP17366.PDF.

78. Hidayat NK, Offermans A, Glasbergen P: **Sustainable palm oil as a public responsibility? On the governance capacity of Indonesian standard for sustainable palm oil (ISPO)**. *Agric Hum Values* 2017 http://dx.doi.org/10.1007/s10460-017-9816-6.

79. Mithöfer D, van Noordwijk M, Leimona B, Cerutti PO: **Certify and shift blame, or resolve issues? Environmentally and socially responsible global trade and production of timber and tree crops**. *Int J Biodiv Sci Ecosyst Serv Manage* 2017, **13**:72-85.

80. • Mosquera-Losada MR, Santiago-Freijanes JJ, Pisanelli A, Rois-Díaz M, Smith J, den Herder M, Moreno G, Ferreiro-Domínguez N, Malignier N, Lamersdorf N, Balaguer F: **Agroforestry in the European common agricultural policy**. *Agrofor Syst* 2018, **92**:1117-1127.
Describes the emergence of 'agroforestry' as a valid land use category within European policy frameworks opening up for further innovation.

81. Singh VP, Sinha RB, Nayak D, Neufeldt H, van Noordwijk M, Rizvi J: *The National Agroforestry Policy of India: Experiential Learning In Development And Delivery Phases. Working Paper 240*. New Delhi, India: World Agroforestry Centre (ICRAF); 2016.

82. Zietsma C, Lawrence TB: **Institutional work in the transformation of an organizational field: the interplay of boundary work and practice work**. *Adm Sci Q* 2010, **55**:189-221.

83. van Noordwijk M, Coe R, Sinclair F: *Central Hypotheses for the Third Agroforestry Paradigm Within a Common Definition. ICRAF Working Paper 233*. Nairobi, Kenya: World Agroforestry Centre; 2016.