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DEVELOPMENT OF A 'VIRTUAL' PES SCHEME FOR THE NAM NGUM RIVER BASIN

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Introduction

This Research Report presents a 'virtual' payments for environmental services (PES) scheme designed as a 'proof of concept'. The 'virtual' PES scheme demonstrates how a PES scheme would be designed and implemented step-by-step in the Lao context and establishes a draft set of guidelines for PES design and operation.

The setting used for the 'virtual' PES scheme is however real. It is the Nam Ngum River Basin (NNRB), the subject of Research Report 2.

The goal of this 'virtual' PES scheme is to increase the familiarity with the PES concept and application amongst Government of Lao officials. The draft set of guidelines will be used in preparation for the design and implementation of PES schemes pilots in the Lao People's Democratic Republic (PDR).

This report presents a 'virtual' case study. The steps taken to design and implement a PES scheme are described to show how they would be taken in the context of the NNRB and to illustrate how they would be taken in future PES schemes implemented in other areas of Lao PDR. The application of the 'virtual' case study to the NNRB is intended to demonstrate the potential practicality of the PES scheme.

This report draws on Research Report 1:Payments for Environmental Services: Concepts and Applications (Scheufele et al. 2013) and 2:The Environmental, Economic and Social Condition of the Nam Ngum River Basin (Phoyduangsy et al. 2013)[1]. Research Report 1 provided the theoretical basis that underpins the PES scheme mechanism design, while Research Report 2 provided information about the Nam Ngum River Basin.

The format of this Research Report is to set out in each section the 20 steps that are required to implement and assess a PES scheme in the Lao PDR context. Integral to the implementation of these 20 steps are the logistical arrangements, the first of which is the establishment of an advisory committee. It is this committee which would oversee the development, implementation and assessment of the PES scheme.

[1] Both reports are available on http://ipesl.crawford.anu.edu.au/publications.

The reader should keep in mind that the steps are presented in a linear fashion. However, this does not imply that the steps are taken sequentially; rather the steps are interdependent and overlapping through time.

This report caters for two types of readers. We recommend that readers who primarily want to understand how the 20 steps can be applied in a practical context should just read the main body of the report. For readers also interested in the technical aspects of the steps, we have provided a range of additional elements included in footnotes and annexes.

Steps required to design and implement a PES scheme in the Lao PDR

- Step 1 — Selecting the geographical area to be involved
- Step 2 — Cataloguing the ES to be supplied
- Step 3 — Identifying the sources of ES demand
- Step 4 — Identifying potential ES supply
- Step 5 — Defining the type and degree of agent intervention
- Step 6 — Selecting the ES buyers
- Step 7 — Securing funds to pay for the ES supply
- Step 8 — Determining the types of returns to ES suppliers
- Step 9 — Bio-physical modelling
- Step 10 — Estimating marginal benefits of supply
- Step 11 — Estimating individual marginal costs of ES supply
- Step 12 — Developing the payment system
- Step 13 — Selecting the ES suppliers
- Step 14 — Determining the payments required from ES buyers
- Step 15 — Establishing the payment transfer mechanism
- Step 16 — Determining the supplier performance measure
- Step 17 — Establishing a monitoring system
- Step 18 — Establishing a penalty system to punish non-complicance
- Step 19 — Contracting the ES suppliers (and buyers)
- Step 20 — Assessing the PES scheme performance

Step 1: Selecting the geographic area to be involved

The criteria used to select the NNRB as the setting for the ‘virtual’ case study site for the PES scheme introduction included the following:

- Changes in natural resource management practices in the NNRB have the potential to increase and/or stabilize the environmental services (ES) supplied by the region given its natural resources endowment (native forests) and the presence of existing threats (agricultural activities of small-scale farmers).
- The NNRB has the capacity to act as an area that is representative of other candidate sites in that it includes development investments (hydro-electric power; tourism). It can thus act as a demonstration site of the principles and processes involved in setting up a PES scheme.
- There are potential suppliers of ES located in the NNRB. They were identified through a review of available data published in reports and other relevant documents (see Research Report 2).

Step 2: Cataloguing the ES to be supplied

The ES to be supplied and/or stabilized under the PES scheme are catalogued through site surveys including the collection of primary data, the analysis of secondary data and a literature review[2].

The catalogued ES for the NNRB are:

- regulation of sedimentation rates in the hydro-electricity power reservoirs[3];
- water regulation (replenishment of the water supply in the dry season and reduction of flooding in the wet season) in the hydro-electricity power reservoirs;
- provision of species diversity of forest animals and plants;
- provision of native forest cover; and
- regulation of water levels in rivers, streams, and reservoirs.

[2] See Research Report 2 'The Environmental, Economic and Social Condition of the Nam Ngum River Basin'.

[3] Soil erosion and resulting reservoir sedimentation might currently not be a problem for hydroelectric power companies. However, an increase in population density and associated agricultural activities in the NNRB over time may raise soil erosion rates and thus reservoir sedimentation in the future to significant levels.

Step 3: Identifying the sources of ES demand

Deteriorating water flow regimes and increasing sedimentation rates in reservoirs can cause a reduction in revenues and an increase in operating costs incurred by **hydroelectric power companies**. These companies would benefit from an improvement in water flow regimes and a reduction in reservoir sedimentation rates.

Low water levels in streams, rivers and reservoirs during the dry season, decreased native forest cover, and a decline in the chance of seeing forest wildlife reduce the enjoyment and thus the attractiveness of visiting the NNRB. Decreasing tourist numbers decrease the profits of **tourism operators** located in Vientiane. The tourism operators would benefit from an increase in water levels in streams, rivers, and reservoirs during the dry season, and continuing/ greater provision of native forest cover and wildlife watching opportunities.

Low water levels in streams, rivers and reservoirs during the dry season, decreased native forest cover, and declines in the chance of seeing forest wildlife reduce the enjoyment and thus the attractiveness of visiting the NNRB. **Domestic and international tourists travelling with a tourism operator** to the NNRB would benefit from an increase in water levels in streams, rivers, and reservoirs during the dry season, and the continuous/ or greater provision of native forest cover and wildlife watching opportunities.

Low water levels in streams, rivers and reservoirs during the dry season, decreased native forest cover, and a decline in the chance of seeing forest wildlife reduce the enjoyment and thus the attractiveness of visiting the NNRB. **Domestic and international independently traveling tourists** would benefit from an increase in water levels in streams, rivers, and reservoirs during the dry season, and continuing/ greater provision of native forest cover and wildlife watching opportunities.

A decrease in species diversity of forest animals and plants reduces the values the **general public of Lao PDR** holds for knowing that the diversity would increase or not further decrease[4]. The general public of Lao PDR would benefit from continuous/ greater provision of species diversity of forest animals and plants.

[4] Existence values

A decrease in species diversity of forest animals and plants reduces the values **the international community** holds for knowing that the diversity would increase or not further decrease. The international community would benefit from continuous/ greater provision of species diversity of forest animals and plants.

Step 4: Identifying potential ES supply

Potential suppliers of ES would be small scale farmers whose current land uses reduce the supply of the catalogued ES through the deforestation of native forests and other damaging agricultural practices in the NNRB.

The ES supply under the PES scheme would have to be additional to what would be supplied without the PES scheme.

The management actions identified to deliver the catalogued ES would include the following:

- Preventing poaching of forest animals inside the National Protected Area (NPA) through community patrols;
- reducing legal hunting of forest animals outside the NPA;
- preventing illegal slash and burn agriculture inside the NPA through community patrols;
- reducing slash and burn agriculture outside the NPA through a reduction of agricultural activity;
- reducing slash and burn agriculture outside the NPA through a change in agriculture towards a more sustainable fruit tree and vegetable agriculture;
- preventing illegal logging inside the NPA through community patrols;
- reducing legal logging outside the NPA; and
- planting native trees on deforested areas inside and outside the NPA.

The number and distribution of potential suppliers and their current land uses and agricultural practices would be identified through site surveys and stakeholder consultations at the farm level. Stakeholder consultations would be conducted following the "Guidelines on stakeholder engagement in REDD+ readiness with a focus on the participation of indigenous peoples and other forest-dependent communities"(UN-REED Programme 2013).

Supplier types may include individuals/ households and communities.

The following institutional arrangements would be assessed and recommendations made to ensure that the legal basis would allow the identified potential suppliers to participate in the PES scheme (see Step 19: Contracting the suppliers):

- the laws and regulations concerning the definition of forest categories that might restrict the proposed bundle of management actions;
- the laws and regulations concerning the viability of land use changes across categories (land utilization rights are bound to land categories) that might restrict the proposed bundle of management actions;
- the current land tenure situation in the NNRB (de jure, de facto, and customary use/utilization rights);
- the laws and regulations concerning the receipt of PES payments across the different supplier types (individuals, communities/ groups);
- the laws and regulations concerning contracts with small-scale farmers/ communities; and
- the laws and regulations concerning service contracts ('agreement between contracting parties whereby the service provider must serve, do, or create something according to the requirements of the service user who must pay for the services at the agreed upon price.') that would allow the contracting of farmers without legal land use/ utilization rights.

Step 5: Defining the type and degree of agent intervention[5]

The PES scheme would link existing ES demand and potential ES supply in the NNRB.

The link between the existing ES demand from

- hydroelectric power companies;
- tourism operators;
- domestic and international tourist traveling with a tourism operator;
- domestic and international independently traveling tourists;
- the general public of Lao PDR; and
- the international community;

and the potential ES supply from

- small scale farmers;

would be established through multiple agents who intercede between the prospective buyers and suppliers facilitating trade.

These agents act as 'brokers' with the capability of reducing the costs of engaging in exchange (transaction costs).

Transaction costs are defined as " … the expenses that buyers and suppliers face in organising and carrying out the process of exchanging resources" (Midgley et al. 2012, p.32).

The reasons why PES exchanges are currently not profitable for the small scale farmers and the potential buyers in the NNRB may include:

- land use/ utilization rights over land/forest and the catalogued ES that would be produced on the land/forest are not well defined, defended, and/or divestible;
- trust between potential buyers and suppliers might be lacking (the suppliers may be unsure if the buyers would pay them for delivering the ES; the buyers may be unsure if the suppliers would deliver the purchased ES);
- the knowledge of quantitative cause-effect relationships between inputs (changed land use and agricultural practices) and outputs (ES) is limited;

[5]For a full discussion of the definition of agents and their potential actions see Research Report 1.

- the costs of negotiations between several buyers and many suppliers are high; and
- the options to transfer the payments from the buyers to the suppliers (payment transfer options) are costly or non-viable.

Reducing these transaction costs could make trading with the otherwise non-marketed, ‘unowned’ ES mutually beneficial to buyers and suppliers.

The types of agents who would act as ‘brokers’ include departments of the Government of Lao PDR (on the national, province, and district level), NNRB organizations, local authorities (village heads/ committees) research institutions (National University of Laos; Australian National University; University of Western Australia), and domestic and international non-government organisations (NGOs).

The agents’ roles, contributions, and degree of intervention to facilitate PES exchanges would be specified through a participatory process.

An advisory committee would oversee the interventions of all agents.

Step 6: Selecting the ES buyers

The PES scheme would provide an opportunity to improve the economic efficiency of allocating the funds raised through compulsory payments of hydroelectric power companies and tourism operators for environmental projects.

Hydroelectric power companies and tourism operators may be obligated to pay levies into government-run funds that are earmarked for environmental projects. If such government-run funds were used to purchase the ES, participation in the PES scheme would be compulsory for the hydroelectric power companies and the tourism operators.

Hydroelectric power companies and tourism operators may be obligated through their Concession Agreements to use company funds to meet environmental obligations. Hydroelectric power companies and tourism operators would have to be convinced to use their funds in the PES scheme since they have the right to choose how to meet the environmental obligations, and hence, how to use these funds.

Positive returns to hydroelectric power companies and tourism operators would receive from participation in the PES scheme would be crucial to convincing them to engage in the PES scheme. Communication would be facilitated through information sessions, discussions and consultations.

Continuous participation in the development and implementation of the scheme would be assisted by including representatives of the hydroelectric power companies and tourism operators into the committee formed to advise the PES scheme development and implementation.

Participation of tourists visiting the NNRB with a tourism operator and those traveling independently could be made compulsory through the introduction of a NPA entrance fee. Where a NPA entrance fee already exists, it might have to be adjusted.

Participation of the international community (not visiting the NNRB) would be voluntary. Payments in the form of donations could be collected through a local or international NGO.

Participation of the general public of Lao PDR (not visiting the NNRB) would be voluntary if donations would be collected through a local and/ or international NGO. Participation would be compulsory if general tax revenues were used to buy the ES.

The existence of a PES scheme may attract further contributions through increasing certainty in the way they are used in producing ES.

Step 7: Securing funds to pay for the ES supply

The payments made by the tourists traveling with tourism operators, independently traveling tourists, the general public of Lao PDR, and the international community as well as existing funds raised through compulsory payments of hydroelectric power companies and tourism operators that are earmarked for environmental projects would be used to make PES payments to the suppliers.

Government-run and private funds may be earmarked for environmental projects.

The laws and regulations concerning the use of public funds for the PES scheme would have to be assessed.

The duration of PES scheme contracts with suppliers would have to be covered by the funding commitment and the retention of the land use/ utilization rights that are held by the suppliers, including the use/utilization rights over the produced ES (see Step 4: Identifying potential ES supply; and Step 19: Contracting the ES suppliers).

Step 8: Determining the types of returns to ES suppliers

Participating small-scale farmers would receive direct returns (the PES payments) and indirect returns (returns other than the PES payments) (Midgley et al. 2012).

The direct returns would be monetary though non-monetary direct returns would be considered if preferred by the small-scale farmers.

Indirect returns might include non-timber forest products (e.g., honey) through reforestation; increased soil fertility through reduction of soil erosion (increased harvests); income from selling cash crops that are planted as part of the scheme (e.g., vegetables, fruits) or on-site water-quality and aesthetic benefits arising from forest protection measures taken under the scheme. Indirect returns might also include capacity building and the potential to assert claims over land.

Step 9: Bio-physical modelling[6]

Bio-physical models would be used to predict the type and quantity of ES each supplier would generate through performing a bundle of management actions. Suppliers would have stated in their individual proposals which management actions they would each like to perform. (see Step 11: Estimating marginal costs of supply).

The bio-physical models would establish quantitative cause-effect relationships between management actions undertaken as part of the PES scheme (inputs) and changes in ES supply (outputs).

As illustrated in Figure 2, the bio-physical models would be used to estimate and compare:

- the ES supply produced through a bundle of management actions; and
- the estimated ES supply that would be produced if no new management actions were applied over the duration of the PES scheme (baseline ES supply).

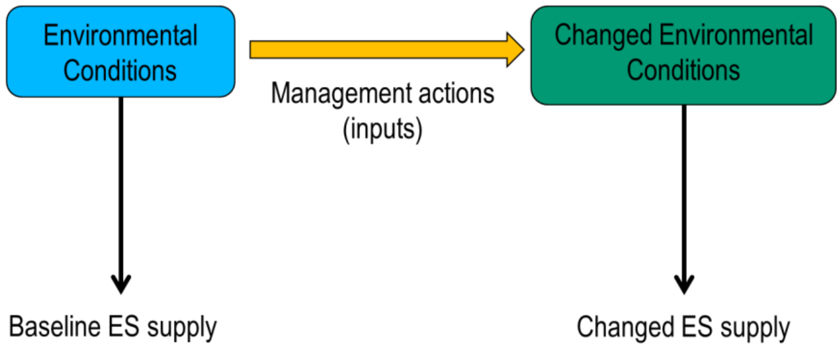

Figure 2

The baseline ES supply (ES supply without new management actions) in the NNRB might decrease over time (the blue line in Figure 3). The new management actions may reduce such

[6] The next three steps are interdependent:

- Step 9: Bio-physical modelling;
- Step 10: Estimating marginal benefits of supply; and
- Step 11: Estimating individual marginal costs of supply.

Together, they provide information required for the development of the payment system and the selection of the ES suppliers.

a decline (the green line in Figure 3a), may stabilize (Figure 3b) or may increase the ES supply relative to the levels currently experienced. (Figure 3c).

The basic idea behind the conceptual bio-physical model for the NNRB (see Figure 4) is that the management actions introduced by the PES scheme would have an impact on the condition of the environment. This impact would cause changes in the ES supply, dependent on various variables that describe the environment and the ways in which the environment is being used. The variables are grouped into seven ‘building blocks’, which represent different variable types. The arrows symbolise the causal links between the variables.

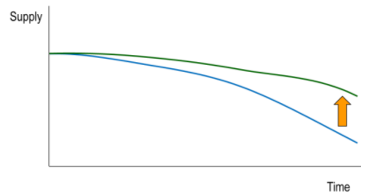

Figure 3a

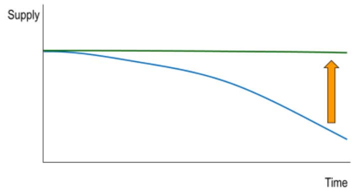

Figure 3b

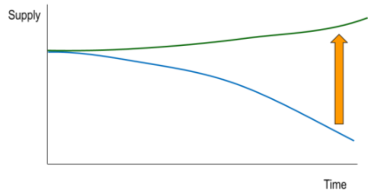

Figure 3c

The explanation of the bio-physical model in the following paragraphs is colour coded, so that the colours assigned to each point relate to the different ‘building blocks’ in Figure 4.

A summary of the relevant variables, their functional relationships, and the data collection requirements are provided in Table 1.

1. Land use practices (T1-T3)

These are variables that capture the current land use practices (main threats) impacting on the ES (Phoyduangsy et al. 2013). The quantification of these variables would require data collection. These variables would need to be measured for the current situation and estimated for the duration of the PES scheme assuming no new management actions.

- $T1$: Hunting/ poaching of animals in native forests;
- $T2$: Slash and burn agriculture in native forests; and
- $T3$: Logging of native forests.

2. New management actions (A1-A3)

These are variables that represent the new management actions that are aimed at reducing the main threats to the ES (Phoyduangsy et al. 2013).

These variables would be quantified at the 'farm level'[7] based on the proposals of potential ES suppliers.

- $A1$: Reducing hunting and poaching of forest animals (prevention/ reduction inside the NPA through community patrols/ reduction outside the NPA);
- $A2$: Reducing the area of forest being cleared (slash and burn) through a reduction of agricultural activity (prevention/ reduction inside the NPA through community patrols/ reduction outside the NPA);
- $A3$: Reducing the area of forest being cleared (slash and burn) outside the NPA through a change in agricultural activity towards growing more fruit trees and vegetables;
- $A4$: Reducing logging of native forest (prevention/ reduction of illegal logging inside the NPA through community patrols/ reduction of legal outside the NPA); and
- $A5$: Reforesting (native trees) deforested areas inside and outside the NPA.

3. Environmental condition (directly impacted by $T1-T3$ and $A1-A5$)

These are variables that capture the condition of the ecosystem either at the catchment or the 'farm level'.

The current levels of these variables would need to be measured using historical data, aerial photography, GIS observations, existing local forest surveys, information from forest departments, the literature, observations from other similar river basins, expert opinions, site visits by the research team

[7] The term 'farm level' includes areas outside the legally or de facto defined farm area (e.g., the NPA), in which management actions would be performed by the ES suppliers (individuals or groups).

and stakeholder consultations. Estimates would need to be made for their levels over the duration of the PES scheme both with and without new management actions, based on the above-mentioned data sources. Because the threats ($T1 - T3$) and the new management actions ($A1 - A5$) impact directly on the environmental conditions, their future conditions would be estimated as a function of the main threats and the new management actions.

- ***Native forest (ha) - NF***

  $NF = f(T2; T3; A2 - A5)$

This variable represents both an ecosystem condition and an ES output (coded blue with a green border).

- ***Hunted/ poached forest animals (numbers) – FA***

  $FA = f(T1; A1)$

- ***Soil eroding agriculture (ha) – SEA***

  $SEA = f(T2; A2 - A3)$

  Fruit tree and vegetable agriculture (ha) – FVA

  $FVA = f(T2; A2 - A3)$

- ***Logged areas (ha) – LA***

  $LA = f(T3; A5)$

4. Processes

These are parameters that capture processes, which affect ecosystem condition variables. They would be assumed to be constant for the period of the PES scheme.

- ***Evaporation (mm/yr) - E***

The quantification of this parameter would require data to be collected from meteorological agencies in Lao or neighbouring countries in comparable locations.

- ***Rainfall (mm/yr) - R***

The quantification of this parameter would require data to be collected from meteorological agencies in Lao or neighbouring countries in comparable locations.

- ***Water use rates of native forests (ML/ha) - WRF***

The quantification of this parameter would require data to be collected from the literature.

- ***Water use rates by agriculture and logged areas (ML/ha) - WRA***

The quantification of this parameter would require data collected by means of bio-physical testing through test plots elsewhere, using water monitoring data from farm accounts (in the NNRB or other basins in Lao), conducting farmer surveys, and/ or seeking advice from agronomists and experts on agricultural water use.

- ***Soil erosion/ runoff rates from soil eroding agriculture and in logged areas (t/ha/yr) – SRA***

$$SRA = f(ST; S; \{FA, SEA, FVA, LA\}; R; AS)$$

This parameter could be estimated as a function of soil type (ST), slope (S), land use type (FA, SEA, FVA, LA), rainfall (R), and area size (AS) using the Universal Soil Loss Equation (Renard et al. 1997).

- ***Soil erosion/ runoff rates from native forests (t/ha/yr) - SRF***

$$SRF = f(ST; S; NF; R; AS)$$

This parameter could be estimated as a function of soil type (ST), slope (S), land use type (NF), rainfall (R), and area size (AS) using the Universal Soil Loss Equation (Renard et al. 1997).

5. External impacts

These variables capture the environmental conditions influenced by management actions and land uses in the NNRB not considered in this model. They are assumed to be constant over the period of the PES scheme[8]. These external impacts would need to be accounted for when calculating the baseline ES provision.

- ***Total sediment loads in rivers and streams from all other land uses (t/yr) - TLO***

The quantification of this variable would require data collection either from water monitoring research or related literature.

- ***Total water use by all other land uses (ML/yr) - TWO***

The quantification of this variable would require data collection from research examining the same land uses as those present in the NNRB. Alternatively, it could be replaced with a ‘base-case flow’ variable, which could capture the average NNRB river flow without changes in smallholder agriculture and native vegetation. Quantifying the base-case flow would require baseline monitoring data from river gauges.

[8]This strategy is one of practical necessity because of the magnitude of external factors that may be relevant.

6. Environmental condition (indirectly impacted or unaffected by T1-T3 and A1-A5)

These are variables that capture the environmental conditions at the catchment and the 'farm level'. The environmental conditions are either indirectly impacted or are unaffected by the threats ($T1 - T3$) and the new management actions ($A1 - A5$).

- ***Soil type – ST***

The quantification of this variable would require data collection through site surveys, stakeholder consultation, and expert opinions.

- ***Slope - S***

The quantification of this variable would require data collection through site surveys, stakeholder consultation, GIS data, and expert opinions.

- ***Distance from rivers – D***

The quantification of this variable would require data collection through site surveys, stakeholder consultation, GIS data, and expert opinions.

- ***Total water use by agriculture and logged areas at the catchment level (ML/yr) – TWA***

$$TWA = f(\{SEA, FVA, DUL, LA\}; AS; WRA)$$

This variable would be estimated as a function of land use type (FA, SEA, FVA, LA), areas size (AS), and water use rate by agriculture and logged areas (WRA). The functional form would be estimated through literature research and expert interviews.

- ***Total water use by native forest at the catchment level (ML/yr) – TWF***

$$TWF = f(WRF; NF)$$

This variable would be estimated as a function of water use rates by native forest (WRF) and total area of native forest (NF).

- ***River flow (ML/yr) – RF***

$$RF = f(R; TWA; TWF; TWO)$$

This variable would be estimated as a function of rainfall (R), the total water use by land use (TWA), total water use by native forest (TWF), the total water use by all other land uses (TWO).

- ***Total sediment loads in rivers and streams from agriculture and logged areas (t/yr) – TLA***

$$TLA = f(AS; R; D; SRA)$$

This variable would be estimated as a function of area size (AS) of each land use type (SEA, FVA, LA), rainfall (R), distance to rivers (D), and runoff rates from each land use type (SRA). The form of the function could be determined through expert review (agronomist, water quality experts). Alternatively, functions could be transferred from existing sediment run-off models in other basins in Lao or the region.

Information on erosion, deposition, and sediment run-off models can be found, for example, in Newham et al. (2004), Owens et al. (2006), Rosewell (1993), and Wilkinson et al. (2004).

- ***Total sediment loads in rivers and streams from native forest areas (t/yr) – TLF***

This variable could be estimated as a function of sediment loads based on area size (AS), distance to rivers (D), rainfall (R), and soil erosion rates from native forests (SRF).

$$TLF = f(AS; R; D; SRF)$$

The functional form could be determined based on the literature or on expert opinions. Sediment loads will vary by location (e.g., steep regions and valleys).

- ***Total sediment loads in rivers and streams (t/yr) – TL***

$$TL = TLF + TLA + TLO$$

This variable would be estimated as a function of total sediment loads in rivers and streams from native forest (TLF), total sediment loads in rivers and streams from agriculture and logged areas (TLA), and total sediment loads in rivers and streams from all other land uses (TLO).

- ***Sediment deposition (t/yr) - SD***

This variable would be estimated as a function of river flow (officially a function of flow and velocity – in this model only a function of flow for simplicity) (e.g., Wilkinson et al. 2004). The functional form would be estimated through literature research and expert interviews.

$$SD = f(RF)$$

- ***Sediment loads into reservoirs (t/yr) – SLR***

This variable represents both an ecosystem condition and an output variable (coded blue with yellow border).

It captures the amount of river sediment that reaches the reservoir. This is not the same as total sediment loads, because there is likely to be some deposition of sediment before the river reaches the dam. This variable would be estimated as a function of total sediments loads in rivers and streams (TL) and sediment deposition (SD).

$SLR = f(TL; SD)$

The functional form would be estimated through literature research and expert interviews.

- ***Water levels in reservoirs (ML) - WLR***

$WLR = f(R; E; RF)$

This variable would be estimated as a function of rainfall (R), evaporation (E), and river flows (RF). The functional form would be estimated through literature research and expert interviews.

7. ES output

These are variables that capture the ES output.

- ***Native forest (ha) – NF***

This variable represents both an ecosystem condition and an output variable (coded blue with green border).

The current levels of this variable would be measured using historical data, aerial photography, GIS observations, existing local forest surveys, information from forest departments, the literature, observations from other similar river basins, expert opinions, site visits by the research team and stakeholder consultations. Estimates would need to be made for their levels over the duration of the PES scheme both with and without new management actions, based on the above-mentioned data sources. Because the threats ($T1–T3$) and the new management actions ($A1 - A5$) impact directly on this variable, its future conditions would be estimated as a function of the main threats and the new management actions.

- ***Species diversity of animals and plants (index) - DPA***

$DPA = f(NF; FA)$

Species diversity is a measure of the number of species in a region, usually weighted in some way to account for 'evenness', that is how equally abundant the different species are (Hill 1973). Commonly used indices of species diversity are species richness (simply the total number of species, not weighted for equality of abundance) or the Shannon's index and Simpson's index (both account for evenness as well as total number of species)(e.g., Magurran 2004).

This variable would be estimated as a function of native forest providing habitat (NF) and the number of hunted/ poached animals (FA). The functional form would be estimated through literature reviews and expert opinions.

A species-area curve is a relationship between area and the number of species found within that area; theoretical species area curves are often used to estimate species richness (Arrhenius 1921, Scheiner 2003). So the impact on species diversity of restoring areas with natural habitat (or losing areas of natural habitat) could be estimated by using a species area curve that has been developed for a similar kind of habitat (tropical rain forest).

The effect of poaching (or stopping poaching) could be estimated by modelling populations, perhaps for one or a few 'iconic' species. This would allow estimating how population size and chance of extinction might be affected by different levels of poaching. Similarly, this model could be used to predict the chance of tourists seeing certain species on a tour/trek as a function of population density.

- ***Sediment loads into reservoirs (t/yr) – SLR***

$$SLR = f\ (TL;\ SD)$$

These variables represent both an ecosystem condition and an output variable (coded blue with yellow border). These variables would be estimated as a function of total sediments loads in rivers and streams (TL) and sediment deposition (SD). The functional form would be estimated through literature reviews and expert opinions.

- ***Water supply in reservoirs (ML) – WSR***

$$WSR = f\ (WLR;\ SLR)$$

These variables measure the amount of water that would actually be delivered to the hydropower plant for use in electricity generation. These variables would be estimated as a function of the water level in the reservoirs (WLR) and the sediment load into the reservoir (SLR), which would reduce the reservoir capacity. The hydro-electricity power plants might have already collected data on these variables. The functional form would be estimated through literature reviews and expert opinions.

- ***Water levels in rivers, streams, and reservoirs (ML) – WLRR***

$$WLRR = f\ (WLR;\ RF)$$

These variables would be estimated as a function of the water level in reservoirs (WLR) and the river flow (RF). The functional form would be estimated through literature reviews and expert opinions.

A Bayesian Network approach (e.g., Marcot et al. 2006, McCann et al. 2006) would be used to quantify the causal links between the variables as probability distributions. By defining relationships as probability distributions, the model will explicitly account for uncertainties associated with the collected data and knowledge about the system.

The benefits of a Bayesian Network modelling approach are its ability to incorporate different data sources (including expert opinions and literature studies). Knowledge about environmental and socio-economic systems can be expressed quantitatively and qualitatively.

This is particularly valuable in a data-poor environment such as may be encountered in the Lao context.

Table 1

Variable	Functional relationship	Data collection
T1 – T3	-	yes
A1 – A5	-	yes
Native forest in steep regions and valleys (NF)	f (T2; T3/ A2-A5)	yes
Hunted/ poached forest animals (FA)	f (T1/ A1)	yes
Soil eroding agriculture (SEA)	f (T2/ A2;A3;A4)	yes
Fruit tree and vegetable agriculture (FVA)	f (T2/ A2-A3)	yes
Logged areas (LA)	f (T3/ A4-A5)	yes
Evaporation (E)	-	yes
Rainfall (R)	-	yes
Water use rates by native forests (WRF)	-	yes
Water use rates by agriculture and logged areas (WRA)	-	yes
Soil erosion/ runoff rates from soil eroding agriculture and in logged areas (SRA)	SRA = f (ST; S;{ FA, SEA, DUL, FVA, LA}; R; AS)	no
Soil erosion/ runoff rates in steep regions and valleys (SRF)	f (ST; S; NF; R; AS)	no
Total sediment loads in rivers and streams from all other land uses (TLO)	-	yes
Total water use by all other land uses (TWO)	-	yes
Soil type (ST)	-	yes
Slope (S)	-	yes
Distance from the river (D)	-	yes
Total water use by agriculture and logged areas (TWA)	f ({SEA, FVA, LA}; AS; WRA)	no
Total water use by native forest (TWF)	f (WRF; NF)	no
River flow (RF)	f (R; TWA; TWF; TWO)	no
Total sediment loads in rivers and streams from agriculture and logged areas (TLA)	f ({SEA,FVA,LA}; AS; R; D; SRA)	no
Total sediment loads in rivers and streams from native forest areas (TLF)	f (NF; D; R; SRF)	no
Total sediment loads in rivers and streams (TL)	TL=TLF+TLA+TLO	no
Sediment deposition (SD)	f (RF)	yes
Sediment loads into reservoirs (SLR)	f (TL; SD)	no
Water levels in reservoirs (WLR)	f (R; E; RF)	no
Native forest (NF)	f (T2; T3/ A2-A5)	yes
Species diversity of animals and plants (DPA)	f (NF; FA)	yes
Sediment loads into reservoirs (SLR)	f (TL; SD)	no
Water supply in reservoirs (WSR)	f (WLR; SLR)	no
Water levels in rivers, streams, and reservoirs (WLRR)	f (WLR; RF)	no

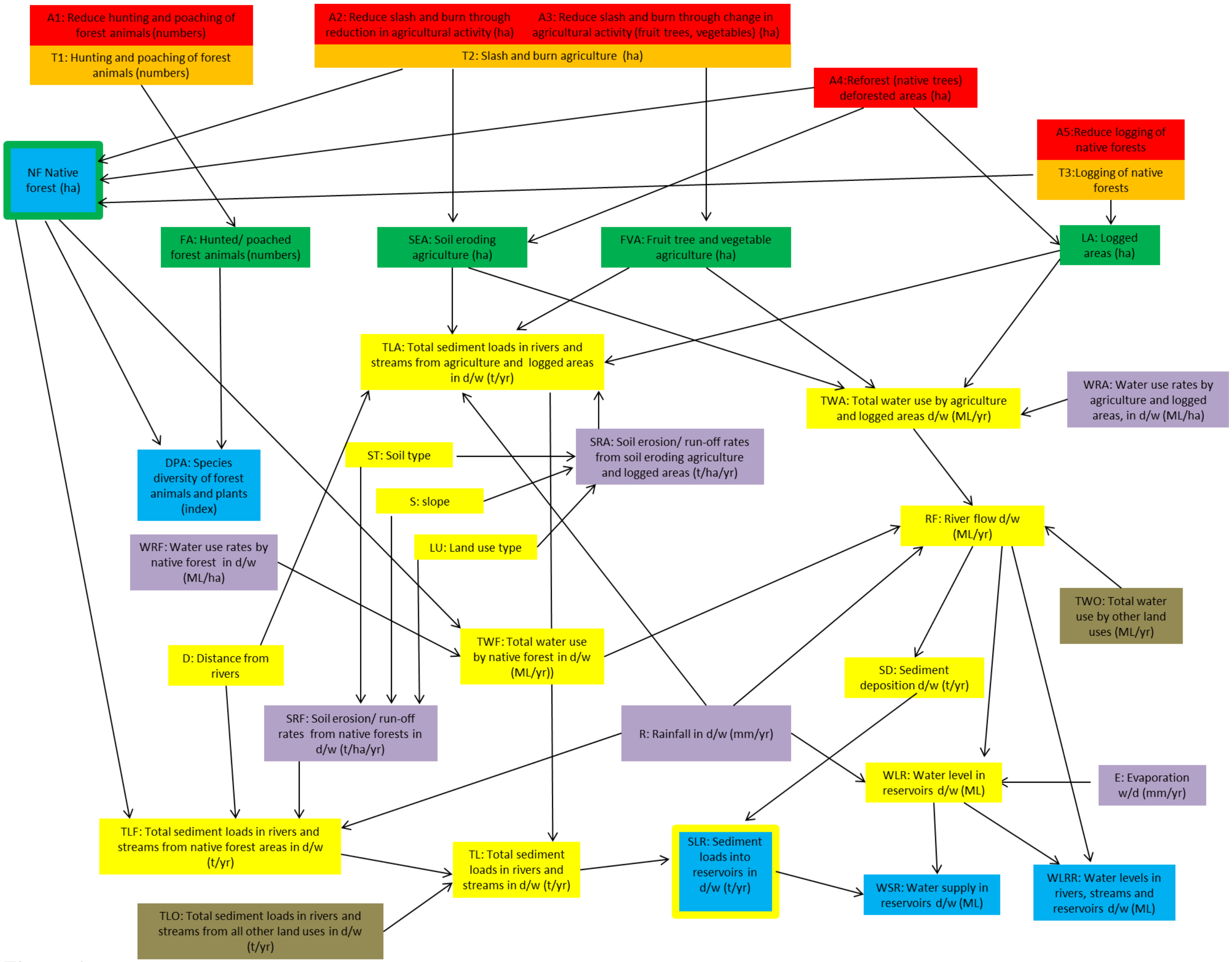
A1: Reduce hunting and poaching of forest animals (numbers)
T1: Hunting and poaching of forest animals (numbers)
A2: Reduce slash and burn through reduction in agricultural activity (ha)
A3: Reduce slash and burn through change in agricultural activity (fruit trees, vegetables) (ha)
T2: Slash and burn agriculture (ha)
A4:Reforest (native trees) deforested areas (ha)
A5:Reduce logging of native forests
T3:Logging of native forests
NF Native forest (ha)
FA: Hunted/ poached forest animals (numbers)
SEA: Soil eroding agriculture (ha)
FVA: Fruit tree and vegetable agriculture (ha)
LA: Logged areas (ha)
TLA: Total sediment loads in rivers and streams from agriculture and logged areas in d/w (t/yr)
TWA: Total water use by agriculture and logged areas d/w (ML/yr)
WRA: Water use rates by agriculture and logged areas, in d/w (ML/ha)
ST: Soil type
SRA: Soil erosion/ run-off rates from soil eroding agriculture and logged areas (t/ha/yr)
DPA: Species diversity of forest animals and plants (index)
S: slope
LU: Land use type
RF: River flow d/w (ML/yr)
WRF: Water use rates by native forest in d/w (ML/ha)
TWO: Total water use by other land uses (ML/yr)
TWF: Total water use by native forest in d/w (ML/yr))
D: Distance from rivers
SD: Sediment deposition d/w (t/yr)
SRF: Soil erosion/ run-off rates from native forests in d/w (t/ha/yr)
R: Rainfall in d/w (mm/yr)
WLR: Water level in reservoirs d/w (ML)
E: Evaporation w/d (mm/yr)
TLF: Total sediment loads in rivers and streams from native forest areas in d/w (t/yr)
TL: Total sediment loads in rivers and streams in d/w (t/yr)
SLR: Sediment loads into reservoirs in d/w (t/yr)
WSR: Water supply in reservoirs d/w (ML)
WLRR: Water levels in rivers, streams and reservoirs d/w (ML)
TLO: Total sediment loads in rivers and streams from all other land uses in d/w (t/yr)

Figure 4

The changes in ES output variables (blue) would be estimated by comparing the model results for three different settings:

Setting 1: Estimating the ES outputs <u>under the current situation</u> with <u>no</u> new management actions:

- The environmental condition variables (green) and the output variable DPA (blue with green border) influenced by current land use practices/ main threats (orange) would be set to the values of the current situation.
- The variables that capture the new management actions (coded red) to reduce the main threats (coded orange) on the ES output variables (coded blue) would be set to a value of zero.

Setting 2: Estimation of the quantity of the ES outputs predicted <u>at the time when the PES scheme is due for completion</u> with <u>no</u> new management actions:

- The environmental condition variables (green) and the output variable DPA (blue with green border) influenced by current land use practices/ main threats (orange) would be set to values predicted at the time when the PES scheme is due for completion.
- The variables that capture the new management actions (red) to reduce the main threats (coded orange) on the ES output variables (blue) would be set to a value of zero.

Setting 3: Estimation of the quantity of the ES predicted at <u>the time when the PES scheme is due for completion</u> with <u>new</u> management actions:

- The environmental condition variables (coded green) and the output variable DPA (coded blue with green border) influenced by current land use practices/ main threats (coded orange) would be set to values predicted at the time when the PES scheme is due for completion.
- The variables that capture the new management actions (coded red) to reduce the main threats (coded orange) on the ES output variables (coded blue) would be set to values as proposed by the potential suppliers.

Estimation of the quantity of the ES outputs generated by the new management actions would have to account for the possibility of a diminishing baseline defined as a decline in each ES type. In this case, ES outputs generated through the new management actions (inputs) conducted within the PES scheme would have to be estimated in three stages:

Stage 1: Estimating the baseline quantities of the ES outputs - the difference of the current quantities of the ES outputs (Setting 1) and the quantities generated in the absence of new management actions at the time when the PES is due for competition (Setting 2).

Stage 2: Estimating the changes in the quantities of the ES outputs - the difference of the current quantities (Setting 1) and the quantities generated in the presence of new management actions at the time when the PES is due for completion (Setting 3).

Stage 3: Estimating the changes in the quantities of the ES outputs generated under the PES scheme - the difference between the baseline quantities of the ES outputs (Step 1) and the changes in quantities of ES outputs in the at the time when the PES is due for completion (Step 2).

The bio-physical model would have to be applied separately to data for the dry and the wet season (marked d/w within the model).

The bio-physical model would be applied at the ‘farm level’, for each potential supplier individually, to capture differences in the effectiveness of the inputs and the marginal costs of ES supply incurred across potential suppliers. This would require differentiation between:

- variables that impact on ES supply and do differ across potential suppliers; and
- variables that impact on ES supply but do not differ across suppliers.

▪ It would be expected that the main differences of the effectiveness of inputs to generate ES outputs across the potential suppliers would be a result of differences in their location within the basin (L), the soil types of their farms (ST), the land use types {SEA, FVA, DUL, LA}, the farm size (AS), and the land slope (S). Data on these variables would be collected through on-farm surveys.

Organising and conducting the data collection for the bio-physical modelling requires the identification of the institutions/ government organisations that would be involved.

Step 10: Estimating marginal benefits of ES supply

The monetary value of the marginal benefits of the ES catalogued in the NNRB would be estimated using two different economic valuation techniques:

- the avoided costs method; and
- discrete choice experiments (see, for example, Barbier et al. 2009).

The avoided costs method would be used to estimate the monetary value of the following benefits:

- reduced sedimentation rates in reservoirs; and
- improved water regulation in reservoirs;

High reservoir sedimentation rates and poor water regulation may result in

- power generation losses caused by reduced turbine efficiency;
- an increase in the frequency of repairs and maintenance;
- an increase in power generation losses due to increased downtime;
- a reduction in the life-span of turbines;
- a reduction in regulating of power generation (floods and droughts vary with seasons); and
- a loss of storage capacity in reservoirs due to sediment deposition (see, for example, Lysne et al. 2003).

The avoided costs would be estimated as a reduction in operating costs and an increase in revenues enjoyed by hydro-electricity companies resulting from a reduction in reservoir sedimentation rates and improved water regulation.

Avoiding the increased operating costs and reduced revenues through improved water regulation and decreased reservoir sedimentation rates would represent the benefits to each of the hydro-electricity companies. These benefits would be estimated per company per year.

Discrete choice experiments would be used to estimate the values of the following ES for current users and non-users of the NNRB:

- Provision of species diversity of forest animals and plants

  The values that respondents may attach to the provision of species diversity of forest animals and plants include direct use values (e.g., opportunity to watch/ experience wildlife and plants), existence values (the value of knowing that certain species will not be extinct), bequest values, and option values for future use. These values cannot be identified separately.

- Provision of native forest cover

  The values that respondents may attach to the provision of native forest cover include direct use values (e.g., landscape beauty, forest experience), existence values (the value of knowing that a certain forest cover will remain), bequest values, and option values for future use. These values cannot be identified separately.

- Regulation of water levels in rivers, streams and reservoirs

  The values that respondents may attach to the water levels in rivers, streams, and reservoirs during the dry season include direct use values (e.g., landscape beauty, nature experience), existence values, bequest values, and option values for future use. These values cannot be identified separately.

Discrete choice experiments are based on surveys that ask respondents to make a choice between the outcomes of alternatives management options. The outcome of each management option would be described by several attributes and vary across the management options. By choosing their preferred management option, respondents make trade-offs between the attributes that describe the alternative management options.

The discrete choice experiments would include bio-physical attributes, an ‘access’ attribute (an attribute that determines whether or not the respondents would could access the areas in the NNRB interesting to tourists), and a cost attribute (the payment to the respondents to undertake the management actions of the respective management option). The levels of the bio-physical attributes would be estimated by the bio-physical models (see Step 9). The levels of the cost attribute would be determined through focus groups. The attribute ‘access’ would be included into the choice sets to allow the estimation of the ‘tourist’ value of the NNRB.

The management options would be presented to the respondents in hypothetical choice scenarios. A zero-cost management option representing the ‘do-nothing’ option would always be available in each of these choices.

Each respondent would be presented with a sequence of choice scenarios.

The payment mode, payment frequency, and the range of the payment levels would be presented to the respondents.

Payment mode, payment frequency, and the range of the payment levels would be different for different groups of respondents (e.g., domestic and international tourists).

Defining the range of the levels of the non-cost attributes would require information about the supply potential to capture diminishing marginal benefits. This information would be collected from potential suppliers as part of their expression of interest.

The data collected from the discrete choice experiment would be used to estimate implicit prices. An implicit price is the average monetary value per unit change in any of the attributes across all respondents, for example, LAK X per hectare of native forest cover per tourist per visit. The aggregate marginal benefits would be calculated as the sum over the implicit prices multiplied by the number of organised and independently traveling tourists, respectively, predicted over the duration of the PES scheme.

The aggregate marginal benefits enjoyed by the tourism operators would be the avoided loss of producer surplus gained through the avoided reduction in tourist numbers predicted over the duration of the PES scheme in the absence of any new management actions multiplied by the number of tourism operators.

The following tasks would be carried out when conducting the discrete choice experiments:

- selecting a pool of potential respondents (sample frame); for example, the population of Vientiane; international tourists arriving at the international airport; domestic and international tourists booking a tour with tourism operators;
- specifying how respondents would be selected (sampling method);
- determining the number of respondents (sample size);
- designing the survey including conducting focus groups and pilot surveys;

- surveying the selected respondents through personal interviews (data collection);
- analysing the data (econometric modelling);
- estimating implicit prices for the attributes; and
- estimating aggregate marginal benefits using the outputs of the bio-physical models at the household level, population data/ data on tourist numbers (users), and data collected from the tour operators.

Organising and conducting the economic valuations requires the identification of the institutions/ government organisations that would be involved.

Step 11: Estimating individual marginal costs of ES supply

The individual marginal costs to the ES suppliers are unknown to the buyers and their agents. They would be estimated through a reverse auction (Vickrey 1961, Vickrey 1962).

The aggregate of each individual's marginal costs of supply, estimated through a reverse auction, would include:

- the costs of fulfilling the contract,
- the costs of forgone profits from previous land and labour use, and
- a risk premium[9].

The auction format would be based on an approach used in the finance industry. Each auction participant would be asked to state the type and quantity of inputs (the management actions they would be willing to perform), being offered a range of prices per unit of input[10]. The prices offered would be interpreted as individual marginal costs for given quantities of inputs as stated by the auction participants. This way, the auction participants reveal their individual marginal costs per unit of input.

A quantified example of two farmers participating in a reverse auction is illustrated in Figure 5 and supports the explanations presented in the orange box below[11].

[9] The individual components of the aggregate marginal costs cannot be identified, rather the aggregate is revealed through the bidding process.

[10]In a competitive auction, such an approach does not provide incentives to claim informational rents. Informational rents (Ferraro 2008) are marginal cost claims that exceed the real marginal costs. By proposing a quantity that would incur individual marginal costs that are either lower or higher than the offered price, auction participations would pass up the opportunity to maximise their individual net returns they would gain from PES scheme participation.

[11]The example is designed to illustrate the principles and does not reflect the real situation in the NNRB. The exchange rate AU$/LAK equals 1/7,218.75 (17 February 2014).

Each participant states the number of trees they each propose to plant, given a range of prices per tree planted that they would be paid.

Farmer 1 proposes to plant 1,000 trees if paid LAK 7,000 per tree and 2,600 trees if paid LAK 21,000. Farmer 2 proposes to plant 2,000 trees if paid LAK 7,000 and 3,600 if paid LAK 21,000.

This example shows that the more trees the farmers propose to plant, the more costly planting an additional tree becomes.

It also shows that the marginal costs for planting trees differ across the two farmers. The marginal costs of planting 2,000 trees are LAK 14,000 for farmer 1 and LAK 7,000 for farmer 2.

Presented in the reverse auction | Stated by auction participants

Farmer 1	
Price per tree	*Number of trees*
LAK 7,000	1,000
LAK 10,500	1,500
LAK 14,000	2,000
LAK 17,500	2,300
LAK 21,000	2,600

Farmer 2	
Price per tree	*Number of trees*
LAK 7,000	2,000
LAK 10,500	2,500
LAK 14,000	3,000
LAK 17,500	3,300
LAK 21,000	3,600

Farmer 1	
Marginal costs per tree	*Number of trees*
LAK 7,000	1,000
LAK 10,500	1,500
LAK 14,000	2,000
LAK 17,500	2,300
LAK 21,000	2,600

Farmer 2	
Marginal costs per tree	*Number of trees*
LAK 7,000	2,000
LAK 10,500	2,500
LAK 14,000	3,000
LAK 17,500	3,300
LAK 21,000	3,600

Figure 5

Conducting the reverse auction would require assembling an organising committee. Its tasks would include:

- designing all documents and plans;
- assisting potential suppliers; and
- conducting the auctions.

The organizing committee could be comprised of provincial, district, and local authorities and/ or other relevant organisations. The tasks would be distributed accordingly.

The training of the provincial, district and local authorities and other involved organisations would be conducted through the appropriate extension agencies.

The opportunity to participate in the reverse auction (and so possibly in the PES scheme) would be advertised by the organizing committee. Small scale farmers would be invited to submit an expression of interest to participate. Participation would be based on the 'Guidelines on free, prior and informed consent'(UN-REED Programme 2013).

To achieve equal opportunities across all ethnic groups, invitations would be extended to all small scale farmers who meet the basic eligibility criteria (see Step 13: Selecting the ES suppliers).

Information about the PES scheme, and the reverse auction in particular, would be provided to interested potential suppliers during general village meetings, familiarization sessions and training workshops for households. If possible, they would be embedded into existing local structures.

Interested potential suppliers would be informed and trained in:

- alternative land uses and management strategies;
- the notion of being 'ES suppliers';
- the concept of competitive auctions; and
- how to prepare a proposal.

The participants would receive the following information to ensure the feasibility and transparency of the reverse auction:

- a menu of management actions (the management framework from which potential suppliers can select a bundle of specific management actions that suit them best);
- information about the payment system (see Step 12: Developing the payment system);
- information about the supplier selection mechanism (see Step 13);
- information about the potential risks to the suppliers and how they would be managed; and
- information that they do not have to participate in the PES scheme if they do not wish to.

The potential suppliers would not be provided with information on the proposals of the other potential suppliers.

The risks to suppliers, buyers and agents would be identified. Both risks and risk management strategies would be communicated to all PES scheme participants.

The (perceived) risks to the suppliers would include:

- The suppliers receive no or lower payments than agreed on due to corruption or lack of capabilities of the involved agents (see Step 5: Defining the type and degree of agent intervention). A careful selection of the involved agents and the possibility for suppliers to file an official complaint to a neutral and independent third-party mediator might reduce this (perceived) risk.
- Contracted land may be requisitioned by the state. Legally confirmed use/ utilization rights would reduce this (perceived) risk.
- The suppliers cannot comply with the contract due to external causes. To minimize this risk, the supplier performance would be input-based (see Step 16: Supplier performance measure) and the monitoring would account for changing external conditions.
- A lack of understanding may have the consequence that auction participants underestimate their true marginal costs of supply and thus incur personal net losses. This risk would be minimized by conducting trainings for and providing support to the participants of the reverse auction.

The risks to buyers would include:

- The buyers receive no or less ES than agreed on due to supplier non-compliance. This risk would be minimized through the use of the bio-physical models that quantify the relationship between management actions and ES, the conditionality of the payments to suppliers and the possibility for buyers to file an official complaint to a neutral and independent third-party mediator.

The risks to agents would include:

- Agents might be liable if suppliers did not conduct the contracted management actions or buyers did not make the payments. This risk would be reduced through legally binding and enforceable contracts between suppliers and buyers (and/ or their agents).

Organising and conducting the reverse auction (including informing and training of agents and auction participants) requires decisions on:

- which institutions/ government organisations at what level would be involved;
- who would train the trainers;
- how would the trainers inform and train the auction participants;
- how would the training be assessed as being successful; and
- who would conduct the reverse auctions.

Step 12: Developing the payment system

The payment system would be determined by the agents (see Step 5: Defining the type and degree of agent intervention), in consultation with the buyers and the potential suppliers. Consultations with potential suppliers would be conducted following the 'Guidelines on stakeholder engagement in REDD+ readiness with a focus on the participation of indigenous peoples and other forest-dependent communities'(UN-REED Programme 2013).

The first payment (to cover inputs other than labour and land) would be made immediately after suppliers sign their PES contracts. The remaining payments would be spread over the contract duration (perhaps half-yearly or yearly). Shorter periods between payments would reduce the investment risk to suppliers (and might increase suppliers' trust in the scheme, and hence their participation rate), but would increase the transaction costs of the scheme.

How the payment rate for a case with a single output type (ES type) produced by a single input type (type of management action) would be determined is described below[12,13].

A quantified example[14] illustrated in Table 2, Table 3, Table 4, Figure 6, and Figure 7 supports the explanation presented in the orange boxes below. The example assumes that one hundred farmers participated in a reverse auction.

The input quantities each auction participant would propose to apply, given their corresponding individual marginal costs per unit of input, would have been estimated in Step 11 (Estimating individual marginal costs of supply).

[12]This section describes a simplified approach to communicate the general principles of this payment system. A more detailed and technical explanation is provided in Annex 1.

[13]This approach can easily be extended to a case where multiple input types produce multiple output types if the input-output relationships are separable across all input types and outputs types. That is, a single output type is produced by a single input type and a single input type produces a single output type. An explanation of determining the payment rate if that is not the case is given in Annex 2.

[14]The example is designed to illustrate the principles and does not reflect the real situation in the NNRB. The exchange rate AU$/LAK equals 1/7,218.75 (17 February 2014).

Table 2 illustrates data relating to two of the one hundred participating farmers. The first two columns present the numbers of trees they each proposed to plant given their individual marginal costs. For example, Farmer 1 proposed to plant 2,000 trees given a marginal cost of LAK 14,000 per tree.

Table 2:

Farmer 1				
Number of trees	Marginal costs per tree	Tons of reduced sediment per year	Input-output conversion factor	Marginal costs per ton of reduced sediment per year
1000	LAK 7,000	12	0.012	LAK 583,333
1500	LAK 10,500	23	0.015	LAK 684,783
2000	LAK 14,000	33	0.017	LAK 848,485
2300	LAK 17,500	43	0.019	LAK 936,047
2600	LAK 21,000	50	0.019	LAK 1,092,000

Farmer 2				
Number of trees	Marginal costs per tree	Tons of reduced sediment per year	Input-output conversion factor	Marginal costs per ton of reduced sediment per year
2000	LAK 7,000	16	0.008	LAK 875,000
2500	LAK 10,500	24	0.010	LAK 1,093,750
3000	LAK 14,000	34	0.011	LAK 1,235,294
3300	LAK 17,500	43	0.013	LAK 1,343,023
3600	LAK 21,000	50	0.014	LAK 1,512,000

Biophysical models (Step 9) would be used to convert the individual input quantities into individual output quantities. This is achieved using individual input-output conversion factors shown in the fourth column of Table 2.

Table 2 illustrates that if Farmer 1 plants 2,000 trees the sediment loads will be reduced by 33 tons per year. The input-output conversion factor for Farmer 1 is calculated as follows:

$$\text{Conversion factor} = 33 \text{ tons} \div 2{,}000 \text{ trees} = 0.017 \text{ tons per tree}$$

The input-output conversion factors would differ across individual suppliers if the effectiveness of the inputs in producing the outputs differed at different locations.

The input-output conversion factors are larger for Farmer 1 compared to Farmer 2. That is, Farmer 1 reduces more sediment for the same number of trees than Farmer 2.

The marginal costs per unit of output are calculated by dividing the marginal cost per unit of input by the input-output conversion factor.

The marginal cost per ton of sediment reduction is calculated by dividing the marginal cost per tree by the input-output conversion factor. This is illustrated in Table 2 for Farmer 1 at a marginal cost of LAK 14,000 per tree planted:

$$\text{Marginal cost per ton} = \text{LAK } 14{,}000 \div 0.017 = \text{LAK } 848{,}485$$

The data on individual quantities of output and individual marginal cost per unit of output would be used to estimate individual marginal cost functions.

The marginal cost function of Farmer 1 is shown Figure 6. The blue diamonds represent corresponding quantity-marginal cost pairs (Table 2, columns 3 and 5). This function shows that reducing sediment loads becomes more costly with increasing sediment reduction.

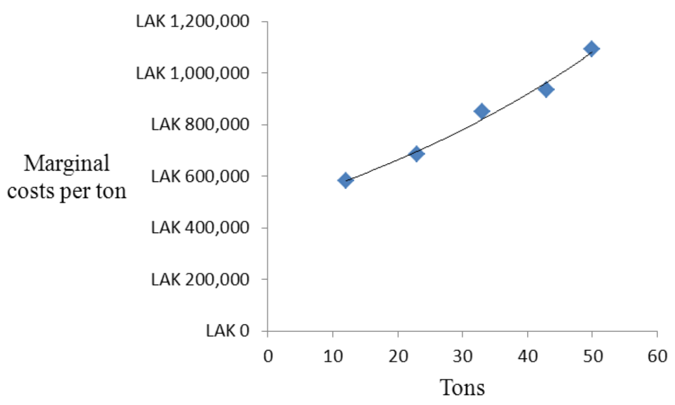

Figure 6: Marginal cost function of Farmer 1

The individual marginal cost functions of all auction participants would be added to estimate the market supply function.

The individual marginal cost functions of all one hundred auction participants are added to create the market supply function.

Setting the market supply function equal to the market demand function[15] (see Step 10: Estimating marginal benefits of supply) would allow the estimation of the efficient quantity of output at the efficient price per unit of output. This is illustrated in Figure 7. The price and quantity combination is efficient because the net benefits to society that are achieved by the PES scheme are maximised[16].

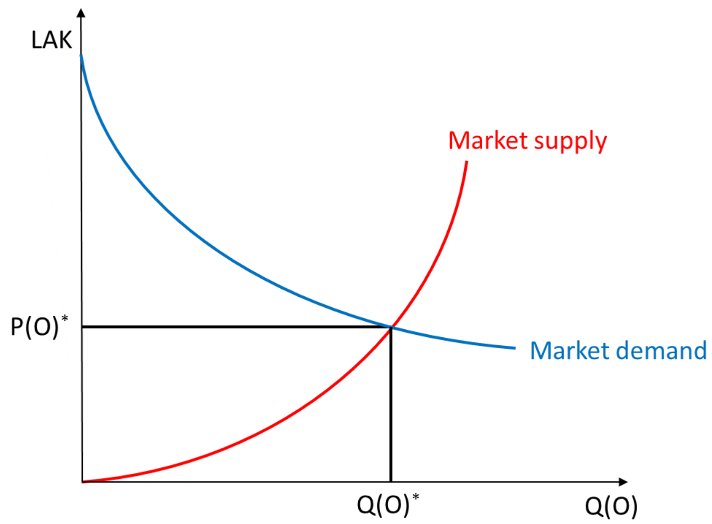

Figure 7: Efficient price and quantity

This example assumes that the estimated efficient price per ton of reduced sediment loads is LAK 1,135,144. The estimated efficient quantity of reduced sediment loads is 4,211 tons.

[15] Aggregated over all buyers.

[16] In the case of a PES scheme with a constrained budget supply might not extend to the level at which market demand (aggregated marginal benefits) is equal to market supply (aggregated marginal costs).

The individual quantity of output each auction participant would be willing to supply at the efficient price would then be identified as the quantity offered at the price used in the auction that is closest to the efficient market price[17][18].

As shown in the marked rows (red arrows) in Table 2, the individual marginal cost per ton of reduced sediment loads that is closest to the efficient market price of LAK 1,135,144 is LAK 1,092,000 for Farmer 1 and LAK 1,093,750 for Farmer 2. The corresponding quantity of sediment reduction is 50 tons per year for Farmer 1 and 24 tons per year for Farmer 2.

The aggregate quantity of output that would be produced by all successful auction participants would be the sum of the quantities of output they each would produce.

This example shows that the aggregate quantity of sediment reduced by the one hundred participating farmers would be 3,700 tons per year[19].

The quantity of input each auction participant proposed to apply at the efficient price would be identified by reversing the input-output conversions performed earlier.

According to the marked rows (red arrows) in Table 2, Farmer 1 will have to plant 2,600 trees to reduce sediment loads by 50 tons per year, whereas Farmer 2 will have to plant 2,500 trees to reduce sediment loads by 24 tons per year.

[17] With the individual marginal costs per unit of output ≤ the efficient market price.

[18] The consequence of this simplified approach is that, for some suppliers, the individual quantity of output produced at the efficient market price would likely be slightly smaller than the individual efficient quantity of output. An increase in production would improve economic efficiency marginally.

[19] The consequence of this simplified approach is that, for some auction participants, the individual quantity of output produced at the efficient market price is slightly smaller than the individual efficient quantity of output. As a result, the aggregate quantity of sediment reduction achieved in the PES scheme (3,700) is slightly smaller than the estimated efficient quantity (4,211).

The total payment each successful auction participant would receive would be calculated as the efficient price per unit of output multiplied by the quantity of output each supplier would produce.

The total payment would represent the returns each successful auction participant enjoys from participating in the PES scheme[20].

As shown in Table 3, the total payment each of the two farmers will receive would be calculated by multiplying the efficient price per ton by the quantity of reduced sediment:

$$\text{Total payment (Farmer 1)} = \text{LAK } 1{,}135{,}144 \times 50 \text{ tons} = \text{LAK } 56{,}757{,}186$$

$$\text{Total payment (Farmer 2)} = \text{LAK } 1{,}135{,}144 \times 24 \text{ tons} = \text{LAK } 27{,}243{,}449$$

The individual price per unit of input each successful auction participant would receive would be estimated by dividing the individual total payment by the individual quantities of input.

As shown in Table 3, the price per unit of input each farmer will receive would be calculated by dividing the total payment by the number of trees[21]:

$$\text{Price per tree (Farmer 1)} = \text{LAK } 56{,}757{,}186 \div 2{,}600 \text{ trees} = \text{LAK } 21{,}830$$

$$\text{Price per tree (Farmer 2)} = \text{LAK } 27{,}243{,}449 \div 2{,}500 \text{ trees} = \text{LAK } 10{,}897$$

Hence, each successful auction participant would receive the same price per unit of output (the efficient market price), whereas the price per unit of input would differ if the

[20] The consequence of this simplified approach is that, for some auction participants, the individual quantity of output produced at the efficient price would likely be slightly smaller than the individual efficient quantity of output. These suppliers would enjoy a small additional rent at the expense of the buyers.

[21] As a consequence of the discrete approach applied in this example, the individual quantities of output produced at the efficient price by Farmer 1 and Farmer 2 are slightly smaller than the individual efficient quantities of output. Farmer 1 and 2 enjoy a small additional rent of LAK 830 and LAK 397 per tree.

effectiveness of the inputs in producing the outputs differs across locations. More effective suppliers would receive a higher price per unit of input than less effective suppliers.

The total costs of each successful auction participant could be approximated by multiplying the marginal costs per unit of input with the corresponding quantities of input each supplier would propose to apply up to the individual efficient quantities[22].

As shown in Table 3, the total costs incurred by each farmer are calculated as follows:

$$\text{Total cost (Farmer 1)}$$
$$= \text{LAK } 7{,}000 \times 1{,}000 \text{ trees} + \text{LAK } 10{,}500 \times 500 \text{ trees} + \text{LAK}14{,}000 \times 500 + \text{LAK } 17{,}500 \times 300 \text{ trees} + \text{LAK } 21{,}000 \times 300 = \text{LAK } 20{,}300{,}000$$

$$\text{Total cost (Farmer 2)}$$
$$= \text{LAK } 7{,}000 \times 2{,}000 \text{ trees} + \text{LAK } 10{,}500 \times 500 \text{ trees} = \text{LAK } 19{,}250{,}000$$

The average costs per unit of input and per unit of output each successful auction participant would incur would be estimated by dividing the individual total costs by the individual quantities of input.

As shown in Table 3, the average costs incurred by each farmer are calculated by dividing the total costs by the number of trees and tons, respectively:

$$\text{Average cost per tree (Farmer 1)} = \text{LAK } 20{,}300{,}000 \div 2{,}600 \text{ trees} = \text{LAK } 7{,}808$$

$$\text{Average cost per ton (Farmer 1)} = \text{LAK } 20{,}300{,}000 \div 50 \text{ tons} = \text{LAK } 406{,}000$$

$$\text{Average cost per tree (Farmer 2)} = \text{LAK } 19{,}250{,}000 \div 2{,}500 \text{ trees} = \text{LAK } 7{,}700$$

$$\text{Average cost per ton (Farmer 2)} = \text{LAK } 19{,}250{,}000 \div 24 \text{ tons} = \text{LAK } 802{,}083$$

[22] A more precise result would be achieved by integrating the individual marginal cost functions up to the individual efficient quantities of output.

The total net returns each successful auction participant would enjoy would be calculated as the difference between the total payments they each receive and the total costs they each incur.

As shown in Table 3, the total net returns each farmer enjoys are calculated as follows:

$$\text{Total net return} = \text{LAK } 56{,}757{,}186 - \text{LAK } 20{,}300{,}000 = \text{LAK } 36{,}457{,}186$$

$$\text{Total net return} = \text{LAK } 27{,}243{,}449 - \text{LAK } 19{,}250{,}000 = \text{LAK } 7{,}993{,}449$$

The average net returns per unit of input each successful auction participant would enjoy would be estimated by subtracting the individual average costs per unit of input from the individual efficient price per unit of input.

The average net returns per unit of output each supplier would enjoy would be estimated by subtracting the individual average costs per unit of output from the efficient price per unit of output.

As shown in Table 3, the average net returns each farmer enjoys are calculated as follows:

$$\text{Average net return per tree (Farmer 1)} = \text{LAK } 21{,}830 - \text{LAK } 7{,}808 = \text{LAK } 14{,}022$$

$$\text{Average net return per ton (Farmer 1)} = \text{LAK } 1{,}135{,}144 - \text{LAK } 406{,}000 = \text{LAK } 729{,}144$$

$$\text{Average net return per tree (Farmer 2)} = \text{LAK } 10{,}897 - \text{LAK } 7{,}700 = \text{LAK } 3{,}197$$

$$\text{Average net return per ton (Farmer 2)} = \text{LAK } 1{,}135{,}144 - \text{LAK } 802{,}083 = \text{LAK } 333{,}060$$

Farmer 1 is, on average, less costly than Farmer 2 in reducing one ton of sediment and thus enjoys a higher average net return per planted tree.

Table 3:

	Farmer 1	Farmer 2
Efficient price per ton	LAK 1,135,144	LAK 1,135,144
Total payment	LAK 56,757,186	LAK 27,243,449
Efficient price per tree	LAK 21,830	LAK 10,897
Total costs	LAK 20,300,000	LAK 19,250,000
Average costs per tree	LAK 7,808	LAK 7,700
Average costs per ton	LAK 406,000	LAK 802,083
Total net returns	LAK 36,457,186	LAK 7,993,449
Average net returns per tree	LAK 14,022	LAK 3,197
Average net returns per ton	LAK 729,144	LAK 333,060

The total payment aggregated over all auction participants would be estimated as the sum of the individual total payments.

The total costs aggregated over all auction participants would be calculated as the sum of the individual total costs.

The total net returns aggregated over all auction participants would be calculated as the sum of the individual total net returns.

This example shows that auction participants would receive a total payment (total return) of LAK 4,200,031,746, incur total costs of LAK 1,977,500,000, and enjoy total net returns of LAK 2,222,531,764 (Table 4).

Table 4:

	Suppliers	Buyers
Total return	LAK 4,200,031,746	LAK 4,997,557,620
Total costs	LAK 1,977,500,000	LAK 4,200,031,746
Total net return	LAK 2,222,531,746	LAK 797,525,874
Total net benefit	LAK 3,020,057,620	

Step 13: Selecting the ES suppliers

The selection mechanism would be consistent with the 'Guidelines on free, prior and informed consent'(UN-REED Programme 2013).

A first selection of potential suppliers would be based on their meeting basic eligibility criteria: potential suppliers would need to be small-scale farmers located in the NNRB with the potential to deliver any or all of the catalogued ES. This potential to deliver any or all of the catalogued ES would depend on their ability to perform any or all of the identified new management actions.

All potential suppliers who meet the basic eligibility criteria would be invited to participate in the reverse auction (Step 11: Estimating marginal costs of supply). Each auction participant would be offered a contract with the quantities of each management action they proposed to perform for the determined efficient price per unit of ES (output) (Step 12: Developing the payment system). That is, the supplier selection mechanism would be a self-selection process governed by individual incentives. Everyone who meets the basic eligibility criteria chooses if and by how much they want to participate. Together, the payment system and the supplier selection mechanism would ensure that the individual marginal costs of output would be smaller or equal to the marginal benefits per unit of output. That is, the ES supply would be economically efficient as is the case in competitive, undistorted markets.

Because participation in the PES scheme is voluntary, potential suppliers can withdraw from the scheme up until the time when they sign a contract to deliver the ES. participation would be based on the 'Guidelines on free, prior and informed consent'(UN-REED Programme 2013).

Communicating the results of the reverse auction/ dealing with unsuccessful auction participants would require the decision on:

- which institutions/ government organisations would be involved and at what level;
- how the results would be communicated to the auction participants; and
- how social tensions that might be created through the exclusion of unsuccessful auction participants could be avoided.

Step 14: Determining the payments required from ES buyers

The following section explains how the payments required from the buyers would be determined.

The efficient quantities of each output type and the corresponding efficient prices per unit of each output type would have been determined using the market demand function and market supply function[23] (see Step 12: Developing the payment system).

Buyers might only want to buy some of the output types produced by suppliers. The hydroelectric power companies might only be interested in reduced sedimentation rates and improved water regulation in the reservoirs, whereas tourists, tourist companies, the general public of Lao, and the international community would be interested in native forest cover, species diversity and water levels in streams, rivers and reservoirs. Each buyer would only pay for the output types they would demand[24].

A quantified example[25] for a single output type supports the explanation presented in these orange boxes.

Two buyers (two hydro-electric power companies) are interested in a reduction of sedimentation rates in their reservoirs.

The buyers within the same buyer type might purchase equal or different quantities of the same output type. For example, tourists interested in species diversity would all enjoy the same quantity of species diversity, whereas hydro-electric companies might enjoy different amounts of sediment reduction. These differences would have to be taken into account.

[23]Marginal benefits aggregated over all buyers.

[24]Different groups of buyers may value the same output type differently. For example, the international tourists may value native forest cover differently than the domestic tourists, the general public of Lao, and the international community. This would increase the number of output types catalogued in the NNRB. For example, the ES type 'native forest cover' would consist of five output types that would correspond to five buyer types: international tourists, national tourists, tourism companies, the general public of Lao, and the international community.

[25]The example is designed to illustrate the principles and does not reflect the real situation in the NNRB.

In the example with two hydro-electric power companies, let's assume that Company 1 and Company 2 enjoy each 70 and 30 per cent of the total quantity of reduced sediment loads, respectively.

The price each company has to pay per ton of sediment reduction is the same as the price the suppliers receive:

$$\text{Price per ton} = \text{LAK } 1{,}135{,}144$$

The aggregate quantity produced by suppliers is 3,700 tons per year.

The quantities of reduced sediment load that each company purchases is calculated as follows:

$$\text{Quantity purchased by Company 1} = 3{,}700 \text{ tons} \times 0.70 = 2{,}590 \text{ tons}$$

$$\text{Quantity purchased by Company 2} = 3{,}700 \text{ tons} \times 0.30 = 1{,}110 \text{ tons}$$

The total payments required from each buyer for each output type purchased would be estimated by multiplying the efficient price per unit of output by the quantity of output purchased by each buyer.

The total payment per year required from each company is calculated as follows:

$$\text{Total payment from Company 1} = \text{LAK } 1{,}135{,}144 \times 2{,}590 \text{ tons} = \text{LAK } 2{,}940{,}022{,}222$$

$$\text{Total payment from Company 2} = \text{LAK } 1{,}135{,}144 \times 1{,}110 \text{ tons} = \text{LAK } 1{,}260{,}009{,}524$$

The total payments aggregated over buyers and output types would be estimated as the sum of the individual total payments required from each buyer for each output type.

The sum of the total payments required from the two companies yields the total payment required from all buyers:

Total payment required from buyers = LAK 4,200,032,746

The total returns each buyer would enjoy from output type would be estimated by integrating the individual marginal benefit functions up to the individual efficient quantities of output.

The total returns aggregated over buyers and output types would be estimated as the sum of the individual total returns enjoyed by each buyer from each output type.

The two hydro-electric power companies enjoy a total return of LAK 4,997,557,620 from the purchase of 3,700 tons of sediment reduction (Table 4).

The total net returns enjoyed by each individual buyer for each output type would be estimated by subtracting total payments required from each buyer for each purchased output type from the total returns each buyer would enjoy.

The total net returns aggregated over buyers and output types would be estimated as the sum of the individual total returns enjoyed by each buyer from each output type.

The two hydro-electric power companies enjoy a total net return of LAK 797,525,874 from the purchase of 3,700 tons of sediment reduction (Table 4).

This payment system allows the distribution of net returns to be shared between suppliers and buyers as happens in competitive, undistorted markets (Figure 8). The net returns to buyers are represented by the area P*BC. The net returns received by the suppliers are represented by the area ABP*.

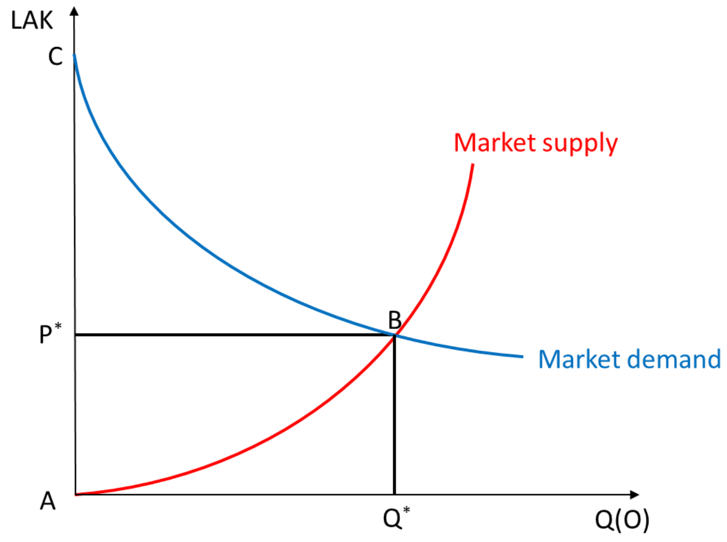

Figure 8

This payment system ensures the generation of social net benefits[26].

The social net benefits generated through the example PES scheme are LAK3,020,057,620 (Table 4).

[26] If the transaction cost of the scheme are smaller than the net benefit generated.

Step 15: Establishing the payment transfer mechanism

A payment transfer mechanism would be required to transfer the payments from the buyers to the suppliers.

The payment transfer mechanism would have to be transparent and simple. Pathways for receipt and dissemination of payments through a reliable, efficient, approachable, honest, trusted institution (Midgley et al. 2011) would have to be found.

Initially, payments would be collected from buyers and distributed to suppliers through the appropriate agency.

In the long run, the aim would be to set up more direct and sustainable transfers using existing links between the buyers and the suppliers through local authorities (e.g. village clusters or villages).

Collecting the buyer payments and transferring them to the suppliers requires decisions on:

- which institutions/ government organisations would be involved and at what level;
- who would collect the payments from the buyers;
- which channels would be used to transfer the payments to the suppliers; and
- how to ensure the accountability of the chosen transfer authority to both the suppliers and buyers.

Step 16: Determining the supplier performance measure

1. Payments to suppliers would be conditional on their performance.

Supplier performance would be assessed using an input-based measure (performing the proposed bundle of management actions) (e.g., Latacz-Lohmann et al. 2005, Engel et al. 2008).

The input-based performance measures would be specified based on the inputs used/ actions conducted:

- number and survival rate of native trees planted inside and outside NPA;
- compliance with the restrictions on slash and burn agriculture outside NPA/ performance of actions to prevent slash and burn in NPA;
- compliance with the restrictions on logging outside NPA/ performance of actions to prevent illegal logging inside NPA; and
- compliance with the hunting restrictions outside NPA/ performance of actions to prevent poaching inside NPA.

Since supplier performance would be assessed by an input-based measure the risk of underperformance would be distributed towards the buyers (and their agents).

The supplier performance would be assessed every six (or twelve months) over the duration of the PES scheme to ensure continuous supplier compliance.

Step 17: Establishing a monitoring system

The monitoring system would be based on robust and simple indicators that can be measured objectively and cooperatively (Midgley et al. 2011).

The established monitoring system would be used to monitor supplier performance and the effectiveness of the used inputs to generate outputs.

Monitoring would be carried out by independent agents. The monitored suppliers would be part of the monitoring process (e.g., they could accompany the team of independent agents) to create confidence that the monitoring would be conducted objectively.

Peer monitoring might develop, which would support supplier compliance.

Impartial, accessible and fair mechanisms for grievance, conflict resolution and redress would be established and accessible during the consultation process and the duration of the PES scheme, including the appointment of a neutral third-party mediator (UN-REED Programme 2013).

Conducting the monitoring would require decision on:

- which institutions/ government organisations would be involved and at what level;
- how the suppliers and buyers would be involved; and
- who decides if the suppliers have fulfilled their contracts.

Establishing a mechanism for grievance, conflict resolution and redress would require decisions on:

- which institution would host that mechanism;
- what is the legal base for such a mechanism; and
- its mechanism.

Step 18: Establishing a penalty system to punish non-compliance

The PES scheme would be designed such that supplier non-compliance would be discouraged (Latacz-Lohmann et al. 2005):

- The contracted management actions would be defined rigorously.
- The payment rates would be attractive to the suppliers.
- The supplier performance would be monitored (high probability of detection).
- The penalties for non-compliance would be costly to suppliers.
- The penalties for non-compliance would be enforced.

Focussing on the first, second, fourth and fifth elements would increase the costs of non-compliance relative to the returns from non-compliance. This would reduce the required monitoring effort, and thus the transaction costs.

Penalties for supplier non-compliance would include:

- reduced payments;
- withheld payments; and
- permanent or temporary exclusion from the PES scheme.

An enforcement strategy would be embedded into the legal and enforcement systems that exist at the local and district levels.

The laws and regulations concerning the terms and conditions under which penalties for non-compliance can be included into PES contracts and enforced would have to be assessed.

Enforcing penalties for non-compliance would require decision on:

- which institutions/ government organisations would be involved and at what level; and
- who would conduct the enforcement.

Step 19: Contracting the ES suppliers (and buyers)

A range of laws and regulations and the current land tenure situation would be assessed to analyse the legal basis for contracting suppliers and buyers:

- laws and regulations that define ES;
- laws and regulations concerning use/ utilization rights over land/ forest and use/utilization rights over the supplied ES;
- laws and regulations concerning the definition of forest categories that might restrict the proposed bundle of management actions;
- laws and regulations concerning the viability of land use changes across categories (land utilization rights are bound to land categories) that might restrict the proposed bundle of management actions;
- laws and regulations concerning the terms and conditions under which the supply of ES can be rewarded;
- laws and regulations concerning the receipt of PES payments across the different supplier types (individuals, communities/ groups);
- laws and regulations concerning whether and how suppliers and buyers (or their agents) could be contracted;
- laws and regulations that would allow contracting farmers without legal land use/ utilization rights;
- laws and regulations concerning the use of public funds for the PES scheme;
- laws and regulations concerning the terms and conditions under which penalties for non-compliance could be included into PES contracts and subsequently enforced;
- the current land tenure situation in the NNRB (de jure, de facto, and customary use/utilization rights).

The contracts with individuals would be signed by each supplier and their buyers (and/ or agents). Subcontracts might be required if the suppliers are groups (e.g., a community or village), which would have to be signed by the community members and the local authority (e.g., village head or village committee).

The contracts might be renewable depending on the success of the pilot PES scheme.

The contracts would include the following:

- the definition of the management actions undertaken by the supplier (quantity, quality, timing);
- the definition of the payment system applied;
- a statement that the negotiated payments are conditional on the delivery of the contracted management actions as defined in the contract;
- a statement that the conditionality of the payments would be ensured though a monitoring system, a penalty system and enforcement mechanisms in case of non-compliance;
- a description of the monitoring system, the penalty system, and the enforcement mechanisms; and
- a statement that assigns the right to both suppliers and buyers to consult and file a complaint, and describing the appropriate process to manage grievance, conflict resolution and redress.

A Discrete Choice Experiment would be conducted to estimate the contract condition preferences of suppliers.

Contracting the suppliers and the buyers would require decision on:

- which institutions/ government organisations would be involved and at what level;
- who would decide whether to contract individuals or communities;
- if communities were contracted as suppliers, who would sign the contracts; and
- who would sign the contracts on the buyer side (buyers and/ or agents).

Step 20: Assessing the PES scheme's performance

The effectiveness of the PES scheme in delivering ES would be assessed using the following indicators:

- the total ES delivered through the PES scheme (estimated through the bio-physical models);
- the supplier participation rate estimated as the ratio of the number of suppliers who participated to invited potential suppliers; and
- supplier compliance (analysed based on the data retrieved from the monitoring and penalty systems).

A survey would be conducted to investigate the reasons for participation or non-participation.

The feasibility of conducting reverse auctions would be examined through surveys of auction participants and the data collected during the development and conduction of the reverse auctions.

The net return distribution between suppliers and buyers would be analysed using data on the total returns to buyers, total costs to suppliers, and the total payments made by buyers to suppliers.

A sensitivity analysis would investigate how changes in the results obtained from the bio-physical models and the economic valuations would impact on the net return distribution between buyers and suppliers.

An assessment of the economic efficiency of the scheme would be conducted by calculating the consumer surplus (the aggregate net return to buyers), producer surplus (the aggregate net return to suppliers) and total surplus (net benefits) generated through the PES scheme. The net benefits generated through the PES scheme would be the difference between total costs (transaction costs incurred by suppliers, buyers, and agents; supply costs incurred by suppliers) and total benefits generated through the ES supply achieved under the PES scheme.

A sensitivity analysis would investigate how changes in the results obtained from the bio-physical models and the economic valuations would impact on the economic efficiency of the PES scheme.

The degree of transparency, perceived fairness, perceptions of distrust and uncertainty, and voluntary nature of supplier participation would be investigated through surveys.

The degree of conditionality would be assessed by analysing of the performance of the monitoring, penalty and enforcement systems.

Identification and evaluation of detrimental social impacts of the PES scheme would be conducted by analysing data on key social characteristics of the contracted suppliers. The data would be collected through surveys at the start and the completion of the PES scheme pilot.

Annex 1:
Determining the payment rate for a single output type by a single input type

Conducting a reverse auction yields data sets $\left\{(I_k, c_k^{(I)})\right\}$ for each auction participant k $[k = 1, \dots, N]$, where I_k is the quantity of input offered by auction participant k, and $c_k^{(I)}$ is the individual marginal cost of input I_k for auction participant k.

For each auction participant k, assume $c_k^{(I)}(I_k)$ is a monotonically increasing function of I_k and thus invertible.

Applying the biophysical model $\vartheta_k(I_k)$ to the quantity of input I_k for each data point $(I_k; c_k^{(I)})$ yields the quantity of output $O_k = \vartheta_k(I_k)$.

Note that the input-output functions $\vartheta_k(I_k)$ would differ between auction participants if the effectiveness of the inputs in producing the outputs differs across different locations.

Dividing the marginal cost per unit of input $c_k^{(I)}$ by the quantity of output per unit of input ${}^{\vartheta_k(I_k)}/_{I_k}$ yields the marginal cost $c_k^{(O)}$ as a function of output O_k:

$$c_k^{(O)}(O_k) = c_k^{(I)}\left({}^{I_k}/_{\vartheta_k(I_k)}\right) = c_k^{(I)}\left({}^{I_k}/_{O_k}\right)$$

Summing $c_k^{(O)}(O_k)$ over all auction participants yields the market marginal cost function (market supply):

$$c^{(O)}(O) = \sum_k c_k^{(O)}(O_k)$$

Setting $c^{(O)}(O)$ equal to the market marginal benefit function (market demand) $b^{(O)}(O)$ allows the estimation of the efficient quantity of output O^* at the efficient price per unit of output $p^{(O)*}$. At this point, the social net benefits are maximised. A PES scheme with a constrained budget supply might not extent to the level at which marginal benefits equal marginal costs.

Each auction participant is offered the same price per unit of output $p^{(O)*}$, whereas the price per unit of input $p_k^{(I)*}$ differs if the effectiveness of the inputs in producing the outputs differs across different locations. More effective auction participants are offered a higher price per unit of input compared to those with lower input effectiveness.

Substituting the efficient price per unit of output $p^{(O)*}$ into the marginal cost function $c_k^{(O)}$ yields the quantity of output each auction participant is willing to supply at $p^{(O)*}$, i.e. O_k^*.

If the input-output function $\vartheta_k(I_k)$ is invertible, substituting O_k^* into the $(\vartheta_k(I_k))^{-1}$ yields the corresponding of input I_k^* each auction participant is willing to supply at $p^{(O)*}$.

The total payment each auction participant will receive by supplying O_k^* is calculated as:

$$P_k^{(O)*} = p_k^{(O)*} O_k^*$$

The total payment each auction participant will receive by supplying O_k^* equals the total payment received for supplying I_k^*:

$$P_k^{(O)*} = P_k^{(I)*}$$

Dividing $P_k^{(O)*}$ by O_k^* yields the average payment per unit of output:

$$\tilde{p}_k^{(O)*} = {R_k^{(O)*}}\Big/{O_k^*}$$

The average payment per unit of output is equal to $p_k^{(O)*}$.

Dividing $P_k^{(I)*}$ by I_k^* yields the average payment per unit of input:

$$\tilde{p}_k^{(I)*} = {P_k^{(I)*}}\Big/{I_k^*}$$

The total cost each auction participant will incur by supplying O_k^* is estimated as:

$$C_k^{(O)*} = \int_{o}^{O_k^*} c_k^{(O)}(O_k) dO_k$$

The total cost each auction participant will incur by supplying O_k^* equals the total cost incurred for supplying I_k^*:

$$C_k^{(O)*} = C_k^{(I)*}$$

Dividing $C_n^{(O)*}$ by O_n^* yields the average cost per unit of output:

$$\tilde{c}_k^{(O)*} = C_k^{(O)*} \big/ O_k^*$$

Dividing $C_n^{(I)*}$ by I_n^* yields the average cost per unit of input:

$$\tilde{c}_k^{(I)*} = C_k^{(I)*} \big/ I_k^*$$

The total net returns each auction participant will enjoy by supplying O_n^* is calculated as:

$$R_k^{(O)*} = P_k^{(O)*} - C_k^{(O)*}$$

The total net return each auction participant will enjoy by supplying O_k^* equals the total net return received for supplying I_k^*:

$$R_k^{(O)*} = R_k^{(I)*}$$

Subtracting the average costs per unit of output from the average payment per unit of output yields the average net return per unit of output:

$$\tilde{r}_k^{(O)*} = \tilde{p}_k^{(O)*} - \tilde{c}_k^{(O)*}$$

Subtracting the average costs per unit of input from the average payment per unit of input yields the average net return per unit of input:

$$\tilde{r}_k^{(I)*} = \tilde{p}_k^{(I)*} - \tilde{c}_k^{(I)*}$$

Summing the total payment over all auction participants yields their aggregate payment for supplying $O_k^{(O)*}$:

$$P^{(O)*} = \sum_{k} P_k^{(O)*}$$

Summing the total costs over all auction participants yields their aggregate costs to auction participants for supplying $O_k^{(O)*}$:

$$C^{(O)*} = \sum_{k} C_k^{(O)*}$$

Summing the total net returns over all auction participants yields their aggregate net returns to auction participants for supplying $O_k^{(O)*}$:

$$R^{(O)*} = \sum_{k} R_k^{(O)*}$$

Annex 2:
Determining the payment rate for multiple output types produced by multiple input types

The determination of the payment rate for multiple output types produced by multiple input types follows, in principle, the same process as described for the single input-output type case described in Annex 1. Yet, the construction of indices is required if one output type would be produced by more than one input type and/ or one input type would produce more than one output type. Indices simplify the case such that it becomes similar to the case of a single input producing a single output described in Annex1. The bundles of inputs and the bundles of outputs are expressed as single units.

However, reversing the indexation to obtain separate input quantities and unit prices for each input type is not possible due to identification problems. The following section describes an approach to approximate the unknown values for input quantities and unit prices.

Conducting a reverse auction yields data sets $\left\{(I_{k,1}, I_{k,2}, \dots, I_{k,n}; c_{k,1}^{(I)}, c_{k,2}^{(I)}, \dots, c_{K,M}^{(I)})\right\}$ for each auction participant k $[k = 1, \dots, K]$ and each input type m $[m = 1, \dots, M]$, where $I_{k,m}$ is the quantity of input m for auction participant k and $c_{k,m}^{(I)}$ is the individual marginal cost per unit of input $I_{k,m}$.

Applying the biophysical model $\vartheta_{k,m}$ to the quantity of input $I_{k,m}$ for each data point $(I_{k,1}, I_{k,2}, \dots, I_{k,n}; c_{k,1}^{(I)}, c_{k,2}^{(I)}, \dots, c_{K,M}^{(I)})$ yields the quantity of each output type t $[t = 1, \dots, T]$, $O_{k,t} = \vartheta_k^{(O_t)}(I_{k,m})$.

Note that the input-output function $\vartheta_k^{(O_t)}(I_{k,m})$ would differ between auction participants if the effectiveness of the inputs in producing the outputs differs across different locations.

The quantities of all input types m auction participant k offers to apply, $I_{k,m}$, are converted into quantities of an indexed input unit $I_k^{(\gamma)}$ using the marginal costs per unit of input type m, $c_{k,m}^{(I)}$, as weights:

$$I_k^{(\gamma)} = {I_k^{(m_1)} c_k^{(m_1)}} \Big/ \left(c_k^{(m_1)} + c_k^{(m_2)} + c_k^{(m_M)}\right) + {I_k^{(m_2)} c_k^{(m_2)}} \Big/ \left(c_k^{(m_1)} + c_k^{(m_2)} + c_k^{(m_M)}\right)$$

$$+ {I_k^{(m_M)} c_k^{(m_M)}} \Big/ \left(c_k^{(m_1)} + c_k^{(m_2)} + c_k^{(m_M)}\right)$$

The quantities of all output types t auction participant k offers to supply, $O_{k,t}$, would be converted into quantities of an indexed output unit $O_k^{(\delta)}$ using the marginal benefits per unit of output type m, $c_{k,t}^{(O)}$, as weights:

$$O_k^{(\delta)} = {I_k^{(t_1)} b_k^{(t_1)}} \Big/ \left(b_k^{(t_1)} + b_k^{(t_2)} + b_k^{(t_T)}\right) + {I_k^{(t_2)} b_k^{(t_2)}} \Big/ \left(b_k^{(t_1)} + b_k^{(t_2)} + b_k^{(t_T)}\right)$$

$$+ {I_k^{(t_T)} b_k^{(t_T)}} \Big/ \left(b_k^{(t_1)} + b_k^{(t_2)} + b_k^{(t_T)}\right)$$

The marginal cost per unit of input type m of all input types m incurred by auction participant k, $c_{k,m}^{(I)}$, is converted into marginal cost per unit of a indexed output $c_k^{(\delta)}$ using the marginal cost per unit of input type m, $c_{k,m}^{(I)}$, as weights:

$$c_k^{(\delta)} = {c_k^{(m_1)} c_k^{(m_1)}} \Big/ \left(c_k^{(m_1)} + c_k^{(m_2)} + c_k^{(m_M)}\right) + {c_k^{(m_2)} c_k^{(m_2)}} \Big/ \left(c_k^{(m_1)} + c_k^{(m_2)} + c_k^{(m_M)}\right)$$

$$+ {c_k^{(m_M)} c_k^{(m_M)}} \Big/ \left(c_k^{(m_1)} + c_k^{(m_2)} + c_k^{(m_M)}\right)$$

Now convert marginal cost of indexed input $c_k^{(\gamma)}$ into marginal cost of indexed output by dividing the marginal cost per unit of indexed input by the quantity of output per unit of indexed input ${O_k^{(\delta)}} \Big/ {I_k^{(\gamma)}}$:

$$c_k^{(\delta)}(O_k^{(\gamma)}) = c_k^{(\gamma)}({I_k^{(\gamma)}} \Big/ {O_k^{(\delta)}})$$

For each auction participant k, assume $c_k^{(\gamma)}$ is a monotonically increasing function of $I_k^{(\gamma)}$ and thus invertible.

This allows expressing the marginal costs $c_k^{(\delta)}$ as a function of indexed output $O_k^{(\delta)}$, i.e. $c_k^{(\delta)}(O_k^{(\delta)})$.

Summing $c_k^{(\delta)}(O_k^{(\delta)})$ over all auction participants yields the indexed market marginal cost function (market supply):

$$c^{(\delta)}(O^{(\delta)}) = \sum_k c_k^{(\delta)}(O_k^{(\delta)})$$

Setting $c^{(\delta)}(O^{(\delta)})$ equal to the indexed market marginal benefit function (market demand) $b^{(\delta)}(O^{(\delta)})$ allows the estimation of the efficient quantity of indexed output $O^{(\delta)*}$ at the efficient price per unit of indexed output $p^{(\delta)*}$. At the equilibrium, the social net benefits are maximised. In the case of a PES scheme with a constrained budget supply might not extent to the level at which marginal benefits equal marginal costs.

Each auction participant is offered the same price per unit of output $p^{(\delta)*}$ whereas the price per unit of input $p_k^{(\gamma)*}$ differs if the effectiveness of the inputs in producing the outputs at different locations. More effective auction participants will receive a higher price per unit of input compared to those with lower input effectiveness.

Substituting the efficient price of output $p^{(\delta)*}$ into the indexed marginal cost function $c_k^{(\delta)}$ yields the quantity of indexed output each auction participant is willing to supply at $p^{(\delta)*}$, i.e. $O_k^{(\delta)*}$.

If the indexed input-output function $\vartheta_k^{(\delta)}(I_k^{(\gamma)})$ is invertible, substituting $O_k^{(\delta)*}$ into the $(\vartheta_k^{(\delta)}(I_k^{(\gamma)}))^{-1}$ yields the corresponding of indexed input $I_k^{(\gamma)*}$ each auction participant is willing to supply at $p^{(\delta)*}$.

The quantities of each input type m, $I_{k,m}$, that correspond with the quantity of indexed input $I_k^{(\gamma)*}$ supplier k offers to apply at the efficient price per unit of indexed output $p^{(\gamma)*}$

would be identified as the quantities at which the price per unit of indexed input $p_k^{(\delta)*}$ is closest to the marginal costs per unit of indexed input $c_k^{(\tau)*}$, with $c_k^{(\tau)*} \leq p_k^{(\delta)*}$.

The consequence of this approach is that, for some suppliers, the individual quantity of output produced at the efficient market price might be smaller than the individual efficient quantity of output. An increase in production would improve economic efficiency marginally.

Annex 3:
Determining the aggregate payments required from ES buyers

The following section explains how the payments required from the buyers would be determined.

The efficient quantity of each output type $[t = 1, \dots, T]$, O_t^*, at the efficient price per unit of each output type $p_t^{(O)*}$ is determined by setting the market demand function equal to the market supply function.

Each buyer only pays for the output types they would demand[27].

The buyers within the same buyer type might purchase equal or different quantities of the same output type. These differences would have to be taken into account.

Multiplying $p_t^{(O)*}$ by the quantity of output each buyer j $[j = 1, \dots, J]$ purchases, $O_{t,j}^*$, yields the total payment required from each buyer for each output type t:

$$P_{t,j}^{(O)*} = p_t^{(O)*} O_{t,j}^*$$

Summing $P_{t,j}^{(O)*}$ over buyers j and output types t yields the aggregate payment required from the buyers:

$$P^{(O)*} = \sum_t \sum_j P_{t,j}^{(O)^*}$$

The total return each buyer will receive by purchasing $O_{t,j}^*$ is estimated by integrating the individual marginal benefit functions $b_{t,j}^{(O)}$ up to $O_{t,j}^*$:

$$B_{j,t}^{(O)*} = \int_o^{O_{t,j}^*} b_{t,j}^{(O)} (O_{t,j}) d(O_{t,j})$$

Summing the total returns enjoyed by buyer j from purchasing $O_{t,j}^*$ yields the total returns aggregated over all buyers:

[27] Different groups of buyers may value the same output type differently. This would increase the number of output types.

$$B^{(O)*} = \sum_{t} \sum_{j} B_{t,j}^{(O)*}$$

Subtracting the total payments required by buyer for purchasing $O_{\mathrm{t,j}}^{*}$ from the total returns they each enjoy yields the total net returns:

$$\mathrm{R}_{\mathrm{t,j}}^{(\mathrm{O})*} = \mathrm{B}_{\mathrm{t,j}}^{(\mathrm{O})*} - \mathrm{P}_{\mathrm{t,j}}^{(\mathrm{O})*}$$

Summing the total net returns enjoyed by buyer j from purchasing $O_{\mathrm{t,j}}^{*}$ yields the total net returns aggregated over all buyers:

$$R^{(O)*} = \sum_{t} \sum_{j} R_{t,j}^{(O)*}$$

This payment system ensures the generation of social net benefits and allows the distribution of net returns to be shared between suppliers and buyers as happens in competitive, undistorted markets.

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