Valuing the climate change impacts of tropical deforestation[1]

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Tropical deforestation is at present responsible for about a quarter of global annual carbon dioxide emissions[1]. If no action is taken, it is expected to continue to be a major contributor to greenhouse gas emissions throughout at least the first half of this century[2]. While several estimates of the costs of reducing deforestation exist[3], there have been no estimates published to date valuing the impacts of deforestation. As part of the Eliasch Review into carbon finance mechanisms for reducing deforestation and Cisco's 'Planetary Skin' initiative, we use PAGE2002, the probabilistic integrated assessment model used in the Stern review[4], to estimate the value of the climate change impacts from 2000 to 2200 derived from one authoritative projection of tropical deforestation[5]. We show that the mean net present value of the impacts is about $12 trillion (in year 2000 $US), with a 5 – 95% range of about $1.5 to $40 trillion, and that, contrary to expectations, this estimate is almost totally insensitive to the emissions scenario on which the emissions from deforestation are superimposed. This invariant $12 trillion mean valuation provides the motivation for taking action to tackle deforestation, whether other abatement options are vigorously pursued or not.

This investigation starts from the projected CO_2 emission rates with and without tropical deforestation. Figure 1 shows the CO_2 emissions under the IPCC SRES A2

[1] This paper was commissioned by the Office of Climate Change as background work to its report 'Climate Change: Financing Global Forests' (the Eliasch Review).

non-intervention scenario[6], with and without the business as usual (BAU) estimates of tropical deforestation from Houghton[7]. Tropical deforestation makes up 25% of emissions in 2000, falling to 15% in 2020, 10% in 2060 and 2% in 2100, as less and less forest remains to be cut down. Deforestation emissions after 2100 are assumed to be zero.

Mean CO_2 concentrations in the A2 scenario without deforestation reach nearly 800 ppm by 2100 and 1400 ppm by 2200. Figure 2 shows that with deforestation the concentrations are on average about 30 ppm higher in 2100 and throughout the 22nd century, with a 5 – 95% range of about 25 to 35 ppm higher. Although the deforestation emissions cease in 2100, their effects on CO_2 concentrations continue because of the long lifetime of CO_2 in the atmosphere, and because of the feedback from temperature rises to natural emissions of CO_2[8], which is included in PAGE2002[9].

Mean global mean temperatures in the A2 scenario without deforestation reach 4 deg C above pre-industrial levels by 2100 and nearly 8 deg C by 2200. Figure 3 shows that with deforestation the global mean temperatures are on average about 0.15 deg C higher in 2100 and 0.1 deg C higher in 2200, with a 5 – 95% range of about 0.1 to 0.2 deg C in 2100, and 0.05 to 0.15 deg C in 2200. These higher temperatures drive the extra emissions of natural CO_2 which help to keep CO_2 concentrations higher in the 22nd century, even when emissions from deforestation have ceased.

Mean annual global climate change impacts in the A2 scenario without deforestation reach $12 trillion by 2100, and over $350 trillion by 2200. Figure 4 shows that with deforestation the annual global impacts are on average about $1 trillion higher in 2100 (and $10 trillion higher in 2200), with a 5 – 95% range of about $0.2 to $3 trillion in 2100 (and $2 to $25 trillion in 2200). For comparison, global world product was about $45 trillion in 2000, rising to $340 trillion in 2100 and $2100 trillion in 2200 in the A2 scenario.

The Stern review uses a pure time preference rate of 0.1% per year, and an equity weight (the negative of the elasticity of the marginal utility of consumption) of 1. This combination gives a consumption discount rate of about 1.5 to 2 % per year for most regions and most time periods. The Stern review pure time preference rate assumptions are at the low end of the plausible range[10], so this investigation uses a triangular distribution for both parameters. The pure time preference rate has <mean, mode, max> values of <0, 1, 2> % per year, and the equity weight has <mean, mode, max> values of <0.5, 1, 2>. With this discounting, the net present value (NPV) of the climate change impacts of deforestation are on average about $12 trillion, with a 5 – 95% range of about $1.5 to $40 trillion. This is the best estimate we have of the impacts of BAU deforestation combined with a BAU path of other emissions from scenario A2.

As well as the SRES A2 non-intervention scenario, the Houghton estimates of deforestation can be combined with an emission path that reflects a strenuous attempt to limit CO_2 concentrations, for instance a path of CO_2 emissions designed to produce a 450 ppm CO_2 concentration using the MAGICC model[11]. Methane and sulphate emissions are adjusted pro rata from the A2 scenario.

Mean CO_2 concentration in the ‘450’ scenario without deforestation reaches 485 ppm by 2100 and 560 ppm by 2200. Although much lower than in the A2 scenario, the mean concentrations do not stay below the 450 ppm target in the long run. This is because of the feedback from temperature rises to natural emissions of CO_2, which is included in PAGE2002. Therefore this path is described as ‘450’, rather than 450.

With deforestation the concentrations are on average about 30 ppm higher in 2100, rising to nearly 35 ppm higher in 2200, with a 5 – 95% range of about 25 to 35 ppm in 2100, and 25 to 45 ppm in 2200. This is very similar to the effect of deforestation on CO_2 concentrations in the A2 scenario, shown in figure 2, as expected.

Mean global mean temperatures in the ‘450’ scenario without deforestation reach 2.9 deg C by 2100 and 4.3 deg C by 2200, about 1 and 3.5 degC below the respective values for the A2 scenario. Figure 5 shows that with deforestation the global mean temperatures are on average about 0.2 deg C higher in 2100 and 0.25 deg C higher in 2200, with a 5 – 95% range of about 0.1 to 0.3 deg C in 2100, and 0.15 to 0.35 deg C in 2200. This is a much larger increase than under the A2 scenario, about 50% larger in 2100 and 150% larger in 2200. The reason is that there is a logarithmic relationship between radiative forcing (i.e. the global warming effect) and concentration, which will make the same deforestation emissions have a greater effect if they add to a lower base, such as the ‘450’scenario, rather than a higher one, such as the A2 scenario.

Mean annual global impacts in the ‘450’ scenario without deforestation reach $6 trillion by 2100 (and about $95 trillion by 2200, beyond the end of the graph). This is about half the value for the A2 scenario without deforestation in 2100, and about 1/4 the value in 2200.

With deforestation the annual global impacts are on average about $1 trillion higher in 2100 (and $12 trillion higher in 2200), with a 5 – 95% range of about $0.2 to $3 trillion in 2100 (and $2 to $40 trillion in 2200). These are very similar to the values under the A2 scenario. The greater increase in global mean temperature caused by the deforestation emissions in the ‘450’ scenario is almost exactly counterbalanced by the non-linear relationship of impacts to temperature. This relationship will make a given temperature increase cause a smaller rise in impacts if it is added to a lower base, such as the ‘450’scenario, rather than a higher one, such as the A2 scenario.

The mean NPV of impacts from 2000 to 2200 in the ‘450’ scenario without deforestation is about $85 trillion, or about 2 times gross world product in 2000. This is less than 40% of the NPV of impacts in the A2 scenario.

With deforestation the NPV of impacts are on average about $12 trillion higher, with a 5 – 95% range of about $1.5 to $40 trillion. This is the best estimate we have of the impacts of BAU deforestation under an aggressive abatement path of other emissions such as the ‘450’ scenario. It is practically identical to the value under the A2 scenario. As the non-intervention A2 scenario, and the ‘450’ scenario enclose the full range of plausible emission paths over the next century, we can conclude that the impacts of BAU deforestation are almost totally insensitive to the emissions scenario on which they are superimposed. This is contrary to claims elsewhere that the marginal impact of emissions will be strongly dependent on emissions scenario[12].

Methods

PAGE2002 contains equations that model:

Emissions of the primary greenhouse gases, CO_2 and methane, including changes in natural emissions stimulated by the changing climate.

The greenhouse effect. PAGE2002 keeps track of the accumulation of anthropogenic emissions of greenhouse gases in the atmosphere, and the resultant increased radiative forcing that results, using a logarithmic relationship between concentration and forcing for CO_2, and a square root form for methane.

Cooling from sulphate aerosols. The direct and indirect reductions in radiative forcing are separately modelled.

Regional temperature effects. For the eight world regions in PAGE2002, the equilibrium and realised temperature changes are computed from the difference between greenhouse warming and regional sulphate aerosol cooling, and the slow response as excess heat is transferred from the atmosphere to land and ocean. Sulphate cooling is greatest in the more industrialised regions, and tends to decrease over time due to sulphur controls to prevent acid rain and negative health effects.

Nonlinearity and transience in the damage caused by global warming. Climatic change impacts in each analysis year are modelled as a polynomial function of the regional temperature increase in that year above a time-varying tolerable level of temperature change, $(T-T_{tol})^n$, where n is an uncertain input parameter. Impacts are aggregated over time using time-varying discount rates.

Regional economic growth. Impacts are evaluated in terms of an annual percentage loss of GDP in each region, for a maximum of two sectors; defined in this application as economic impacts and non-economic (environmental and social) impacts.

Adaptation to climate change. Investment in adaptive measures (e.g. the building of sea walls or the development of drought resistant crops) can increase the tolerable level of temperature change (T_{tol}) before economic losses occur and also reduce the intensity of both noneconomic and economic impacts.

The possibility of a future large-scale discontinuity. This is modelled as a linearly increasing probability of a discontinuity that substantially reduces gross world product occurring as the global mean temperature rises above a threshold.

The PAGE2002 model uses relatively simple equations to capture complex climatic and economic phenomena. This simplification is justified because the results approximate those of the most complex climate simulations[13], and because all aspects of climate change are subject to profound uncertainty. To express the model results in terms of a single 'best guess' could be dangerously misleading. Instead, a range of possible outcomes should inform policy. PAGE2002 builds up probability distributions of results by representing over 50 key inputs to the calculations by probability distributions, making the characterisation of uncertainty the central focus.

The full set of equations and default parameter values in PAGE2002 are included in Hope[14].

As the mean results all come from 1000 PAGE2002 runs, their standard error is about 1/30 the standard deviation of the results from PAGE2002. This standard deviation for the NPV of impacts of BAU deforestation is about $15 trillion, so the mean results for the NPV of impacts have about a 95% chance of being within $1 trillion (2 standard errors) of the true value.

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This work was funded by Cisco IBSG Global Climate Change practice and its 'Planetary Skin' initiative and HM Government's Office of Climate Change as part of the Eliasch Review. The development of PAGE2002 was funded by the GB Office of Gas and Electricity Markets.

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Figure 1 CO2 emissions by date with and without BAU deforestation

Source: SRES A2 scenario and Houghton BAU deforestation scenario

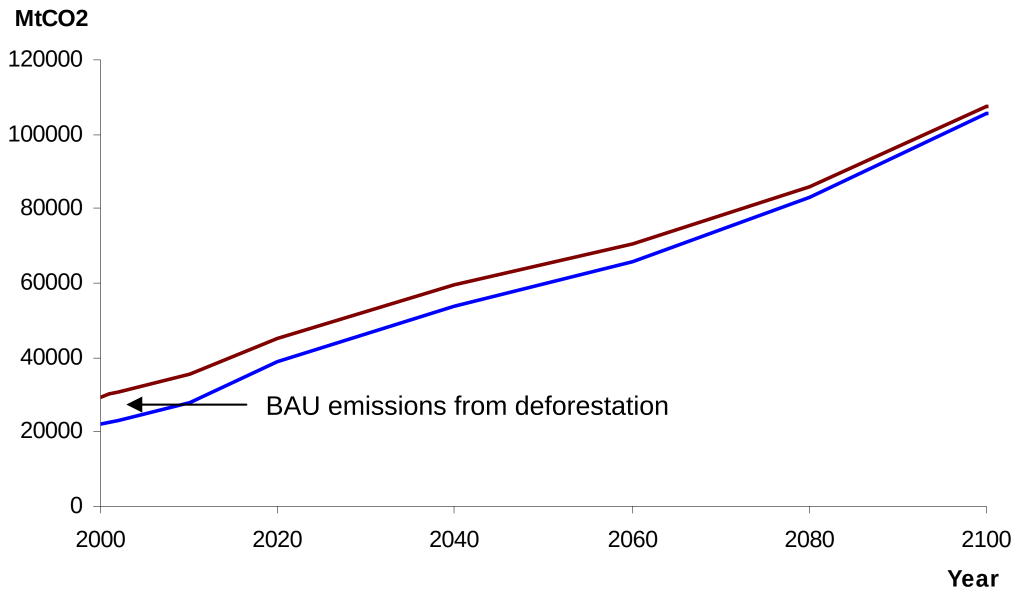

Figure 2 Increase in CO_2 concentration by date as a consequence of BAU deforestation

In each of figures 2 to 5, the thick line is the mean result, and the thinner lines are the 5 and 95% points on the probability distribution.

Source: 1000 PAGE 2002 runs with SRES A2 and Houghton BAU deforestation scenario.

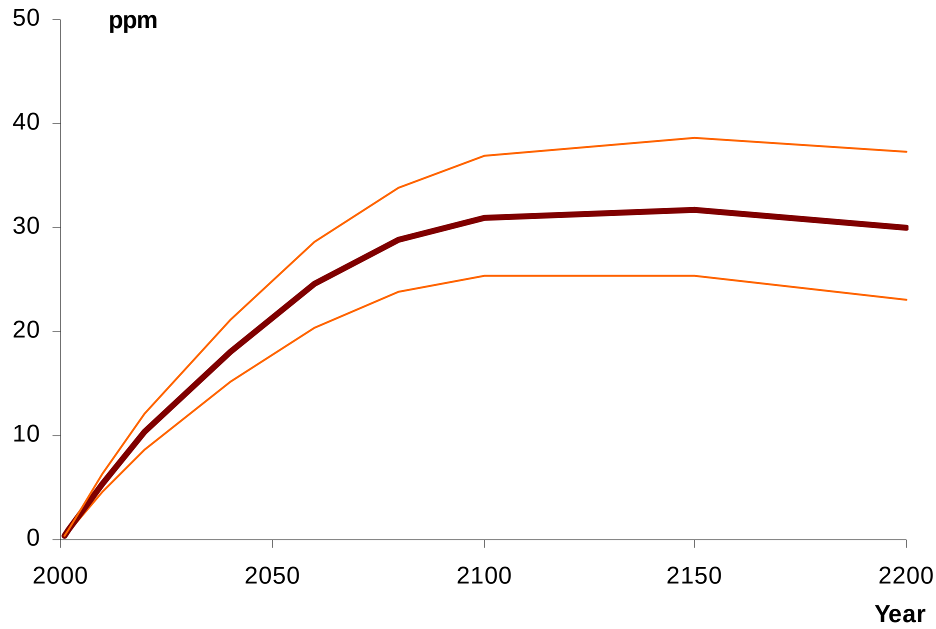

Figure 3 Increase in global mean temperatures by date as a consequence of BAU deforestation

Source: 1000 PAGE 2002 runs with SRES A2 and Houghton BAU deforestation scenario.

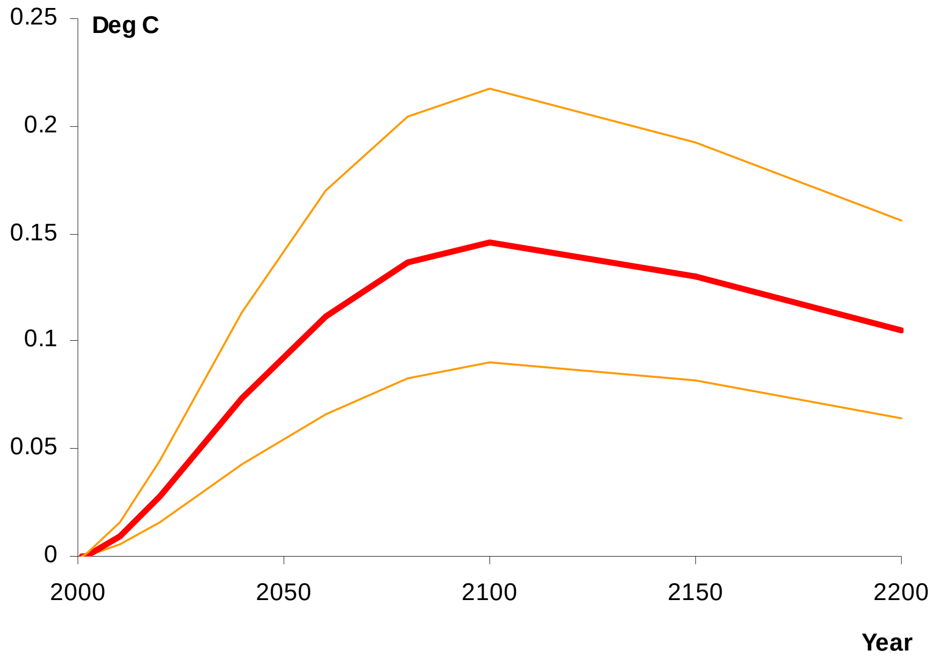

Figure 4 Increase in annual global impacts by date as a consequence of BAU deforestation

Source: 1000 PAGE 2002 runs with SRES A2 and Houghton BAU deforestation scenario.

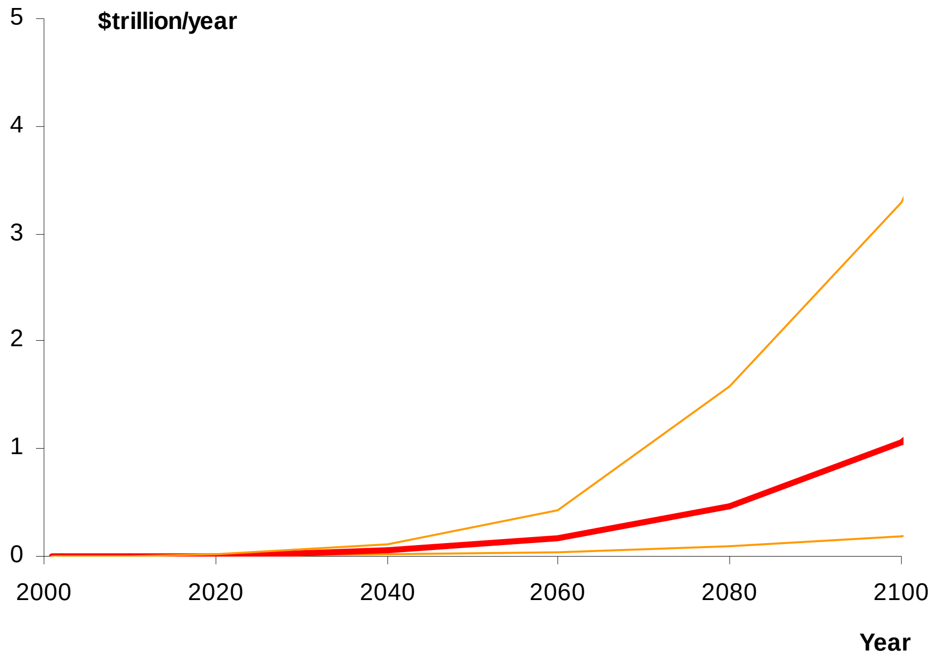

Figure 5 Increase in global mean temperatures by date as a consequence of BAU deforestation, ‘450’ scenario

Source: 1000 PAGE 2002 runs with ‘450’ and Houghton BAU deforestation scenario.