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ORIGINAL ARTICLE

A little REDD model to quickly compare possible baseline and policy scenarios for reducing emissions from deforestation and forest degradation

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Abstract A simple model allows rapid comparison of typical baseline and policy scenarios which might be considered under international programs to avoid CO_2 emissions caused by forest clearing, such as REDD (Reducing Emissions from Deforestation and Forest Degradation). These tests of REDD policy scenarios can also include CO_2 stored in forest products. The value of avoided emissions can also be determined if expected carbon prices, constant or varying, are included. The paper discusses simple illustrative example comparisons as well as possible feedback effects within larger scale setting of CO_2 offset availability, CO_2 price and emissions reductions.

Keywords Avoided emissions · Carbon emissions · CO_2 emissions · Deforestation · Model · Emissions reductions · REDD · Vensim · System dynamics

1 Introduction

1.1 Climate change, CO_2 and forests

Our warming climate is, to a large extent, the result of CO_2 emissions[1] from a number of human activities. Discussions concerning this problem usually emphasize industrial and transportation sources of CO_2. However, land use change, especially deforestation, is another important source. Worldwide, deforestation and forest degradation account for more than 20% of all human-caused CO_2 emissions (Mollicone et al. 2007).

With regard to climate change, forests were first seen as potential carbon *sinks*. The planting of new trees was seen as a means of removing excess CO_2 from the atmosphere and storing it. Use of forests to absorb CO_2 as a means of offsetting emissions became a

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[1] Other important greenhouse gasses include methane, nitrous oxide and certain fluorinated gasses. Water vapor, also a greenhouse gas, increases as atmospheric tempertures rise—a positive feedback.

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major part of the Kyoto Protocol via the ‘Clean Development Mechanism’. Through sometimes complex international arrangements people could be paid to plant trees to sequester carbon.

But the various carbon trading schemes which evolved *did not* provide for the protection of *existing* forests, even though deforestation and forest degradation are major sources of CO_2 emissions, especially in forested developing countries. There were incentives to plant new trees but no mechanism to reward protection of carbon in existing forests.

1.2 REDD: reducing emissions from deforestation and forest degradation

The REDD concept was developed as a means of protecting carbon stocks already present in existing forests. REDD was given tentative approval at the December 2007 Bali meeting of the UNFCC (Anon 2008).[2] The mechanism that developed involves extending carbon trading possibilities to carbon stocks that *would have been lost if forest had been cut.* That is, rather than pay directly for forest protection, the concept is to pay for protection of forest carbon stocks compared to agreed upon, expected, baseline loss of carbon to the atmosphere. Carbon credits would accumulate based on the difference between sequestered carbon stocks caused by a policy scenario and those assumed under a baseline scenario. In most scenarios no new CO_2 is sequestered, but CO_2 emissions are reduced.

REDD is difficult in principle and more difficult in practice. While not discussed in detail here, some of these difficulties should be mentioned. Measurement of carbon stocks can be an involved and expensive process (e.g. see Brown et al. 2008) which increases transaction costs substantially. Determination of, and agreement on, a baseline scenario may be difficult, and may involve significant political maneuvering. Thus there may be difficulty in ensuring the *additionality* of CO_2 stock differences caused by a particular policy scenario. Deforestation prevented by a REDD agreement may merely *leak* out to reappear as deforestation in another location. Also, permanence of the forest protected, and CO_2 sequestered, can be questionable. (For discussions of REDD see: Kanninen et al. 2007, Peskett and Harkin 2007; Angelsen 2008b; Pirard and Karsenty 2009).

Because REDD involves the protection of existing forested lands, it can provide many co-benefits including the protection of biodiversity, forest livelihoods, and forest derived ecosystem services. While these benefits are not directly included in the REDD concept they may help to offset previously mentioned problems, and payments for REDD could complement payments for other environmental services. Policy scenarios other than full forest protection are under serious consideration for inclusion in REDD. Such scenarios could include improved forest management and harvest techniques which can lead to higher carbon stocks in managed forests (Putz et al. 2008). Thus, it is possible that REDD payments might also complement income from the production of forest products.

The REDD concept of paying to prevent deforestation can be misleading. Some (politicians, for example?) may believe that a standing rainforest can be used to directly obtain CO_2 payments. Such thinking might be as follows: The CO_2 in my 1,000 ha forest is about 200 t/ha and the price of CO_2 is about 10 $/t so if I protect the forest I can get 1,000*200*10=$2,000,000! But REDD doesn’t work that way. Protection is measured against a baseline. If the baseline were full protection the payments for protecting forests would be *zero*. That is, payments are made for improvements over a business as usual

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[2] REDD in the Bali document stands for Reduced Emissions from Deforestation in *Developing Countries*, but later the meaning of the DD morphed into Deforestation and Forest Degradation. Some authors use the term REDDD to include both ideas.

scenario.[3] This is both the strength and weakness of REDD. Optimistically, REDD will provide payments for a climate change benefit: reduced CO_2 emissions. However, there is still no possible reward under this mechanism for communities, governments, or nations who have been, and still are, fully protecting forests.

The model provided here provides a means of examining carbon stock changes and possible REDD payments under different baseline and policy forest management scenarios. A number of illustrative examples are provided. The overall purpose is to provide a simple model that can quickly examine various possible REDD scenarios as a prelude to looking at these in a more detailed manner.

2 Model basics

A simple model illustrates the basics of carbon storage in a forest[4] as a prelude to illustrating some of the issues related to compensating forest 'owners' for protecting existing forests as might occur under the proposed program to reduce emissions from deforestation and forest degradation, or REDD. The models use Vensim system dynamics modeling software[5] to examine changes in model variables over time.

In the basic model a *forest area* (ha) can be deforested and can be replanted. For most situations, deforestation rate is calculated as a fraction of existing forest, but other formulations, such as constant area cleared per year, can be substituted. Forest lands can remain in steady state without deforestation, can be deforested, or can remain in a steady state with continuous clearing and replanting. The forest area could also be increased (Fig. 1).

The stock, Amount of C Stored in Forest Lands, is treated in the model as a co-flow (e. g. see Sterman 2000, section 12.2). This stock tracks carbon changes due to changing amount of forest, fixing of carbon by the existing forest, and carbon being lost through deforestation. The amount of carbon sequestered in this stock approaches a maximum saturation above which no additional carbon will be stored (Fig. 1). The model does not include partitioning of carbon into sub-components (e.g. leaves, stems, soil, etc.), but a future model could include these separate carbon stocks. Simple models are useful for preliminary investigation of various scenarios, but more detailed models may be necessary to fully appreciate the many manifestations of natural and human influences on forest processes affecting CO_2 stocks (e.g. see Kurz et al. 2009). Nevertheless, this model will accurately track carbon in a uniformly managed forest where different parts of the forest are in different stages of regrowth. Key model components are indicated in Table 1.

3 Example output

3.1 Example single model output

This example illustrates the deforestation of a 100,000 ha forest. Forest is cleared at a rate of 5,000 ha year^{-1} for 5 years and no re-growth or replacement occurs. These removals cause an immediate decrease in carbon stored in forest land (Fig. 2).

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[3] Not discussed here is the additional, possible, limitation referred to as a 'crediting baseline' which could further limit carbon payments (Angelsen 2008b).

[4] The definition of forest is left to the user.

[5] The models can be run with the free Vensim model reader, or a free version of the software, both available at www.vensim.com. The model is available from the author.

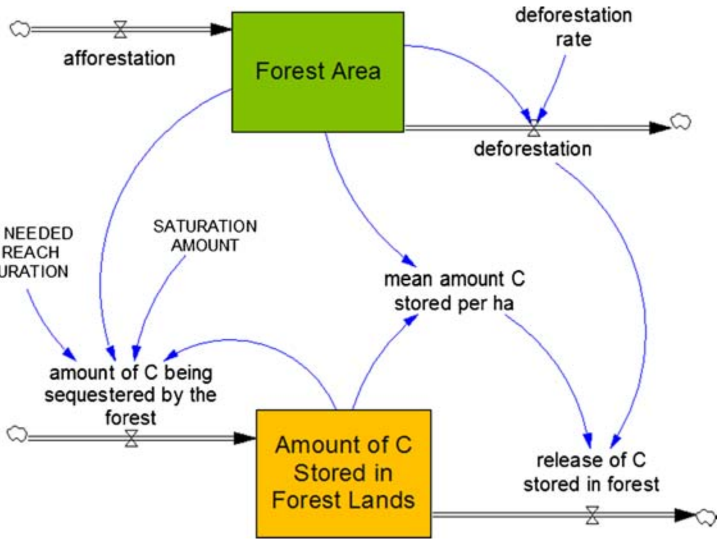

Fig. 1 Model elements which calculate additions and losses of forest land and track carbon stored in forest lands. Forest Area is determined by addition or removal of forest. A co-flow tracks addition of carbon due to both forest additions and growth, as well as loss of carbon which typically equals the loss of forest times the mean amount of carbon in each land unit. Under harvesting scenarios this loss is calculated somewhat differently (see text). Two essentially identical models are used to compare baseline and policy scenarios. In the figures system dynamics modeling conventions are: Stocks (i.e. state variables) are indicated by boxes and capitalized text, flows are indicated by pipes and lower case text, auxiliary variables are indicated by lowercase text, constants are indicated by upper case text

In a second illustration, a 100,000 ha forest is cleared and replanted at the same rate: 5,000 ha year^{-1} for 5 years. The total forested area does not change. However the amount of carbon stored drops, and takes about 65 years to recover to its original value (Fig. 3).

Table 1 Main components used in the model. Values shown here are those used in the examples, but can be changed to examine other scenarios. By using an area of 1 ha we can conveniently see the per ha differences in carbon storage

Item	Meaning	Typical values used	Units
Forest area	Total area of forest	Initial value: 1 or 100,000	ha
Amount of carbon stored in forest lands	Carbon actually stored in forest lands.	Initial value usually 200	tons ha^{-1}
Saturation value	Maximum amount of carbon that can be stored by each hectare of forest.	200	tons ha^{-1}
Time needed to reach saturation	Time constant used to determine the time needed for the forest to become fully saturated.	15 years. Full saturation will be reached in about 60 years.	year
Deforestation rate	Fractional rate at which forest land is deforested.	Varies. e.g. 0.03 year^{-1}	year^{-1}
Forestation rate	Rate at which area is added to the forest.	Varies. Can be fraction or fixed amount per year.	year^{-1} or ha year^{-1}

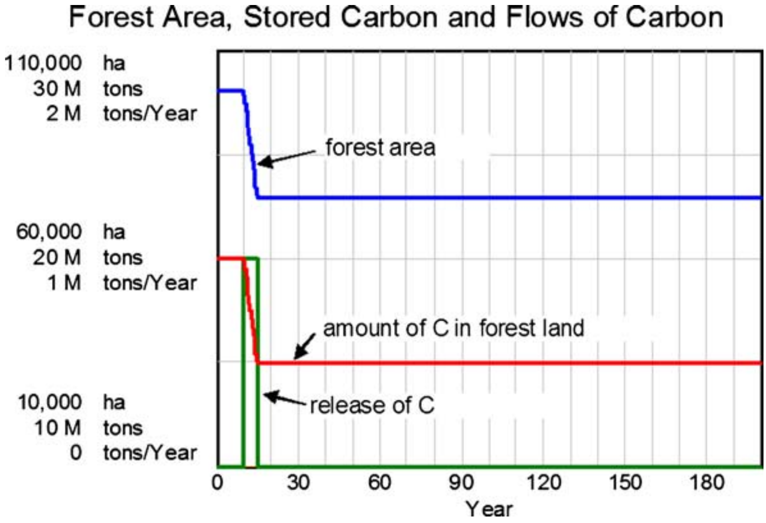

Fig. 2 A simple example illustrating removal of forest and loss of carbon in an imagined baseline scenario. In the model parallel structures capture baseline and policy scenarios for comparison

3.2 Comparing example baseline and policy forest management scenarios

The simple examples above each deal with only a single example scenario. In order to compare a baseline scenario with a policy scenario, a copy of the same sub-model permits parallel calculation of differences in carbon sequestration and storage under baseline and policy scenarios. This allows rapid examination of a number of situations with minimal modification to the model. Basic details of the following examples are presented in Table 2.

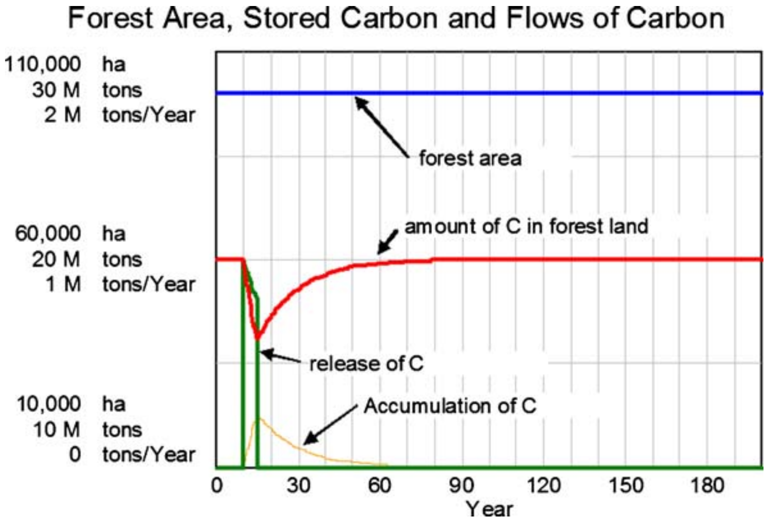

Fig. 3 In this example, for five years forest is cleared and replanted at the same rate. Forest area does not change, but stored carbon drops considerably and takes a long time to return to its original value even after clearing with replanting stops

Table 2 Basic details of example scenarios

Scenario	Baseline		Policy	
	Forestation	Deforestation	Forestation	Deforestation
Prevent deforestation A	0	3%	0	0
Prevent deforestation B	0	Constant amount	0	0
Prevent deforestation (alternate baseline)	2% (e.g. re-growth)	5%	0	0
Less deforestation	0	3%	0	1%
Switch to sustainable forest management	0	3%	3%	3%
Switch to plantation management	0	3%	10%	10%
Switch to intensive plantation management	0	3%	12.5%	12.5%

3.2.1 Prevent deforestation

In the first example it is assumed that baseline deforestation occurs at a rate of 3% of remaining forest per year. The policy scenario is complete protection of the forest. The initial forest is assumed to be mature and thus fully saturated with carbon. In this and the following examples calculations are made for one ha of forest allowing direct output of per ha values of carbon storage and differences.

Because the baseline and policy scenarios start with the same amount of forest there is no initial difference between the two. Over time the amount of CO_2 benefit of protection grows because the difference between what would have happened to the forest and full protection becomes larger. Eventually all forest would have been cut, so the carbon benefit of full protection ultimately approaches the CO_2 saturation amount (Fig. 4).

This example illustrates a possible difficulty with the REDD concept: payments are, in theory, based on the difference between carbon in the forest under the baseline and policy scenarios, but these differences take considerable time to grow. This difficulty might be addressed via payment schedules which provide start-up payments. On the other hand, the largest *changes* in avoided emissions (e.g. avoided tons of CO_2 per year) occur early under

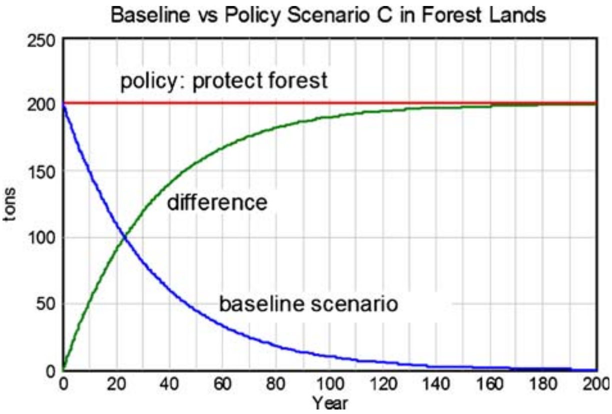

Fig. 4 Comparison of C stocks with a 3% deforestation baseline and a full protection policy scenario. Avoided carbon emissions equal the difference between the two policies (also shown by the *green line*). These gradually approach the full saturation value, but this value is not reached for many years

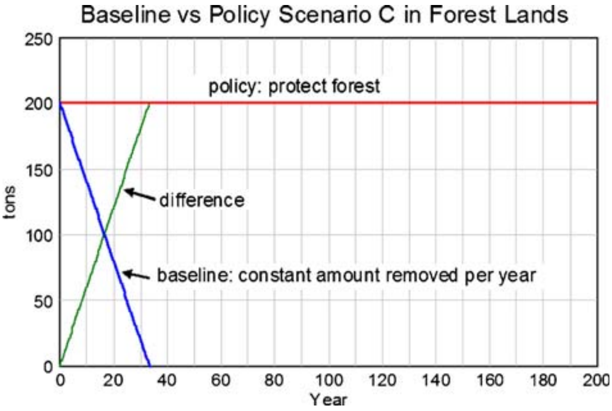

Fig. 5 As in the previous figure but with a constant area of deforestation per unit time (*blue*) and no deforestation (*red*) scenarios. The difference between the baseline and policy scenario is shown in green

most policy scenarios and payment should probably be based on the increasing magnitude of the carbon difference rather than the carbon stock present (see discussion below).

In comparison with the above example we could also assume that baseline deforestation does not occur as a fractional rate but rather as a fixed amount of land per year until all the forest is gone. The difference between this assumed baseline and a policy scenario of no deforestation results in a much more rapid accumulation of avoided emissions of CO_2 compared to the previous example (Fig. 5). The large difference between these two examples illustrates the importance of selecting an appropriate baseline. Nevertheless avoided emissions accumulated during the earlier years (e.g. up to year 10) are similar in these two examples.

3.2.2 Different baselines

The determination of a baseline scenario has been a topic of continuing concern (Pirard and Karsenty 2009). The baseline deforestation rate is often assumed to be a direct clearing of intact forest as a fixed percentage per year, as the previous example 3%. A realistic alternative is the clearing of forest at a *net rate* of 3% whereby the actual clearing is 5% coupled with partial re-growth covering 2% of the forest. These baselines are compared to a policy of full forest protection (Fig. 6).

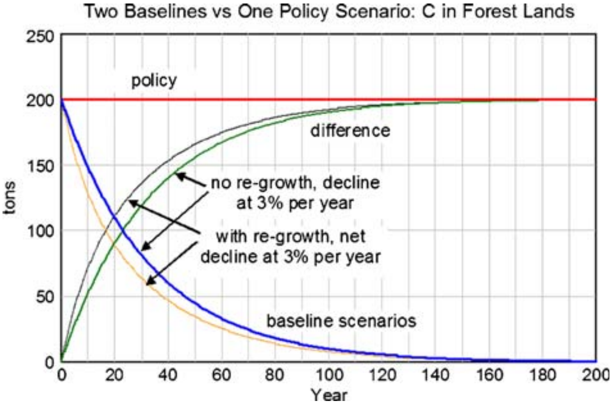

Fig. 6 An example illustrating the importance of baseline determination. An area is deforested at 3% per year, but in one case (no re-growth) this is a pure deforestation scenario. In the other case (with re-growth) although the decline in forest area is 3% per year, the area not yet deforested is partly composed of younger, smaller, trees which hold less carbon. Policy scenario is full forest protection. All values in t C on one ha

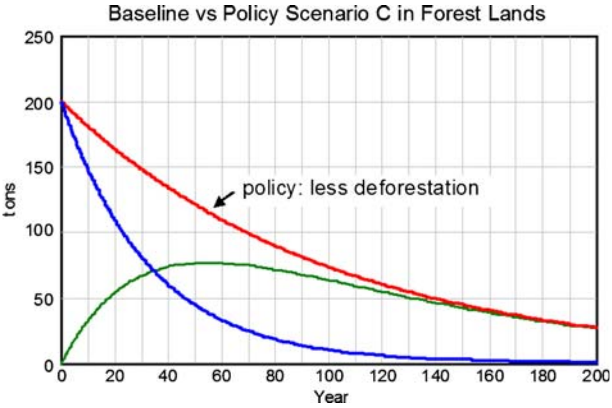

Fig. 7 A policy scenario allowing a slower deforestation rate, 1% compared to a 3% deforestation baseline, can also provide some C benefits. Ultimately however that C is lost

This alternate baseline creates a younger forest holding less carbon. At year 20 this scenario protects about 20 t ha^{-1} less than the simpler 3% scenario (89 vs 109 t ha^{-1}). Consequently, the carbon benefits of protecting it are greater than if the forest was merely cleared at a 3% rate.

3.2.3 Less deforestation

Policy scenario benefits, in terms of avoided emissions and value, are not necessarily limited only to no-cut scenarios. In this example we assume the policy scenario will reduce deforestation from the 3% baseline to 1% per year. Less deforestation results in some additional stored carbon, but a relatively small amount and not forever. Ultimately both scenarios lead to complete loss of the forest and no net increase in carbon storage. However, this comparison illustrates that any reduction in the deforestation rate could have some carbon benefits and these might provide time for other emissions reducing policies to be implemented (Fig. 7).

3.2.4 Sustainable forest management

The following example assumes that we can’t stop deforestation, but we can immediately replant (or there is relatively rapid natural regeneration), and policies are changed so the land remains as managed forest. Forested area remains constant but the mean age of the forest and the amount of carbon stored is lower than it would be under full protection (Fig. 8).[6]

This scenario results in a younger, faster growing forest which would appear to be storing more CO_2 compared to a no cut scenario which has no net carbon uptake. However, in steady state, by definition, the forest management scenario also has no net carbon uptake. Also, the overall effect of harvesting is that, even in steady state, there is less stored carbon than under a no-cut scenario since the average age of the forest is younger. This seemingly

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[6] In *replanting/ regeneration* scenarios we assume that the trees are harvested for a purpose, and thus assume that tree and carbon removal is done by removing older ‘trees’. This in turn requires a modification of the model whereby carbon loss is not via removal of *average* carbon per ha, but via removal at a rate comparable to removal of areas of forest with the age equal to the rotation time. See model for further information.

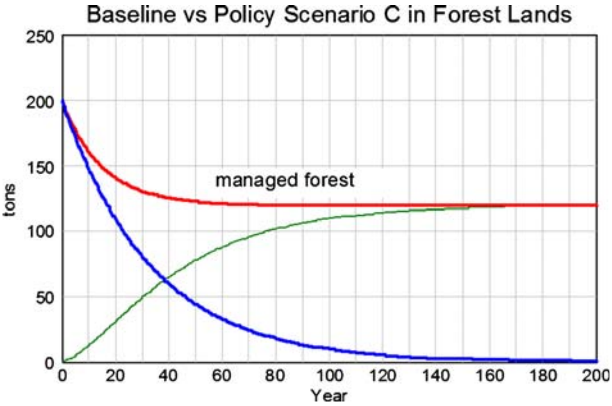

Fig. 8 Forest management scenario. Here forest is harvested at 3% per year and is replanted (or is regenerated naturally) at the same rate. From a C perspective this policy is significantly better than deforestation, but not as beneficial as full protection. Green line illustrates the net C benefits of the forest management scenario

contradictory situation was also pointed out by Harmon et al (1990). Nevertheless, from a CO_2 perspective a forest management scenario is significantly better than the baseline deforestation scenario.

3.2.5 Plantation management

Some have suggested that forest plantations are a viable option to prevent deforestation and store carbon (Cacho et al. 2004). This example illustrates a situation where a policy of gradual conversion of forest to plantation is compared to a baseline deforestation scenario. The plantation rotation time is assumed to be 10 years, with a gradual conversion of all the forest to plantation.

Because of the conversion of forest to plantation at an annual rate of 10% compared to deforestation at a rate of 3% the plantation policy scenario causes more carbon loss prior to year 36 than the baseline. Subsequently the plantation scenario would store more carbon, but only about 50 t ha^{-1} compared to 200 t ha^{-1} in the original forest (Fig. 9).

Because of species selected and management techniques, pulp plantation trees can have a faster growth rate, reaching carbon saturation more quickly, but may also have a lower saturation level. One example, *Acacia mangium*, might have values more like 175 t/ha carbon saturation and a time constant of 12 rather than 15 years (based on Cacho et al. 2004) and a rotation time of 8 rather than 10 years (dashed lines in Fig. 9).

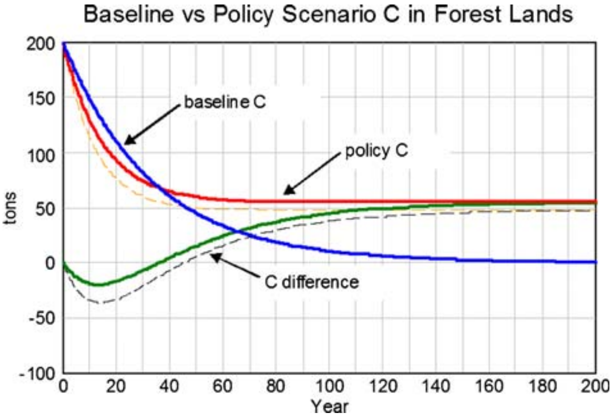

Fig. 9 Example policy scenarios whereby forest is rapidly converted to intensive plantation (*red lines*) rather than being deforested (*blue lines*). Dashed lines indicate outcomes using parameters more likely for rapid-growth short rotation plantations. Note that the difference (*green lines*) is negative (policy is worse than the baseline) for the first 35 years of the scenario

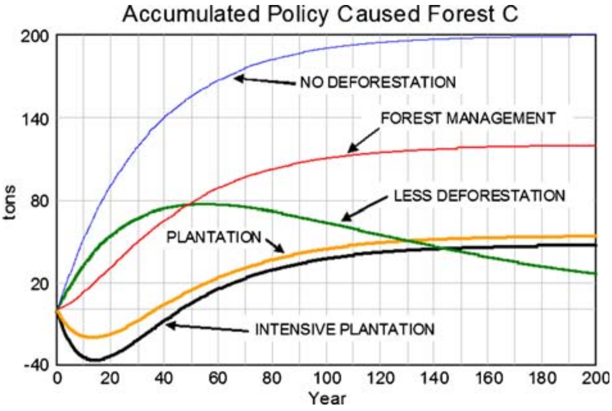

Fig. 10 Comparison of avoided carbon emissions under five policy scenarios. All scenarios are compared to a baseline in which forest is being destroyed at a rate of 3% of remaining forest per year. The forest management scenario assumes a 33 year rotation and plantation management assumes a 10 year rotation. Recall that average carbon content includes areas of re-growth in the managed forest and plantation scenarios

Note that both plantation scenarios are worse than the baseline 3% deforestation baseline for the first 35, or 45, years of the comparison. This is because these scenarios convert forest at a faster rate then the baseline and also hold significantly less carbon after plantation establishment.

3.3 Comparison of examples

A comparison of the five theoretical scenarios compared to the baseline of a 3% rate of deforestation indicates that the no deforestation scenario is clearly the best policy in terms of avoided CO_2 emissions. However, such a policy may be hard to implement. One likely outcome of attempting such a policy would be less deforestation, rather than zero deforestation. A possible alternative would be low intensity forest management, a policy which performs better than a 1% deforestation scenario, especially if carbon in forest products is included in the analysis (see next section). Plantation scenarios perform poorly and are worse than the baseline deforestation scenario for the first 35 years of the comparison (Fig. 10).

4 Inclusion of CO_2 stored in forest products

If policy scenarios are to include managed forests, then perhaps it might become important to consider carbon stored in long term forest products as part of the carbon calculations whether or not this carbon is included in REDD payment schemes. Often only a small fraction of forest carbon is incorporated into products, but products with long half-lives can account for an appreciable amount of stored carbon. If we assume that 56% of forest carbon is in logs and bark, roughly 54% of the logs can be converted to wood products and roughly 80% of wood products are converted to the final product then we can assume an upper limit of about 25% conversion of forest carbon into a final forest product (Harmon et al. 1990).[7] The half-life of carbon in forest products has been reported by several authors (e.g. Skog et al. 2004, Miner 2006). For example carbon in wood incorporated into houses in the USA has a half-life of 80 to 100 years (Skog and Nicholson 1998).

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[7] This excludes immediate burning, or conversion, of biomass for energy which could have CO_2 benefits via the replacement of oil products used for these purposes.

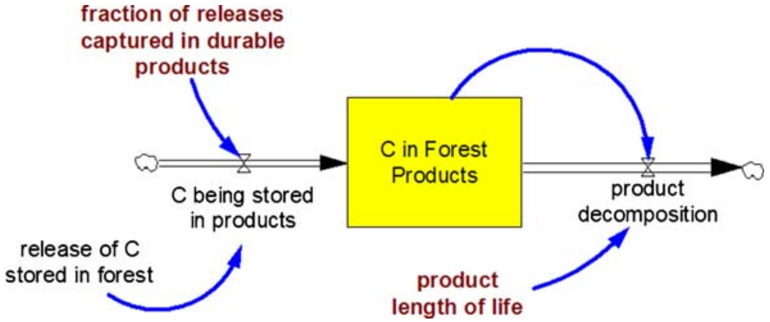

Fig. 11 A fraction of C from harvested forest is captured in forest products. If these are long lived then the stock of C in these products can be substantial. A similar structure calculates the C stock for products resulting from policy scenarios

The model was modified to account for carbon stored in products from both baseline and policy scenarios that include harvest of forest products (Fig. 11). This modification also accounts for carbon in baseline products (if any) after a policy scenario is implemented. In other words, even after a baseline scenario is stopped there is still carbon in products produced in the past (not shown in Fig. 11).

A typical REDD policy scenario is full forest protection. However, other forest management scenarios involving harvest of forest products may be more practical to implement. Currently plans for REDD do not incorporate carbon in forest products, partly because adding this additional component to an already confused and, sometimes, controversial policy might be overly complicated. Nevertheless, such calculations might be important in the future.

Consider a comparison between a baseline scenario, a plantation of fast growing trees used for paper, and a policy scenario which converts that plantation to slow growing timber trees used for construction of houses (Table 3). This result illustrates both the carbon benefits of moving away from rapid turnover plantation management, as well as the importance of considering carbon in forest products. There is more carbon stored in the slower growing forest and a significant amount stored in the long-lived wood products compared to the short term paper products. In fact, taken together prevented emissions ultimately amounts to almost 135 t/ha although this level of benefit is not reached for many years (Fig. 12).

5 Paying for REDD—valuing avoided emissions

Discussion about payment for avoided emissions has focused mostly on the value of additional carbon stored under a policy scenario compared to a baseline scenario. The additional carbon protected is represented by the orange box at the top of Fig. 13. It is tempting to merely multiply this by the current carbon price to obtain a value for carbon difference accumulated, but because prices in the carbon market will change this would not be appropriate. It may be reasonable to value carbon at the time it is ‘saved’.[8] Thus, in the model, a co-flow is used to track the accumulating value of carbon (bottom stock Fig. 13).

Sometimes the focus of payment schedules for REDD has been the stock of carbon saved, i.e. tons of avoided emissions, and its accumulated value. However, a payment schedule is more reasonably based on the increasing value of that stock (i.e. \$ year^{-1}) which is based on

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[8] Variable carbon prices can be implemented in the model, but are not used in the examples.

Table 3 Values used in comparing plantation and timber management scenarios with the inclusion of carbon in forest products

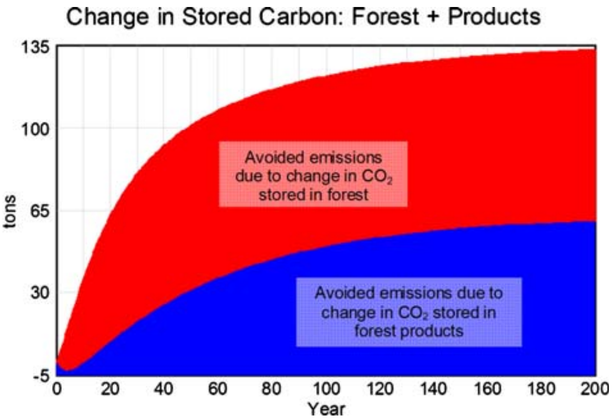
Scenario component	Baseline: Plantation	Policy: Timber management
Forestation	12.5%	3%
Deforestation	12.5%	3%
Fraction of C incorporated into products	30%	25%
Product half-life	3 years	40 years

the change taking place in the carbon stock difference (t year^{-1}). In the model that value is represented by the net *accumulating value of carbon due to policy differences* (bottom of Fig. 13). This suggestion assumes that payments are to be based on actual amount of the carbon difference, and the value of those emissions as determined by the carbon market.

Different perspectives on carbon value for these REDD examples are presented in Fig. 14. Using 200 t ha^{-1} carbon in the original forest and a fixed carbon price of 10 \$ t^{-1} eventually results in an accumulated value of \$2,000 ha^{-1} for the forest protection scenario (Fig. 14A). The associated net flow for carbon value would start at about 60 \$ ha^{-1}year^{-1} for the first full year of forest protection. These payments would then follow an exponential decline reaching about 10 \$ ha^{-1}year^{-1} in 60 years (Fig. 14B). Payment schedules for all scenarios presented approach zero because policy carbon stocks approach saturation for each particular scenario and the assumed baseline carbon stock approaches zero. Actual payment scenarios might be formulated as a truncated version of these flows, for example for 30 years. Because of increasing uncertainty as payments are projected into the future, managers may also be interested in the net present value of such payments (Fig. 14C).

Some scenarios can produce negative values for carbon flow because the policy scenario emits more CO_2 during part of its lifetime than the baseline. For example, the plantation scenario at first converts natural forest to plantation more rapidly than the forest would have been removed by the assumed deforestation rate. Eventually the carbon stock in the plantation will be larger than what would have been found in the land undergoing deforestation, but for the first 36 years the plantation carbon stock is less than what would have occurred under the baseline scenario. This type of scenario implies a modification of the 'payment for saved carbon flow' concept, because the carbon flow becomes positive while there is still a negative carbon stock difference. In such situations payments could be based on the increasing value

Fig. 12 Results of a comparison between a baseline scenario of intensive plantation management and policy scenario of longer term rotation timber management where C in forest products is also considered



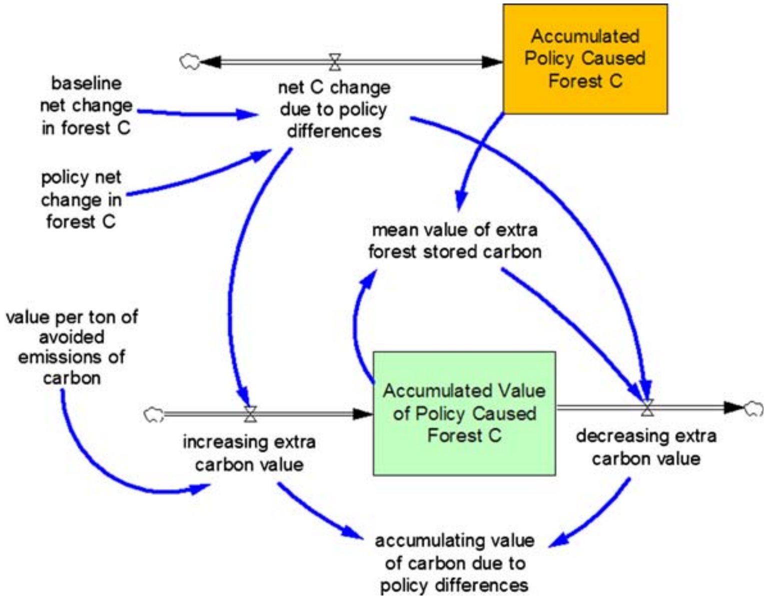


Fig. 13 Portion of the model representing the accumulation of the C difference between a baseline and a policy scenario, and the means of tracking the value of this carbon. The net flow *accumulating value of carbon due to policy differences* represents the best option for determining the value of payments, if payments are to be based on actual C differences between a baseline and a policy

of saved carbon only when the scenario carbon stock is also larger than the baseline stock. In other words, we should not pay for policy caused carbon improvements that were needed to replace a policy caused carbon loss. In fact, it is unlikely that such a scenario would be possible under REDD protocols.

6 REDD's bigger realm

The implementation of REDD is not just a matter of calculating and assigning values to changes in forest carbon, as difficult at those tasks may be in the real world. A number of larger policy issues, some illustrated in Fig. 15, must also be considered.

Some payment will almost certainly have to be made prior to the reduced emissions being verified. There is also a question as to who will actually receive payments. The underlying philosophy of REDD is that people can be reimbursed for their role in protecting the climate, especially in cases where such protection prevents people's use of income generating activities… such as agricultural developments on cleared forest land.[9] It is this cash incentive that is attracting participation in REDD projects, which are springing up around the world. Although individuals might be motivated by this incentive, REDD projects are not normally geared toward individuals. REDD projects, tend to target owners or managers of large blocks of land. Although payments *may* ultimately go to individual land users, targets for REDD involvement would normally be government agencies, or government in general, including local government. How such entities might be paid, and how they will use or distribute

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[9] This is a subset of the concept of payments for ecosystem services (PES).

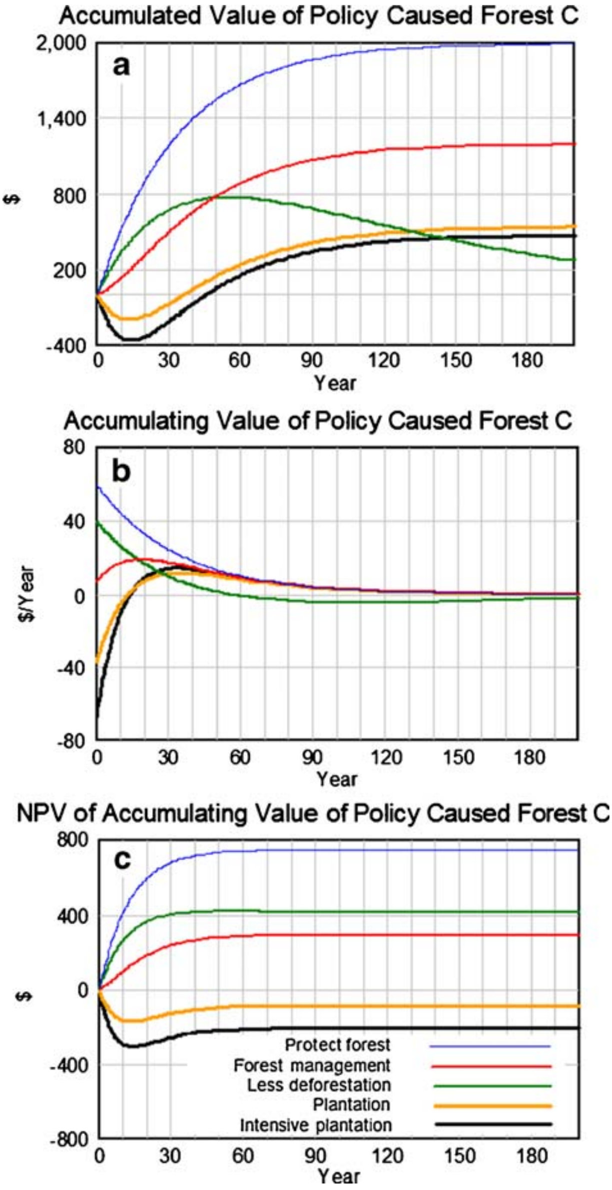

Fig. 14 Basis for REDD payments. Accumulated forest carbon (from Fig. 10) has a value ($) shown in part A. This is a result of of the accumulating value ($ Year^{-1}) of this carbon shown in part B. This is the value most closely related to most proposed payment schemes. The net present value of this flow is presented in panel C. Note that policies releasing more C than a baseline can produce negative values and/or flows. All policies are compared to a baseline of 3% per year deforestation. Policies: Full Protection, 1% deforestation, Forest Management—3% harvest with replanting / re-growth, Plantation Forestry—10% harvest and replanting, intensive plantation—12.5% harvest and replanting

REDD income equitably, is still under discussion (Okereke and Dooley 2009; Rights and Resources Initiative 2008).

The expectation of cash payments has heightened interest in these programs. But without a clear understanding of the mechanisms for payment (especially since such mechanisms have not yet been worked out) there is the possibility that expectation of payment may be inflated compared to actual future payment. This might lead to disappointment, reduced

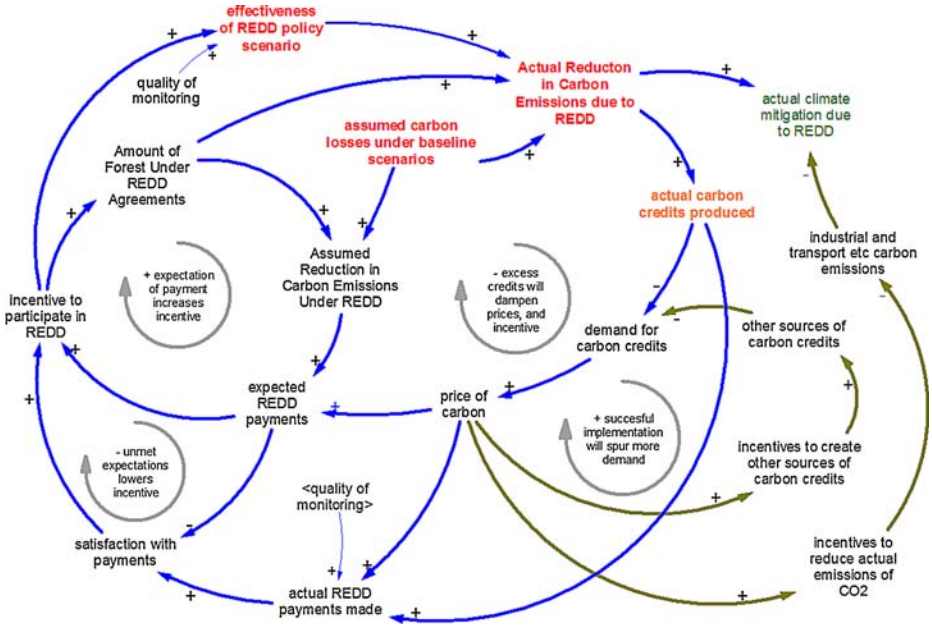

Fig. 15 Some of the interrelationships within the bigger realm where REDD would operate. The components labeled with red lettering are those found in the model, black lettering indicates components closely related to the specific issues of REDD implementation and brown lettering indicates some additional larger scale effects

participation in REDD programs, and decreased adherence to agreed on emissions-reducing scenarios. These ideas are illustrated in the causal loop diagram in Fig. 15.

Another serious concern is the possibility that widespread implementation of REDD projects might flood the carbon market thereby lowering the price of carbon (e.g. see Livengood and Dixon 2009). This might have several effects. A lower carbon price could make REDD and carbon sequestration projects less attractive ultimately, after some delay, leading to fewer carbon credits on the market thus raising the price again. But initially, and more importantly, a lower carbon price will raise incentives to buy carbon credits rather than implement real reductions in other CO_2 emissions. If cheap REDD carbon credits flood the carbon market, the overall effectiveness of REDD as an emissions reducing strategy will be compromised (Fig. 15, right side).

7 Comments and conclusions

In theory, REDD payments will be based on avoided CO_2 emissions. Payments would be based on the market value of the forest carbon difference—the difference between a baseline and a policy scenario. The value will be higher if carbon stocks are well verified and stable, lower if they are not.

In reality this all becomes rather tricky. Baseline deforestation rates are hard to measure accurately, especially when projected into the future. Past rates may not be good predictors. Deforestation rates can accelerate as forests disappear and demand for forest products remains high. Conversely forest transition theory indicates country wide deforestation rates will decline as a country becomes more developed (Rudel et al. 2005; Angelsen 2008a). These issues complicate the determination of the REDD baseline.

Carbon under a policy scenario would appear simpler to determine, at least after the policy is implemented. But such determinations, and verification, can be complicated (Brown et al. 2008), and in any case some payments will often have to be made *in advance* of policy implementation. This necessity arises because implementation activities incur costs, and in developing countries it is unlikely that costs will be met based on a promise of future payment. More likely is a situation where initial payments will be made based on the promise of carbon credits to be delivered. This could place investors in REDD carbon credits in a precarious position. It would appear that payment schemes will include initial payments based on a projected, modeled, carbon difference, followed by payments based on follow-up field measurements and corrections based on measured differences. In such cases simple models allowing initial comparisons and discussion of possible policy and baseline scenarios will be useful.

The model is valuable because of its simplicity but that also avoids real world complications caused by many confusing policy issues. Inclusion of some of these issues in future dynamic model could make the model more interesting and useful and still perhaps maintain its simplicity.

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