Eco-Carbon Accounting for Evaluating Environmental Impacts and Co-benefits of Combined Carbon Management Projects: Application and Case Studies

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1. Introduction

As a consequence of the Kyoto Protocol, a large number of carbon management projects dealing with land use (in particularly forestry), renewable energy, and waste management are currently being developed and analyzed. Considering that carbon management practice is relatively sparse, it is not surprising that there exist a number of problems. Three shortcomings are of particular importance for the argument pursued in this article:

First, there is a discernible lack of integration and linkage of forestry projects and bio-energy projects utilizing wood wastes with other carbon management project types, such as those aiming at carbon reductions and removals through efficiency improvements in industry and power generation, renewable energy technologies, or waste management.

Furthermore, the separation of the certification and carbon credit evaluation procedures between these different project types could reduce the incentives for implementing these projects, for example under the Clean Development Mechanism (CDM) and Joint Implementation (JI) schemes.

Finally, although recommended, the evaluation of socio-environmental (SE) impacts and co-benefits is not integrated in a comprehensive way with the central carbon accounting process. Although carbon management projects affect local communities with socio-environmental impacts, and provide them with benefits, the need for corresponding quantitative impact/benefit assessment during the project planning and design phases has often been overridden by the perceived importance of economic analysis. In our view, however, all types of analysis should accompany and thus complement each other, in order to provide a richer picture for decision-making.

There are a number of studies in the literature pointing at possible ways to overcome these shortcomings. The Institute of Environmental Physics, Energy and Climate at the Swiss Federal Institute of Technology (2003) and the CarboEurope (2002) project have come up with methods and sets of criteria that aim at evaluating sustainable projects under the Clean Development Mechanism (CDM). Moreover, some ecological-economic analyses and environmental management studies, (for example Scott and Bilyard et al. 1998, and De Groot et al. 2002) address causal relations between human activities and SE impacts/co-benefits, and suggest a typology for the valuation of ecosystem functions.

In order to make inroads in terms of achieving a consistent and comprehensive carbon management framework, it is clearly necessary to first clarify and better understand the relations between project activities and SE impacts/co-benefits, and as well to develop approaches that can more holistically evaluate these impacts/benefits, and thus assist project managers and policy makers.

In order to achieve this objective, we propose several measures: First, carbon management practice should look at projects in integration, by linking the projects' accounts and evaluating their performance as one system. Based on such an evaluation, impacts can be minimised, and benefits be maximised in a coordinated, synergistic way.

To meet this end, we are developing a method which we term 'Eco-Carbon Accounting' (ECA), and which is designed to deal with carbon reduction effects and SE impacts/co-benefits. This method fulfils two basic functions: 1) the identification of relations between project activities, and carbon and socio-environmental impacts/benefits, and 2) the holistic evaluation of these impacts/benefits. The method is flexible in a spatial sense, since it can be applied at both an international project level (for example CDM) and a regional level (for example in a domestic strategic project).

In the following, we will first give a detailed outline of Eco-Carbon Accounting. In Section 3 we will present two case studies: one CDM project and one regional forestry project in Japan. The article is concluded in Section 4.

2. Eco-Carbon Accounting

An ECA task proceeds in two stages: First, a graphical model is set up, with compartments representing activities and impacts/benefits, and arrows linking these compartments representing causal links (see Fig. 1 and Section 2.1). In parallel, a numerical representation of the graph is compiled in form of an interactions matrix. At present, this model is created with the help of expert interviews, however a statistical approach is envisaged for future applications. Second, SE impacts/co-benefits and costs are evaluated quantitatively, based on the graphical model, using cash-flow and environmental-economic analysis. These techniques will be explained in detail in Section 2.2.

2.1. Graphical model

During the course of developing our accounting method, we found it helpful to express the causal model underlying our application in graphical form. This facilitates both clarity for the analyst in understanding the complexity of interactions, and visualisation for decision-makers. In designing the graphical model, we initially followed a simple cause-and-effect logic, but because of the nature of many carbon management projects, we subsequently saw the need to insert an intermediate layer (Fig. 1).

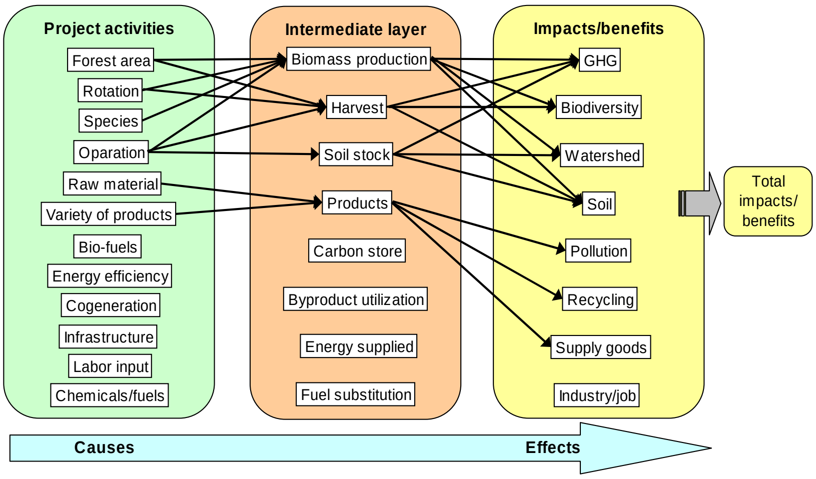

Fig. 1: Schematic of the graphical model

While dealing with practical case studies (see below), it has been convenient to frequently refer to the graphical model in order to clarify the relationships between project activities and SE impacts/benefits. The graphical layout is also adopted for the visualisation of the quantitative results following the data collection and analysis.

Another important function of graphs such as in Fig. 1 is that it eases the task of delineating each project system with a finite boundary. For example, for the purpose of the case studies documented in this paper, we defined a system boundary of combined carbon management projects which contains as project and intermediate activities (“cause” side): land use (afforestion, reforestation and forest management), biomass use by manufacturing industries, and bio-fuel use in energy supply and steel-making. On the “effect” side, we appraise four types of environmental impacts/co-benefits (greenhouse gas emissions, biodiversity, watershed, soil, and pollutant emissions), and three types of socio-economic impacts/co-benefits (recycling, commodity output, and job creation). Tab.1 below provides an overviews of cause-effect compartment.

Probably the most fundamental step of ECA is complementing the arrows in a graphical model of the type shown in Fig. 1 with numerical coefficients. This is a classical problem in ecological-economic analysis which was already encountered by Daly 1968) and Isard *et al.* 1972). Experiences from these and subsequent attempts have abundantly demonstrated the dearth of understanding about ecological-socio-economic interactions, and the utter lack of adequate data. As a consequence, instead of further pursuing an information-based approach, we focus on a value- or utility-based, anthropocentric approach to enumerate our transactions matrix, and hence apply “expert judgment”.

Accordingly, the data we collect are not observations, but responses from interviews, which reflect human judgment about the strength of correlations between the compartments in the graphical model. Each respondent is given a questionnaire showing an interaction matrix with cause and effect compartments labeled, but cells empty. The respondents’ task is to decide on the magnitude of correlation, based on their scientific and professional background and experience, but following a rating rule (Tab. 2).

Tab. 1: Project activities, intermediate output, and SE impacts/co-benefits

Cause-effect compartment	Explanation	Unit
Project activities		
Forest area	Plantation and cultivation area	ha
Rotation	Rotation length between plantation and clear-cut (final-cut); forestry operation methods	year
Species	Species selection for plantation and cultivation	-
Oparation	Intensity of thinnning and clear-cut, density of forest; forestry operation methods	%
Raw material	Raw material for manufacturing	m^3, t
Variety of products	Variety of wood products	-
Bio-fuels	Bio-fuel production as input for power plants	m^3, t
Energy efficiency	Energy conversion efficiency	%
Cogeneration	Sequential use of energy for the production of electrical and useful thermal energy	-
Infrastructure	Infrastructure input into process within the system boundary	$ or other
Labor input	Labor input into process within the system boundary	$ and emp-y
Chemicals and fuels	Chemicals input and fuel consumption into process within the system boundary, causing pollution within the system and elsewhere	L or t or J
Intermediate layer		
Biomass production	Standing biomass or standing crop, net primary production, amount of vegetable matter produced	t, m^3
Harvest	Harvest (natural resources)	t, m^3
Soil stock	Biomass or carbon content of soil	t or m^3
Products	Production of wood manufacturing	t, m^3
Carbon store	Carbon store until decay, related to product life cycle	t CO_2e
Byproduct utilization	Byproduct utilization within system boundary	%
Energy supplied	Supply of energy, such as sold electicity, used by manufacturing process	kWh, J
Fuel substitution	Substitute of fossil fuel by bio-energy	kWh, J
Impacts/benefits		
1)Environmental		
GHG	GHG balance: removals + storage - emissions	tCO_2e
Biodiversity	Biodiversity, value aspect of ecosystem	not yet quantified single unit
Watershed	Regulation of watershed and retention and storage of water resource	not yet quantified single unit
Soil	Soil conservation, such as erosion control	not yet quantified single unit
Pollution	Chemical safety, low emissions/pollution	t or ppm or other
2)Socio-economic		
Recycling	Cyclical use of resources, reducing waste	% or other
Goods/Services	Commodity output (goods and services), market value	$ or other
Industry/Job	Industrial income and job creation	$ and emp-y

Tab. 2: Rating rule for respondents of questionnaire.

Rating by respondent	Value inserted in cell	Correlation coefficient*
Very strong	3	0.7
Intermediate	2	0.4
Weak	1	0.2
Absent	0	0.05

* We interpreted respondents as correlation coefficient by Iwanaga et al.(2003)

The correlation coefficients in Tab. 2 note that the respondents make their decision about the interaction strengths without prior knowledge about the correlation coefficients. The translation into the latter is made by the analyst, and yields a final transactions matrix (Fig. 2). A criticism of the interview approach is provided in Section 4.

Code	Cause-effect compartment	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	11	12	13	14	15	16	17	18
101	Forest area	-																											
102	Rotation	3	-																										
103	Species	3	1	-																									
104	Oparation	3	2	3	-																								
105	Raw material	3	2	2	1	-																							
106	Variety of products	2	2	3	1	2	-																						
107	Bio-fuels	0	0	0	0	0	0	-																					
108	Energy efficiency	0	0	0	0	0	0	3	-																				
109	Cogeneration	0	0	0	0	0	0	3	3	-																			
110	Infrastructure	1	1	0	1	1	2	3	2	2	-																		
111	Labor input	1	1	0	1	1	2	3	2	2	3	-																	
112	Chemicals/fuels	1	1	0	1	0	1	1	2	2	2	2	-																
113	Biomass production	3	3	3	2	1	1	0	0	0	0	0	1	-															
114	Harvest	3	3	3	3	3	2	0	0	0	2	2	1	3	-														
115	Soil stock	3	3	3	3	2	2	0	0	0	1	1	1	3	3	-													
116	Products	3	3	2	2	3	2	0	0	0	2	2	1	3	3	3	-												
117	Carbon store	0	0	1	1	1	2	0	0	0	1	1	1	1	3	2	2	-											
118	Byproduct utilization	1	1	1	1	2	2	1	1	1	1	1	1	3	3	2	3	3	-										
119	Energy supplied	1	1	1	1	1	1	3	3	3	2	1	1	2	2	2	3	2	2	-									
120	Fuel substitution	0	0	1	1	1	2	1	2	3	1	1	1	2	2	2	3	3	3	3	-								
11	GHG	3	3	2	2	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	-							
12	Biodiversity	3	3	2	3	1	1	0	0	0	1	1	1	2	3	2	3	2	2	1	2	2	-						
13	Watershed	3	3	2	3	2	2	0	0	0	1	1	1	3	2	3	2	1	1	1	1	2	3	-					
14	Soil	3	3	3	3	2	2	0	0	0	1	1	1	2	3	3	3	1	1	1	1	3	2	3	-				
15	Pollution	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	2	2	2	1	-			
16	Recycling	2	2	1	2	1	3	3	2	2	2	2	1	1	2	2	2	1	2	1	1	3	2	3	2	1	-		
17	Supply goods	2	2	2	2	3	3	2	2	2	2	2	1	0	2	2	3	1	1	1	1	2	2	3	2	1	3	-	
18	Industry/job	0	0	0	0	2	2	2	2	2	2	2	1	0	2	2	2	1	1	1	1	3	2	3	1	1	3	3	-

Fig. 2: An example interaction matrix.

After having arranged the interview data, the transactions matrix is subjected to quantitative causal analysis and path analysis (Kojima, 2002). These methods involve multivariate and covariance structure techniques.

The output of the quantitative causal analysis is visualised using a path representation, once again employing the compartmental graphic in Fig. 1. As a result, interactions are represented by cause-and-effect links between project activities, intermediate layers and impacts/benefits (Fig. 3).

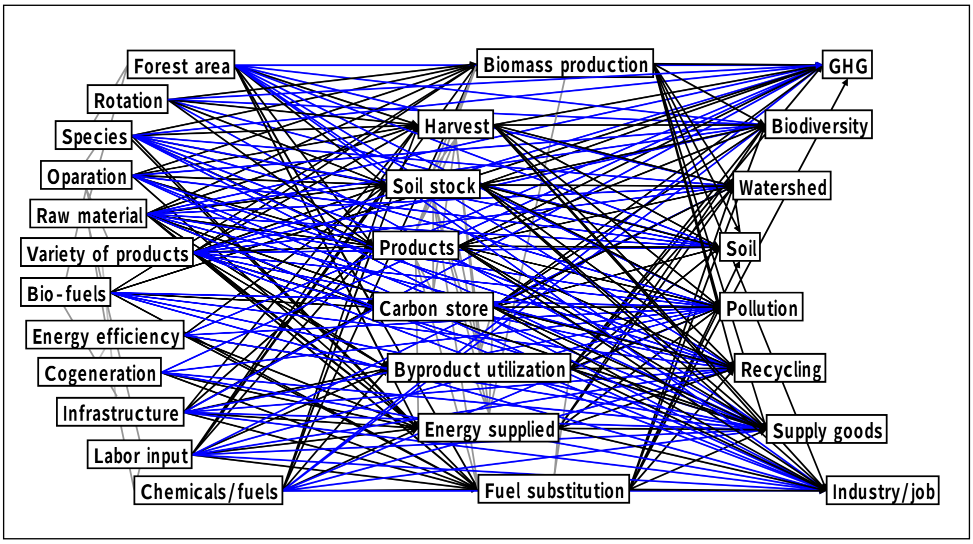

Fig. 3: Visualisation of outputs from quantitative analyses of interview data.

Ideally, Fig.3 would now be used for quantifying total impacts/benefits. However, the interactions matrix in Fig.2 could so for only be expressed as correlation coefficients in one compartment from causes in another. Therefore, in this preliminary study, total impacts/benefits were calculated separately (See 2.2).

2.2. Evaluation of total SE impacts/co-benefits and costs

SE impacts/benefits are evaluated as individual benefits as total benefit with a rating, and as multidimensional benefits.

First, we evaluated individual benefits, which are impact/benefits in terms of the compartments, for example GHG, biodiversity etc. From these, we can calculate total benefits as follows:

$$Benefit_{total} = F(Benefit_1; Benefit_2; ....; Benefit_i) \quad (1)$$

for the eight impacts/benefits compartments shown in Tab.1.

Of course, in order to be able to determine a total benefit measure, it is necessary to weight individual benefits.

In this study, we evaluated some quantifiable individual benefits as follows.

Individual benefits in terms of GHG are estimated as a net balance of GHG removals by forestry sink and emission reductions in manufacturing or bio-fuel power generation in units of tCO_2:

$$Benefit_{GHG} = \sum \left(GHGremovals_i + GHGstorage_i - GHGemissions_i \right) \quad (2)$$

Individual benefits of goods/services out put are estimated the sum of commodity values, at market prices in units US$.

$$Benefit_{goods/services} = \sum goods/services_i \quad (3)$$

Impacts of pollution from fuel consumption and chemicals use could be assessed, by using an environmental impact assessment method (for example LIME, Life-cycle Impact assessment Method based on Endpoint modeling; developed in the Research Center for Life Cycle Assessment at the National Institute of Advanced Industrial Science and Technology, 2003).

In order to further ease decision-making, some of these individual benefits – GHG, goods/services, and job creation – could be combined into a total benefit measure, expressed in terms of a unit of common understanding. One candidate for such a unit is the net present value (NPV), defined as,

$$NPV = \sum_{t=0}^{T} \frac{B_t}{(1+r)^t} - \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} \quad (4)$$

where B_t denotes benefits at time t, C_t costs at time t (both aggregated by summation), and r is the selected discount rate. If $NPV > 0$, the project is deemed beneficial.

Note that especially when applied to environmental issues, (monetary) cost-benefit analysis has significant drawbacks. First, and probably most importantly, some impacts such as biodiversity, soil and watershed are at present not quantifiable at all, and may not be for some time.

3. Case studies

3.1. Description of the project activities

So far, two case studies are able to provide an insight into how ECA might be applied to real-world applications, and what experiences could be gleaned from the outcomes. These case studies are 1) a feasibility study on an international afforestation project in the scope of the Clean Development Mechanism (CDM) carried out by a Japanese paper company, and 2) a feasibility study for a domestic Japanese strategic project involving forest cooperatives and wood manufacturing industries in the Maniwa region of Okayama prefecture (details in Tab. 3).

Tab. 3: Summary of the two projects assessed using ECA.

Case study	CDM project in Madagascar [1]		Regional carbon management project in Japan [2]	
Location	Toamasina		Maniwa, Okayama	
Project life time (year)	30		30	
Combined-project components	Base line	Project	Base line	Project
1) Afforestation/Forest management	abandoned land	afforestation	forest management	forest management
Area (ha)	-	10,000	25,000	25,000
Species	-	eucalypts	cedar and cypress	cedar and cypress
Rotation (year)	-	10	45	90
Intensity of thinning and clear-cut [3]	-	favorable(100%)	weak(40%)	favorable(100%)
2) Wood material manufacturing	-	chipping and charcoal factory	wood mill	wood mill and charcoal factory
Variety of products	-	chips, charcoals	timber, chips, biomass materials	timber, chips, charcoals, biomass materials
3) Renewable energy	-	installed in factories	-	installed in factories
Bio-fuels	-	wood waste	-	harvest and wood waste
Energy power (MW)	-	2.4	-	8.0
Electricity	-	factory utilize and supply to power grid	-	supply to power grid
4) Carbon storage	-	-	-	charcoals for agriculture

1) The project scenario and related data was obtained from Oji Paper Co. LTD (2004) . A part of bio-energy project scenario was assumed in this study.
2) The project scenario and related data was obtained from the latest study of Nomura (2004)
3) Implementation rate of thinning and clear-cut based on an operation plan(%)

3.2. Results of the two ECA case studies

As already outlined in Fig. 1, we estimated four types of SE impacts/co-benefits resulting from the combined carbon management project. These are two environmental impacts (emission of greenhouse gases and pollution), one economic benefit (commodity output, that is goods and services), and one social benefit (job creation). We estimated a base line scenario and project scenario for each impacts/co-benefits, and compared them (Tab. 4).

Tab. 4: Four types of SE impacts/co-benefits resulting from the combined carbon management project

Impacts/ benefits[1]	Environmental						Socio-economical				
Project	GHG [2]			Pollution			Goods/services			Job creation	
CDM Madagascar	Removals	$ktCO_2$	36	SO_x	t	27	Chip	10^3m^3	4,000	Employment (Person)	254
	Reductions		43	NO_x		73	Charcoal	10^3t	9		
	Storage		0	Total [4]	$10^6{}_{LIME}$	0.07	Electricity	GWh	224		
	Total		80								
	10^6US$ [3]		7.3	10^3US$		-	10^6US$		171	10^6US$	5.8
	% of total cost		4.1	% of total cost		-	% of total cost		95.7	% of total cost	0.03
National project Maniwa, Japan	Removals	$ktCO_2$	8,369	SO_x	t	409	Timber	10^3m^3	1,836	Employment (Person)	615
	Reductions		1,634	NO_x		278	Chip	10^3m^3	1,832		
	Storage		237	Total [4]	$10^6{}_{LIME}$	574	Biomass materials	10^3m^3	900		
	Total		10,240				Charcoal	10^3t	72		
							Electricity	GWh	2,635		
	10^6US$ [3]		51	10^3US$		-	10^6US$		3,772	10^6US$	1,007
	% of total cost		1.1	% of total cost		-	% of total cost		85	% of total cost	23

1) SE impacts/benefits shows sum during project periods (30 years).
2) Accounting method of carbon is the base line and credit approach.
3) A carbon credits of removals by sink is adopted a temporary credit.
4) Integrated values by LIME (Research Center for Life Cycle Assessment,2003).

Before total impacts and benefits were calculated, the systems had to be delineated by a boundary. Fig. 4 provides a self-explanatory schematic of the result of this process, and for the sake of brevity, no further details shall be provided here.

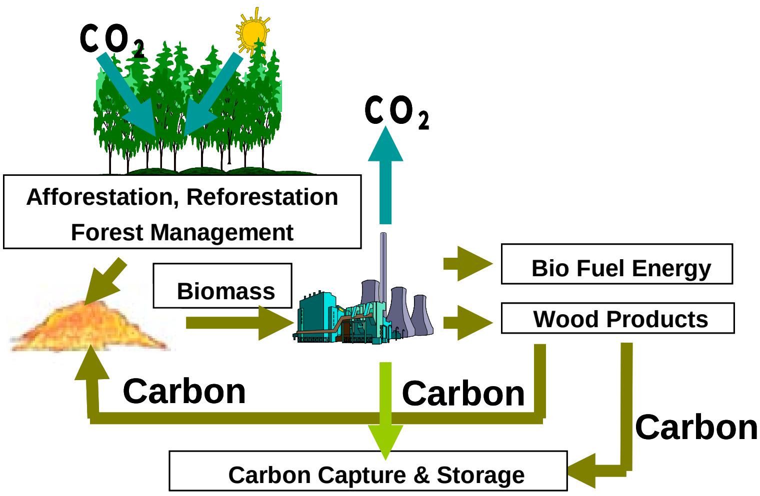

Fig. 4: Boundary chosen for Eco-Carbon Accounting (ECA) of the two case studies.

In order to evaluate the total SE impacts/co-benefits and costs in economic terms, a number of estimations were carried out. Economic benefits arising out of the revenue from selling carbon credits and renewable energy were established as follows: The revenue from selling carbon credits was used as an estimate of the economic benefit of reduced greenhouse gas emissions, while the revenue from selling renewable electricity to the power grid was used as an estimate of the economic benefits of the renewable energy supplied.

In these calculations, the electricity price in Madagascar was taken as 0.04 US$/kWh, while that in the Maniwa region is 0.1US$/kWh. As for the revenue from carbon credits, ideally a shadow price should be assumed. However, reliable shadow price estimates are hard to come by. Even though some approximations are available, for example from the DNE21 model by Fuji and Yamaji (Akimoto et al., 1998), it was decided to follow a conservative approach (compare Nomura 2003: Latest study) by using the present market price of carbon (data obtained from the feasibility report; Oji Paper Co. LTD, 2004).

Based on these data we arrive at the following results:

	Madagascar		Maniwa	
Carbon credit revenue	4.3	%	1.4	%
Renewable energy revenue	5.2	%	7.1	%

Finally, we estimated the net present value (NPV) of the project using ECA, including both revenues from carbon credit and renewable energy sales. The discount rate for economic benefit was set to be 5%.

3.2.1 The Madagascar case study

This CDM project scenario stretches over 30 years. Clear-cutting occurs first after 10 years and then after 20 years, with a subsequent 10-year harvest period each clear-cut. Post-harvest removals are excluded from our analysis. So this is the main reason for the relatively small removals in Tab.4.In a comparative analysis, this CDM projects would provide many socio-economic benefits, goods/services output and would create job creation.Using wood waste would provide charcoal (equivalent for 200 households per year) and renewable energy to local communities and cities in Madagascar.

On the other hand, project would bring about additional negative environmental impacts, for example pollution in terms of SO_x and NO_x, and watershed impacts. However, table.4 shows that these impacts are only minor, and in Madagascur there are no environmental regulations anyway.

In this study, because of lack of data, we could not assess impacts of soil and watershed, however there assessment is necessary.

Carbon credits and renewable energy revenue both increase the NPV of the project, estimated at about 3 million US$.

3.2.2 The Maniwa case study

With the help of the graphical model and the interaction matrix analysis, a few interesting findings could be distilled from the data collected in the interviews. First, a longer rotation period applied during forest management would yield an increased biomass production, which in turn would positively affect greenhouse gas sequestration. Longer rotation might also increase soil stock and provide benefits for the watershed, however these effects could not be enumerated in this preliminary study because of a lack of data. The downside of this management change would of course be that less timber could be harvested, resulting in a diminished value of commodity output (goods and services), and hence negatively affecting society.

Second, increased utilisation of biomass wastes positively influences greenhouse gas sequestration, either through replacement of fossil energy by biofuels, or through storage of carbon in charcoal and other wood products. In addition, some of the wood waste products require labour and acquire added commodity value, and thus increase output. On the other hand, employment, income and output are lost in the traditional energy supply industries due to the replacement of fossil fuels.

Third, an increase in the intensity of forest thinning and clear-cut would increase the harvest and in turn wood/biomass product output, jobs and social benefits, but would decrease greenhouse gas reductions because of low carbon removal rates.

Carbon credits and renewable energy revenue would increase the NPV slightly. Nevertheless for Maniwa, the NPV was estimated to be negative at about 172 million US$. This result is caused by factors, such as industrial structural problems associated with high cost of forest management and low prices of logs and wood products.

4. Preliminary conclusions and research outlook

In this study we have introduced the Eco-Carbon Accounting (ECA) method, and investigated how this method can be applied to carbon management projects that focus on forestry activities. For these projects we have defined and causally connected 28 compartments that contain indicators for socio-economic-environmental impacts and benefits, using a graphical model. This graphical model provides the underlying framework for ECA, by providing a clear picture of a project system’s interdependencies, both assisting the analyst during the investigation, and the decision-maker in interpreting results, and deciding on priorities for initiating changes towards improved management.

During the Maniwa case study we found a strong influence of the rotation period, the intensity of forest thinning and clear-cut, and the utilisation of biomass wastes, on greenhouse gas avoidance and removals, through replacement of fossil fuels and storage of carbon in wood products, which in turn contribute to economic output and employment creation.

We would like that this is an ongoing study and that the findings presented here are preliminary. We are aware that our method needs improvements, in terms of concepts and methodology, as well as regarding the information and data used. One aspect that we plan to address is the substitution of the expert interview stage with statistical approaches, as much as possible. We recognise the problem of involving human judgment into the analytical process, and the subjectivity and qualitativeness it entails. Experimental psychology and social research will be consulted in order to shed more light on the validity of this approach. We envisage that more numerical approaches such as the Delphi method (Linstone, H. and Turoff, M editors,) will subsequently replace interviews and questionnaires.

Other changes will have to address the problems of uncertainty of relationships and the quantifiability of indicators. During both the intermediate cause-effect modeling and the final impact/benefit/NPV calculation only quantifiable indicators were considered. A wealth of not (yet) quantifiable indicators is necessarily left out. Even those indicator that lend themselves to quantitative analysis, are of varying nature and expressed in incommensurable units, requiring multi-criteria decision tools, weighting, and sustainability criteria. An analytical hierarchy process (AHP) method could assist in gaining ground on this front.

In addition to requiring modification, the method needs to be extended as well. The present study operates with a limited number of compartments only for the sake of simplicity during method development. Exogenous factors such as climatic, geographical and ecosystem features as well as market demand and prices should be incorporated if adequate data can be found. Probably even more important for the immediate business environment of the decision-maker are community issues, for example of cultural/religious and recreational nature, which can at times be strongly linked to industry activities affected by carbon management projects. In particular, stakeholders will be concerned about issues of land use, and stakeholder relationships therefore need to be a future compartment of the ECA framework.

In spite of this host of shortcomings and challenges, we believe that the ECA method that we have developed – once matured – has many applications such as

- certification of sustainable carbon credits at both project and regional level,
- informing decision-makers, policymakers and investors,
- project design and assessment,
- ongoing monitoring and management of projects, and
- accounting of global carbon sequestration activities including carbon capture and storage.

This study – although preliminary – is a first attempt to sketch a consistent, comprehensive and holistic approach to carbon accounting which, after being exposed to critical review and improved in an iterative process, will hopefully progress to a stage where it will be able to be applied widespread.

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