Domesticated elephant on the road in India: cultural service, income opportunity or disservice to elephants and people alike?
Photo by World Agroforestry Centre/Meine van Noordwijk

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CHAPTER 3

Tradeoffs

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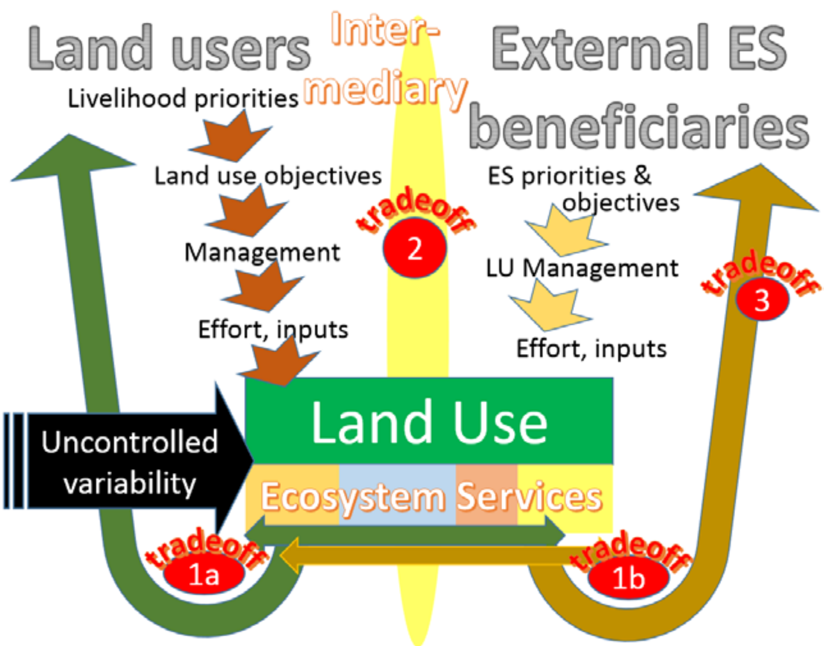
Highlights

- Ecosystem Service tradeoff assessment is needed in all stages of a developing PES scheme
- Tradeoffs relate to stakeholder perspectives, ES categories and PES efficiency *vs* fairness
- Coinvestment seeks synergy between landscape functions and associated human benefits
- Ecological buffers support both climate change adaptation and mitigation
- Tradeoff analysis requires 'boundary work' to achieve mutual understanding and respect



3.1 Introduction

In chapter 1 we saw how ecosystem services (ES) related to land use provide humans with many ways to increase their well-being[1]. In chapter 2 we considered ES typologies and metrics that are used to quantify services[2]. In this chapter we focus on tradeoffs. Tradeoff can be a verb (trading off one benefit against another) and a noun, describing the relationship between two variables (in part of the range) where an increase in one tends to be associated with a decrease of the other. A temporal tradeoff is, for example, between having and eating your cake. A spatial tradeoff can exist, for example, between using water on-site for plant growth and allowing water to runoff and be used elsewhere. A complex multi-stakeholder tradeoff exists where forms of payment are given in exchange for specific services (based on the 'willingness to pay' tradeoff), and are accepted by a party who finds the reward offered worth the effort (based on the 'willingness to accept' tradeoff), with the whole transaction being part of a wider efficiency-fairness tradeoff among multiple PES paradigms. We here discuss three types of tradeoffs in the context of PES, relate them to learning loops, ecological buffers, climate change and scale, and then relate this all to the steps to get a PES mechanism started and through adaptive learning make it a success, while perceptions of tradeoffs by all parties involved keep changing.

3.2 Three levels of tradeoff

The first type of tradeoff to consider in PES is that among ecosystem services. Ecosystem services relate to issues of water, biodiversity, climate vulnerability and the material goods that can be derived from functioning (agro)ecosystems. A common typology (see chapter 2) classifies these services on the basis of the type of human benefits as: ***provisioning*** (e.g. food, clean water and usable energy), ***regulating services*** (sheltering humans from environmental variation such as the extremes of climate and the drought and floods that would be our fate if rainfall would not be buffered, and the effects of pests and diseases if these wouldn't have natural enemies), ***cultural services*** (e.g. of landscapes that are integrated with a sense of identity that help in recovering from overstressed urban life, or explore the wonders of nature) and ***supporting services*** that allow the recovery of ecosystem structure and function over longer time frames. The relative importance of these services for increasing human well-being depends on the degree of saturation of 'basic needs' (as discussed in chapter 1). The local perspective tends to differ from those at larger distance (but affected by local decisions on land use). Including all of the various benefits people anywhere on the globe derive from ecosystems under a single umbrella term ecosystem services or ES helps to argue for the importance of the socio-ecological infrastructure of life. However, it may mask rather than identify the many tradeoffs between the various categories of services. If the term ES includes everything, it excludes nothing. Thus it may mean nothing in as far as meaning depends on contrasts. The primary tradeoff is between provisioning services, often linked to markets and with direct financial consequences, and the other ES (Table 3.1).

Table 3.1 Examples of the first type of trade-off among ecosystem services (B_x, G_x, P_x, W_x refer to Table 2.3)[2]

ES Function 1	*versus* ES Function 2	Consequences for PES design
Examples of strongly negative tradeoffs between ES		
Food production (P) for local consumption	All other ES reduced by conversion to agriculture (B, G, W)	Sufficient payments to allow outsourcing of (staple) food[3]
Erosion control by perennial vegetation on slopes (W6)	Food production (P) for local consumption	China's grain-for-green program[4]
B2, B3, W9 in 'integrated' agricultural landscapes	Minimizing yield gaps (P3)	Certification and premium prices for products from ES-friendly landscapes[5]
Active recreation (B6)	Integrity of conservation areas (B1)	Zoning, guided ecotourism, entry charges for protected areas
Water transmission (total water yield; W1), irrigation water supply to crops (W3)	Buffering peak flows (W2), Water quality (W4)	Compensating land owners in 'rainfall harvesting' areas
Examples of approximately neutral tradeoffs between ES		
Protecting C-stocks (G1), Restocking with carbon (G3)	Biodiversity (B)	'Neutral' tradeoff[6] implies explicit targeting for two-way synergy is needed
Minimizing yield gaps (P3)	Minimizing N-use efficiency gaps (G5)	Active search for 'climate smart' agricultural solutions[7]

The second type of tradeoff relates to the human response to such a situation: by making actual choices, weights are implicitly assigned to the apparent 'value' these variables represent to the decision maker[1]. If one of the two variables is expressed in monetary terms, the tradeoff becomes a 'price', and the trading (off) can become a payment. Willingness to pay (WTP) and willingness to accept (WTA) reflect two prices; if WTP (across all stakeholders) is higher than WTA a transaction is possible, with the way the net benefit of differences between these prices is partitioned a reflection of bargaining power, transaction costs and effectiveness of an intermediary. Intermediaries aiming for a well-functioning PES scheme need to understand the WTP and WTA tradeoffs, and seek a path that provides at least some net benefits for all.

In terms of this second tradeoff, a central theme in environmental economics[2] is that money (financial transfers) are the simplest way for allowing all stakeholders to make their own tradeoff decisions on how to use it. If all entities in a comparison can be expressed in the same units (i.e., currency), a search for an optimal solution comes down to adding and subtraction – or the slightly more advanced algebra of linear programming and full inclusion of risk and uncertainty (with the basic utility-under-risk equation going back to Daniel Bernouilli in 1738[3]). However, across the multiple scales of time and space, the various components of human wellbeing and their shortfalls (or degree of saturation), make the conversion of ecosystem services to a financial value itself a complex and contested effort. Valuation in a single currency as currently practices may add to the confusion rather than help to resolve it. The deceptively simple concept of 'payment' for 'ecosystem services' breaks down in a much more complex social and political reality of decision making. One perspective that helps to understand this complexity is that a balance must be found[8] in the tradeoff between

[1] This line of argument is a common attempt to retrofit a 'rational decisions' model on actual choices made

[2] Also termed *meso* economics; by contrast ecological economics is *giga* economics, fitting within planetary boundaries[15]

[3] https://fr.wikipedia.org/wiki/Daniel_Bernoulli

'efficiency' (obtaining maximum increase in ecosystem services per amount of money invested) and 'fairness' (recognizing and respecting the common but differentiated responsibility for our commons, from local to planetary scale).

A further aspect of the tradeoff in the emergence of PES mechanisms is the optimal threat perception[9]: if the external beneficiaries of ES perceive no threat, as it is in the best interest of land users to maintain high levels of ES, they may not perceive a need to pay for what can and should be provided for free; if, on the other hand, the threat to ES is perceived to be very high, they may not see PES as having any chance to effectuate change. In-between is an optimal threat perception level in which PES proposals are accepted as fair and efficient. The problem is, however, that one often doesn't know where the current threat perception is relative to the optimum, and consequently whether emphasizing the threat to ES or the feasibility of solutions is most effective in bringing PES funding to the negotiation table.

Box 3.1 Temporal tradeoffs and discount rates

One of the key challenges in human decision making is the way immediate, short-term benefits can be compared to their long term costs and/or long term benefits foregone. It is a standard practice in economic analysis to discount future costs and benefits relative to immediate ones, on the basis of a discount rate. The compound interest calculations that predict the value of deposits in a bank serve as basis for relating future to current costs. In the context of ES there are three challenges in this approach:

1. Human brains are notoriously poor in comparing future and immediate benefits, and if discount rates are inferred from actual choices (e.g., 10 USD now or 20 USD tomorrow), they are usually very high.
2. Intergenerational equity considerations may suggest that the natural capital of the Earth should not be allowed to decline between human generations, and thus the future value of ES (under increased scarcity) is likely higher rather than lower than the current one; applying a negative discount rate might be appropriate.
3. Effective discount rates are influenced by other sources of uncertainty, e.g. regarding land tenure. If land users face a risk of evictions they may opt for land uses with short-term benefits, rather than what offers the best returns in the long term. Increasing tenure security may trigger more ES friendly land use choices.

The third type of tradeoff thus is in the choice of mechanism within the broadly defined PES concept. As introduced in chapter 1, PES is one of several avenues ES-beneficiaries (or victims of ES-decline) can use to increase ES supply. When and where is a financial transfer appropriate and helpful to enhance the ES most needed? How does it evolve over time: is it an initial investment, or expected to be a recurrent payment for an indefinite period? How can the PES-investors ensure that tradeoffs between supply of the various ES types match their long-term and changing interests? How can the PES-acceptors secure their own interests in continuing innovation and change, not burdened by overly prescriptive rules of the game? A major step in finding solutions that meet the interests of all involved is when PES contracts can refrain from prescribing activities, but shift to defining performance of a landscape as supplier of quantified levels of specified ES. This requires, however, that all parties to a PES contract have a common understanding of how ES can be influenced and quantified. This in itself requires a major investment in boundary work[10], aiming for a common understanding of the issues and options. It involves a choice in the tradeoff between investment in human capacity and immediately tangible ES results.

3.3 Tradeoff analysis as part of learning loops

If we consider landscapes as dynamic socio-ecological systems[11], we can analyze the way change comes about as part of a continuous learning loop (Figure 3.1). Steps in this learning loop are the observation and documentation of change and its consequences, via interpretation, the search for alternative solutions (e.g., land uses or LU) and their combination at scenario level to help form multi-stakeholder platforms for further change[12]. Tradeoffs are inherent and happen in all stages, but they differ in character: there are tradeoffs (of the first type) between the various functions that are relevant to various stakeholders, there are tradeoffs (of the second type) between these functions when various 'new solutions' and 'scenarios' are considered, and finally tradeoffs (of the third type) between stakeholders in their interest and ability to form long-term coalitions for change in mutually desirable directions.

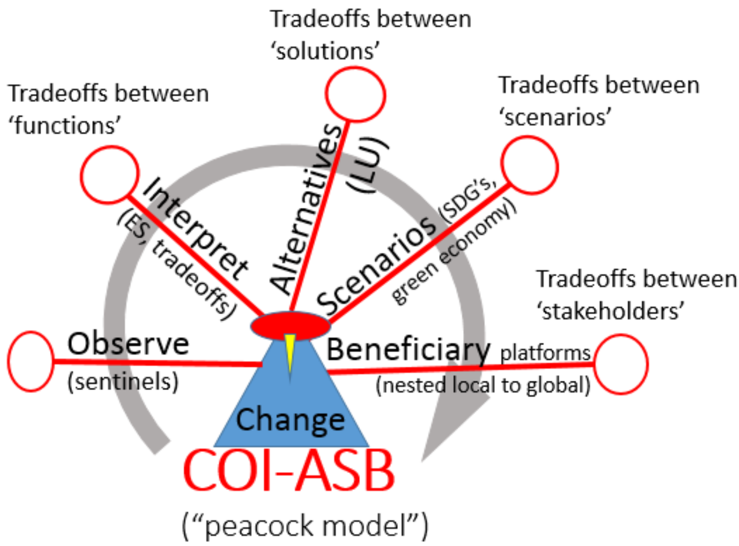


Figure 3.1 The Change-Observe-Interpret-Alternatives-Scenarios-Beneficiaries ('COI-ASB') cycle contains tradeoff concepts which exist at all stages, but are different in character.

A further dimension of all ES discussions, and one that calls for continued learning by all, is climate change. Since the adoption of the UN Framework Convention for combatting Climate Change (UNFCCC) in 1993, efforts to reduce the rate of global climate change by control of emissions of greenhouse gasses have been discussed under the heading 'mitigation', while efforts to reduce negative impacts of ongoing climate change on human wellbeing are described as 'adaptation'. At a high level the tradeoff may be clear (i.e., the slower mitigation efforts proceed the more adaptation is needed; the easier adaptation reduces political platform for ambitious mitigation). Separate mechanisms and financing institutions emerged for mitigation and adaptation that made synergy between the two an exception rather than a rule[13,14]. The Paris Agreement of December 2015 recognized the need for synergy between the two aspects, but did not yet achieve integration and merger of the involved institutions and mechanisms that evolved separately. Where mitigation efforts have often relied on market mechanisms and forms of PES with performance-based financing, adaptation has been approached by projects and investment. A full synergy of adaptation and mitigation may require institutional concepts, which transcend these distinctions.

3.4 Buffering

A specific proposal for an overarching concept to seek synergy in a world of multiple tradeoffs and choices tradeoffs is that of buffer (Fig. 3.2)[15]. Detailed knowledge of all the multiple stressors and impending crises is not needed where there is sufficient buffer. Global climate change is accompanied (and enhanced) by the simplification of agricultural landscapes and removal of forest patches, trees and landscape elements that are not directly profitable, yet support ecosystem services[16, 17,18]. Efforts to counter this trend of landscape simplification by changing the way profitability is perceived and calculated, through effective forms of PES, can achieve both a reduction of vulnerability to climate change (adaptation), as well as reduce net greenhouse gas emissions (mitigation). To which degree they do so, may still need to be separately assessed, but major progress on both fairness and efficiency axes could be achieved if the common but differentiated responsibility concept of the UNFCCC (mostly used to describe relations between nations) were applied at landscape scale, in seeking synergy of mitigation and adaptation efforts. This will require that place-based ES that rely on location-specific adaptive solutions need to be reconciled with globally uniform and efficiency-seeking carbon markets. Recent arguments[19] that water plays a much larger role in the tree/forest – climate relationship can help redressing the balance between perceived local and global benefits of enhanced tree cover. A generic 'enhanced buffering' approach to landscapes can be based on one of the assets in reducing tradeoffs (Figure 3.2). For example, ecological buffer in the form of insurance premiums can play the role as either mitigation or adaptation strategy without knowing which risk will actually come your way. Being insured allows you not to worry too much.

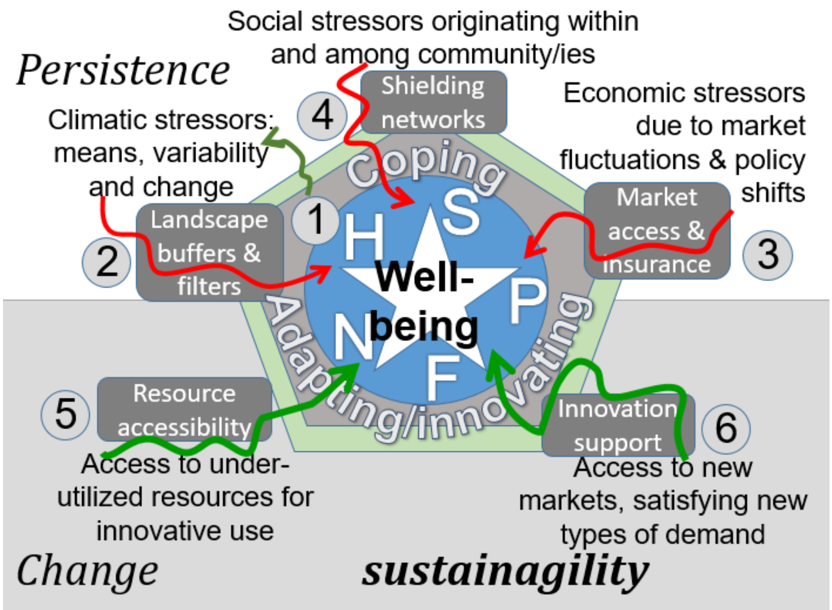


Figure 3.2 Buffering[20] as an integrative concept that applies to all types of assets e.g., financial (F), social (S), human (H), natural (N), build-up/physical (P), protects human wellbeing from the various stressors and threats (2, 3, 4; red arrows) and is helped by the various defenses (1, 4, 6; green arrows).

3.5 Trade-offs, scale and reversibility

Most of the literature related to ecosystem services perceived trade-offs on three dimensional scales: *spatial scale*, which refers to whether the effects of a change in land use (LU) and associated ES are felt locally or at a distant location; *temporal scale* (Box 3.1), whether the effects of the tradeoffs take place immediately or slowly (in the future), and what level of agility can be expected in a longer time perspecte[5]; and *reversibility*, which refers to the likelihood that the perturbed ES may return to its original state if the perturbation ceases[21], modified by concepts of the desirability of global development change.

Although, there are many studies that quantify the spatial distribution of ecosystem functions that support ES, little attention has been paid to quantify the temporal and reversibility aspects due to the lack of temporally and spatially replicated monitoring surveys[15,22]. However, as simple as one may think of, these tradeoffs depend on the management choices made by humans explicitly or may arise unintentionally.

Most synergistic opportunities arise by further analysis of apparent tradeoffs across scales particularly in the land use sector. The way a system is defined in space, time or institutions shapes many of the tradeoffs. To manage these tradeoffs, the boundaries of the system that is being managed will often need to be modified. Managing tradeoffs requires understanding the time and scale at which the extent of the tradeoffs becomes apparent[12,23]. For instance, including nitrogen-fixing trees into farmlands reduces the potential area that can be used for growing crops. However, in the long-run, when the trees grow and begin to fix nitrogen, the productivity of the farmlands increases offsetting some of the production space losses. There are frequent references to the issue of eucalyptus planting in the highlands of Ethiopia being associated with influences on ground water level. However, in view of the severe deforestation the country has experienced, there is a serious need for fast growing tree species like *Eucalyptus* that produce wood for energy and construction. Producing the same amount of wood from native species will likely cost more water. The ground water level effects were often cited when the plantations are on a large scale but there is limited concern when such fast growing trees are planted in small-scale. Scale effect on tradeoffs is very crucial when we consider watershed level interventions involving upland and lowland communities where any inappropriate implementation of activities in the upland areas may have detrimental consequences in the low-lying areas. Hence, some tradeoffs are scale dependent, the management of which therefore requires good understanding of the effect of the same, and time dimension of tradeoffs management therefore is crucial as it enables proper planning of the time and the level of scale at which tradeoff management is worth the investment.

3.6 The three tradeoff categories in a PES life cycle

We now have the concepts for a second look at the three types of tradeoff over the life cycle of a PES scheme. In Figure 3.3, there are three groups of actors: A) land users whose management objectives and strategies, and level of efforts are tuned to reach their livelihood goals; B) external ES beneficiaries whose goal is to make sure that the target ES will continuously flow; C) intermediaries, trying to align choices by the two other groups in terms of the key tradeoffs.

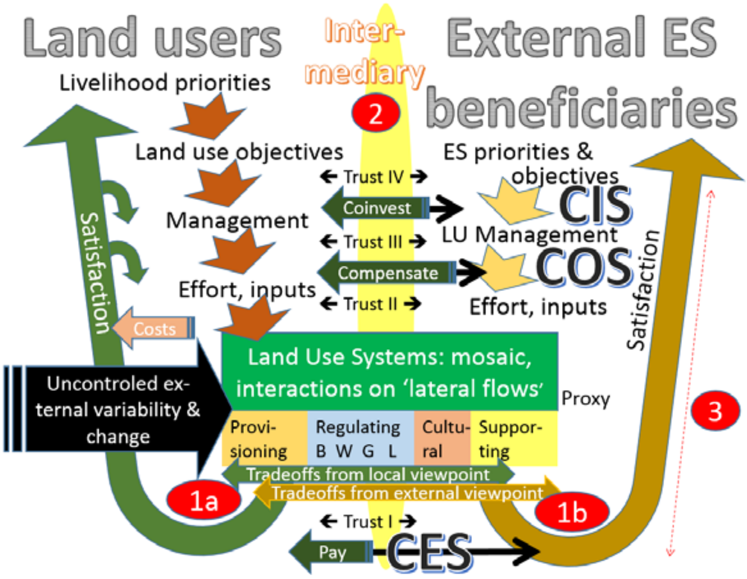


Figure 3.3 Key trade-offs (1, 2, 3) emanating between land users and external beneficiaries; B, W, G and L refer to the typology of ecosystem services discussed in chapter 2; the CES, COS and CIS paradigms of PES were introduced in chapter 1 (modified from[24]).

The three tradeoff classes from the introduction can now be reinterpreted as:

1. The landscape (land use systems in mosaic context), its adequacy in providing desired ES and the tradeoffs land users and external beneficiaries make in terms of PES
2. Efficiency, Fairness and Trust as criteria for an evolving PES scheme
3. PES paradigms: CES, COS and CIS

1. *The differences in perceptions between local and external stakeholders on how a landscape should be managed to suit their specific interests*. This tradeoff requires understanding of the different farming practices and future plans (incl. LU preferences in response to the uncontrolled external variability such as climate change) of the land users and how these affect the perceived goal of the external beneficiaries. If goals between these two actors are different, intermediaries could negotiate between these actors whether the management strategies, practices and plans (e.g., agricultural intensification vs. extensification or do nothing at all) at the landscape level can support continuously the flow of targeted ES. Table 3.1 provides suggested tools that can be used together with the stakeholders. Guiding tools appropriate for corporate entities as ES beneficiaries are also available[25]. The chance for financial incentives to bring the two groups together depends on the willingness to accept (WTA) of commitments to enhance ES by land users in return for incentives, and the willingness to pay (WTP) of ES beneficiaries who provide such incentives in return for (expected) increase in ES. Both WTA and WTP involve tradeoffs at actor level. If WTP exceeds WTA there is space for negotiated win-win solutions, if WTP is less than WTA it is unlikely that PES contracts can emerge unless WTA and WTP perceptions change. One way to analyze this tradeoff is the use of conservation auctions (Con$erv)[26], which is designed to efficiently allocate conservation contracts and reveal hidden information on the opportunity costs of supplying environmental services.

2. *Efficiency, Fairness, and Trust as criteria for an evolving PES scheme*. The perceived tradeoff between efficiency and fairness in governance of natural resources may be primarily one of time. In the longer run, it isn't efficient to ignore fairness perceptions, as social unrest, protest and open conflict can do considerable damage. It isn't fair either to be inefficient and waste resources that could have better uses. Where trust between parties is low, a 'performance-based' payment system is attractive to the external sources of finance, with an emphasis on efficiency. Where restrictions on current land use (whether 'legal' or not) are imposed, a form of compensation is appropriate to move from conflict to cooperation. Where trust further develops between external and local stakeholders PES, contracts could move from outcome indicators and activities, to one of shared objectives and coinvestment in management of the resources for multiple goals.

3. *The tradeoff between different PES paradigms*. Acknowledging these tradeoffs can invite and promote dialog, creativity, and learning[27]; thus allowing for more comprehensive planning and reducing the probability of disappointment and disillusionment associated with designing PES schemes[10]. The three PES paradigms (Commoditization of ES or CES; Compensation for Opportunities Skipped or COS; and Co-investment in Stewardship or CIS) relate to the level of legality of current land uses and to levels of trust needed as precondition. The main question in this trade-off concept is whether the targeted PES paradigm is efficient, fair and applicable in the context of the land-use system. A subtle negotiation is required to clarify and establish the following preconditions[28]:

   - Clarity of property rights over land and trees
   - Compliance with legal requirements for generation of environmental services
   - Existing commodity markets with interest in enhancement of ES
   - Legality of ES reducing practices that are foregone and now compensated
   - Level of trust between the land users and ES beneficiaries.

   The Multi-Scale Payments-for-environmental services' paradigms (MuScaPES) tool helps clarify the range of possibilities between the PES paradigms[29]. Since in most cases, a market-like PES is very rare in developing countries due to non-existence of proxies and unclear land rights, co-investment in ES paradigm is aimed at, which generally has high acceptance and chances of success due to the high trust level among stakeholders or lower perceived threat to property rights.

Small-scale logging the remaining natural forest, while *Acacia mangium* (left) plantations take over the former swidden landscape in Central Vietnam: tradeoffs between provisioning and conservation functions. Photo: World Agroforestry Centre/Meine van Noordwijk

3.7 Tools for explicit tradeoff analysis

In line with the various tradeoffs discussed here, trade-off assessment tools (Table 3.2) should have a strong participatory aspect to optimize multi-functional use of ecosystem services at the same time avoid potential conflicts and misunderstanding of different actors[30,31,32,33]. Tools such as Con$erv, RABA, RaCSA, RHA, FALLOW model, and MuScaPES explicitly involve non-specialists knowledge. On the other hand, RABA, RaCSA, RHA and RUPES games are cost effective (<$10,000) and time-bound appraisal tools (for a period of six months) targeted for local stakeholders providing ES. These tools primarily comprise of stakeholder analysis, participatory ES modeling/assessment and consultation/discussion about perception of involved stakeholders.

Table 3.2 Additional tools/methods for tradeoffs assessment used for the purpose of designing PES scheme

Tool	Ecosystem service model/ assessment embedded	Examples of application	Stakeholder engagement
System dynamics			
FALLOW[34]	Carbon storage and sequestration, biodiversity, water retention, agroforestry yield, sediment regulation, and land use change scenarios	Landscape level (Thailand, Indonesia, Philippines, Vietnam)	Involvement through stakeholder consultation and focus group discussion
Agent-based modeling approach			
LB-LUDAS[35]	Carbon storage and sequestration, biodiversity, and production yields (between monoculture and agroforestry)	Watershed level (Jambi province, Indonesia; Ghana)	Involvement through participatory land use mapping and focus group discussion
Stakeholder analysis/ Rapid rural appraisal			
RUPES game[36]	Agroforest products, watershed services, carbon stocks, biodiversity	Site-level (Indonesia, Philippines, Vietnam)	Strong
Targeting specific ES			
RABA[37]	Agrobiodiversity	Site-level (Indonesia, Philippines, Vietnam)	Strong
RaCSA[38]	Carbon stocks	Site-level (Indonesia, Philippines, Vietnam, Sub-Saharan Africa)	Strong
RHA[39]	Watershed services	Site-level (Indonesia, Philippines, Thailand Vietnam)	Strong

Also, there is a growing use of models in ES tradeoffs and five common approaches or model types that have the capacity to integrate various knowledge (i.e., participation and engagement) are available namely, system dynamics (e.g., FALLOW model), Bayesian networks (e.g., ARIES; www.ariesonline.org), agent-based models (e.g., MIMES; www.afordablefutures.org), coupled-component models (e.g., InVEST; www.naturalcapitalproject.org) and expert system (e.g., knowledge-based models such as TESSA or Toolkit for Ecosystem Services Site-based Assessment[40]). These tools are good at explaining quantitatively the flows and stocks of ecosystem services, spatially and temporally explicit, and good for scenario forecasting[41]. Further comparative analysis of these modeling tools[42] is needed. However, the integration of knowledge can be a side activity in the modeling processes and may occur at any stage from the elaboration of knowledge to the use of models while the level of success of the model outputs depend on how connected stakeholders are to the model (*salience*) and how relevant the model outputs are to policy and extension activities (*legitimacy*)[43].

3.8 Conclusions

This chapter has presented three classes of tradeoffs that relate to the way PES schemes can emerge, mostly from the perspective of an intermediary, who tries to be an honest broker with long-term mutual trust building as primary role (and business model). Because most of the tradeoffs relate to the perceptions of the different stakeholders, the best way to deal with these is through negotiation support: actively exploring the multiple types of knowledge and explanatory framing that stakeholders use. Negotiation support in this sense may lead to investment in institutionalizing rewards or payments for ES. It requires skills beyond the disciplinary, technical scientific assessment in which most professionals have been trained.

References

[1] Namirembe S, Leimona B, van Noordwijk M, Minang PA. 2017. Co-investment in ecosystem services: global lessons from payment and incentive schemes. Chapter 1 of *this book*.

[2] Lusiana B, Kuyah S, Öborn I, van Noordwijk M. 2017. Typology and metrics of ecosystem services and functions as the basis for payments, rewards and co-investment. Chapter 2 of *this book*.

[3] van Noordwijk M, Bizard V, Wangkapattanawong P, Tata HL, Villamor GB, Leimona B. 2014. Tree cover transitions and food security in Southeast Asia. *Global Food Security* 3: 200-208.

[4] Jun H, Sikor T. 2017. Justice notions in payment for environmental services: Insights from China's sloping land conversion program. Chapter 27 *this book* **UPDATE WHEN ONLINE**

[5] Jackson LE, van Noordwijk M, Bengtsson J, Foster W, Lipper L, Pulleman M, Said M., Snaddon J, Vodouhe R. 2010. Biodiversity and agricultural sustainagility: from assessment to adaptive management. *Current Opinion in Environmental Sustainability* 2: 80–87.

[6] Sullivan MJ, Talbot J, Lewis SL, Phillips OL, Qie L, Begne SK, Chave J, Sanchez AC, Hubau W, Lopez-Gonzalez G, Miles L. 2016. Diversity and carbon storage across the tropical forest biome. *Scientific Reports* 7: 39102

[7] van Noordwijk M, Brussaard L. 2014. Minimizing the ecological footprint of food: closing yield and efficiency gaps simultaneously? *Current Opinions on environmental Sustainability* 8:62–70.

[8] Leimona B, van Noordwijk M, de Groot R, Leemans R. 2015. Fairly efficient, efficiently fair: Lessons from designing and testing payment schemes for ecosystem services in Asia. *Ecosystem Services* 12: 16-28.

[9] Van Noordwijk M, Chandler F, Tomich TP. 2004. *An introduction to the conceptual basis of RUPES: rewarding upland poor for the environmental services they provide.* Bogor, Indonesia: World Agroforestry Centre-Southeast Asia. p. 41.

[10] Leimona B, Lusiana B, van Noordwijk M, Mulyoutami E, Ekadinata A, Amaruzaman S. 2015. Boundary work: Knowledge co-production for negotiating payment for watershed services in Indonesia. *Ecosystem Services* 15: 45-62.

[11] Minang P, van Noordwijk M, Freeman O, Mbow C, De Leeuw J, Catacutan D. 2015. *Climate-Smart Landscapes: Multifunctionality In Practice.* Nairobi, Kenya: World Agroforestry Centre (ICRAF). p. 404.

[12] van Noordwijk M, Lusiana B, Leimona B, Dewi S, Wulandari D. 2013. *Negotiation-Support Toolkit For Learning Landscapes.* Bogor, Indonesia: World Agroforestry Centre.

[13] Duguma LA, Minang PA, van Noordwijk M. 2014. Climate change mitigation and adaptation in the land use sector: from complementarity to synergy. *Environmental Management* 54: 420-432.

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

[15] van Noordwijk M, Leimona B, Jindal R, Villamor GB, Vardhan M, Namirembe S, Catacutan D, Kerr J, Minang PA, Tomich TP. 2012. Payments for Environmental Services: Evolution Toward Efficient and Fair Incentives for Multifunctional Landscapes. *Annual Review of Environment and Resources* 37: 389-420.

[16] Bayala J, Sanou J, Teklehaimanot Z, Ouedraogo S, Kalinganire A, Coe R, van Noordwijk M. 2015. Advances in knowledge of processes in soil–tree–crop interactions in parkland systems in the West African Sahel: A review. *Agriculture, Ecosystems & Environment* 205: 25-35.

[17] van Noordwijk M, Bayala J, Hairiah K, Lusiana B, Muthuri C, Khasanah N, Mulia R, 2014. Agroforestry solutions for buffering climate variability and adapting to change, in: Fuhrer, J., Gregory, P.J. (Eds.), *Climate change Impact and Adaptation in Agricultural Systems*. CAB-International, Wallingford (UK), pp. 216-232.

[18] Kuyah S, Öborn I, Jonsson M, Dahlin AS, Barrios E, Muthuri C, Malmer A, Nyaga J, Magaju C, Namirembe S, Nyberg Y, Sinclair FI. 2016. Trees in agricultural landscapes enhance provision of ecosystem services in Sub-Saharan Africa. *International Journal for Biodiversity Science, Ecosystem Services and Management* 12**:** 255-273.

[19] Ellison D, Morris CE, Locatelli B, Sheil D, Cohen J, Murdiyarso D, Gutierrez V, van Noordwijk M, Creed IF, Pokorny J, Gaveau D, Spracklen D, Tobella AB, Ilstedt U, Teuling R, Gebrehiwot SG, Sands DC, Muys B, Verbist B, Springgay E, Sugandi Y, Sullivan CA. 2017. Trees, forests and water: cool insights for a hot world. *Global Environmental Change* (DOI: 10.1016/j.gloenvcha.2017.01.002)

[20] van Noordwijk M, Hoang MH, Neufeldt H, Öborn I, Yatich T. 2011. *How trees and people can co-adapt to climate change: reducing vulnerability through multifunctional agroforestry landscapes*. Nairobi, Kenya: World Agroforestry Centre.

[21] Rodriguez JP, Beard J, Douglas T, Bennett EM, Cumming GS, Cork SJ, Agard J, Dobson AP, Peterson GD. 2006. Trade-offs across space, time, and ecosystem services. *Ecology and Society* 11(1).

[22] Holland RA, Eigenbrod F, Armsworth PR, Anderson BJ, Thomas CD, Gaston KJ, 2011. The influence of temporal variation on relationships between ecosystem services. *Biodiversity and Conservation* 20: 3285-3294.

[23] Harvey CA, Chacón M, Donatti CI, Garen E, Hannah L, Andrade A, Bede L, Brown D, Calle A, Chara J, Clement C. 2014. Climate-smart landscapes: opportunities and challenges for integrating adaptation and mitigation in tropical agriculture. *Conservation Letters* 7: 77-90.

[24] van Noordwijk M, Leimona B. 2010. Principles for fairness and efficiency in enhancing environmental services in Asia: payments, compensation, or co-investment. *Ecology and Society* 15: 17

[25] Waage S, Stewart E, Armstrong K. 2008. Measuring corporate impact on ecosystems: a comprehensive review of new tools. Business for Social Responsibility. San Francisco, CA (USA).

[26] Leimona B. 2013. Conservation auction and environmental servces enhancement (Con$erv). In: van Noordwijk M, Lusiana B, Leimona B, Dewi S, Wulandari D. (Eds.) *Negotiation-support toolkit for learning landscapes*. Bogor, Indonesia: World Agroforestry Centre.

[27] Hirsch PD, Adams WM, Brosius JP, Zia A, Bariola N, Dammert JL. 2011. Acknowledging conservation trade-offs and embracing complexity. *Conservation Biology* 25: 259-264.

[28] Namirembe S, Leimona, B, van Noordwijk M, Bernard F, Bacwayo KE. 2014. Co-investment paradigms as alternatives to payments for tree-based ecosystem services in Africa. *Current Opinion in Environmental Sustainability* 6: 89-97.

[29] Leimona B, Namirembe S, van Noordwijk M, Minang PA. 2013. Multi-scale payments-for-environmental services paradigms (MuScaPES). In: van Noordwijk M, Lusiana B, Leimona B, Dewi S, Wulandari D. (Eds.) *Negotiation-support toolkit for learning landscapes*. Bogor, Indonesia: World Agroforestry Centre.

[30] De Groot RS, Alkemade R, Braat L, Hein L, Willemen L. 2010. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity* 7: 260-272.

[31] Martín-López B, Gómez-Baggethun E, García-Llorente M, Montes C. 2014. Trade-offs across value-domains in ecosystem services assessment. *Ecological Indicators* 37 Part A: 220-228.

[32] Villamor G, Palomo I Santiago C, Oteros-Rozas E, Hill J. 2014. Assessing stakeholders' perceptions and values towards social-ecological systems using participatory methods. *Ecological Processes* 3: 1-12.

[33] Wegner G, Pascual U, 2011. Cost-benefit analysis in the context of ecosystem services for human well-being: A multidisciplinary critique. *Global Environmental Change* 21: 492-504.

[34] van Noordwijk M. 2002. Scaling trade-offs between crop productivity, carbon stocks and biodiversity in shifting cultivation landscape mosaics: the FALLOW model. *Ecological Modelling* 149: 113-126.

[35] Villamor GB, Le QB, Djanibekov U, van Noordwijk M, Vlek PLG. 2014. Biodiversity in rubber agroforests, carbon emissions, and rural livelihoods: An agent-based model of land-use dynamics in lowland Sumatra. *Environmental Modelling & Software* 61: 151-165.

[36] Villamor GB, van Noordwijk M. 2011. Social role-play games vs individual perceptions of conservation and PES agreements for maintaining rubber agroforests in Jambi (Sumatra), Indonesia. *Ecology and Society* 16(3): 27.

[37] Kuncoro SA, van Noordwijk M, Martini E, Saipothong P, Areskoug V, Putra A, O'Connor T. 2006. Rapid agrobiodiversity appraisal (RABA) in the context of environmental service rewards: protocols for data collection and case studies in rubber agroforests and Bungo district, Jambi Indonesia and fragmented forest in north Thailand. Bogor, Indonesia: World Agroforestry Centre.

[38] Hairiah K, Dewi S, Agus F, Velarde S, Ekadinata A, Rahayu S, van Noordwijk M. 2011. *Measuring carbon stocks land use systems: a manual*. Bogor, Indonesia: World Agroforestry Center (ICRAF).

[39] Jeanes K, van Noordwijk M, Joshi L, Widayati A, Farida, Leimona B. 2006. *Rapid hydrological appraisal in the context of environmental service rewards*. Bogor, Indonesia: World Agroforestry Centre.

[40] Peh KSH, Balmford A, Bradbury RB, Brown C, Butchart SH, Hughes FM, Stattersfield A, Thomas DH, Walpole M, Bayliss J. 2013. TESSA: A toolkit for rapid assessment of ecosystem services at sites of biodiversity conservation importance. *Ecosystem Services* 5: 51-57.

[41] Kelly RA, Jakeman AJ, Barreteau O, Borsuk, ME, ElSawah S, Hamilton SH, Henriksen HJ, Kuikka S, Maier HR, Rizzoli AE, van Delden H, Voinov AA. 2013. Selecting among five common modelling approaches for integrated environmental assessment and management. *Environmental Modelling & Software* 47: 159-181.

[42] Bagstad KJ, Semmens DJ, Waage S, Winthrop R. 2013. A comparative assessment of decision-support tools for ecosystem services quantification and valuation. *Ecosystem Services* 5: 27-39.

[43] Barreteau O, Bots P, Daniell K, Etienne M, Perez P, Barnaud C, Bazile D, Becu N, Castella J-C, Daré WS, Trebuil G. 2013. Participatory approaches and simulation of social complexity, in: Edmonds B, Meyer R. (Eds.) *A Handbook on: Simulating Social Complexity*. Springer, pp. 197-234.