Estimating Biofuel Payback Periods

Rationale

Can biofuels help prevent dangerous climate change? In order to answer this general question we need to ask a more specific question:

> "Will promoting biofuels reduce total global GHG emissions over the period to 2050 (or 2030, or even 2100), when compared with other possible policies?".

The simplest alternative to promoting biofuels is a policy of preserving forests and other natural ecosystems and encouraging reforestation or rewilding. This is almost equivalent to doing nothing, since natural ecosystems do not need human management. They merely need protecting.[1] We must therefore compare a policy of growing biofuels with a policy of reforestation and preventing deforestation.

Biofuel crops are claimed to reduce carbon emissions by taking up carbon from the atmosphere and then releasing it as they are burnt, supposedly giving zero net emissions. The logic then continues by asserting that the use of biofuels "displaces" the carbon emissions from fossil fuel alternatives that would otherwise have been used instead. In order to answer the question of whether using biofuels – or which biofuels – will reduce total GHG emissions by 2050, we need to determine how long we would need to grow the biofuel crop for in order to compensate for the alternative of retaining or restoring a natural ecosystem on the same land.

This paper notes the steps that are needed to assess a given biofuel crop. It uses illustrative numbers of the approximate values that would apply for a crop (rapeseed or wheat, say) grown in Europe. The same method can be followed for any biofuel crop, for example, palm oil in Indonesia.

The analyses currently informing public policy use measures that do not answer the questions that should be driving policy.[2] Typically, they derive "GHG savings" per tonne of biofuel, without reference to the asset employed, i.e. the land. In contrast, the approach used in this paper is analogous to that which is used in business to evaluate investment proposals.

When the correct method of assessment is used, it is obvious that a policy of addressing the threat of dangerous climate change by promoting the cultivation in Europe of the biofuel feedstocks that are currently refinable is a complete non-starter. Such a policy cannot lead to a reduction of total GHG emissions, compared to obvious, simpler and cheaper policy alternatives with far fewer drawbacks, over any reasonable timeframe.

Method

Step 1: How much carbon would the land store if we didn't cultivate it?

In Europe, most arable land would support the forest ecosystem that covered the whole continent several thousand years ago. Such forested land would store at least 100 tonnes more carbon per hectare than it does when cultivated.[3]

Step 2: What is the annual yield of the biofuel crop?

How much biofuel would be produced from a hectare of feedstock? Let's be very generous and say that a hectare would yield biofuel with an energy content equal to an amount of fossil fuel that would emit 2 tonnes of carbon.[4]

Astute readers will note that we are already in a position to answer our original question: will growing biofuels (in Europe) reduce carbon emissions and therefore global warming over the period to 2050, compared to a programme of reforestation? Will the planet be hotter in 2050 if we grow biofuels or if we don't?

We have to divide the 100 tonnes of carbon in the forest we could grow (Step 1) with the 2 tonnes per year carbon "saving" of the biofuel crop. That gives us a payback time of 50 years. There are only 43 years until 2050, so the answer is already no, we'd be better off growing a forest than biofuel feedstock.

But let's carry on.

Step 3: What energy did we have to put in to grow the feedstock and make it into biofuel?

It turns out that we have to put in a significant amount of energy to make fertilizer, till, harvest, transport and process the crop (and so on). The amount of energy we have to put in is of the order of a quarter of the energy in the biofuel. We could put this energy in either by burning fossil fuels or by using biofuel. Either way, we have to reduce the carbon saving of the biofuel crop.

Our 2 tonne carbon saving per hectare from Step 2 is reduced to 1.5 tonnes and our payback period to about 67 years.

Step 4: Other GHG emissions?

It turns out that fertilizer adds nitrogen to soils, but also leads to emissions of the greenhouse gas nitrous oxide (N_2O), of which a molecule causes about 300 times the warming of a molecule of CO_2. The Nobel laureate Paul Crutzen has recently co-authored a paper suggesting that the effect of N_2O resulting from the cultivation of biofuel feedstocks such as oilseed rape and wheat is of the same order and may even exceed the cooling effect of the (supposed) displacing of CO_2 emissions when the biofuel is used.[5] But let's be generous, let's assume that the N_2O only causes a quarter of the warming the CO_2 would have caused. This assumption is moreorless equivalent to disregarding the new findings of the paper by Paul Crutzen et al.

Our 2 tonne carbon saving per hectare from Step 2 is reduced by a further 0.5 tonnes, from 1.5 tonnes per hectare after Step 3, to 1 tonne per hectare. Our payback period is now 100 years. It will still be hotter in 2100 if we grow biofuel crops in Europe, than it would be if we don't.

The UK government's analysis is based on a concept of the "annual GHG saving" of biofuel crops. This is difficult to understand as it doesn't start with the critical resource we are employing, namely the hectare of land. Nevertheless, it is worth stressing that the figures we are using in Steps 3 and 4 are very similar to those used in official assessments of biofuels. The "annual GHG saving" of biofuel crops is expected to be in the region of 50%.[6] A combination of our Steps 3 and 4 is equivalent to a "GHG saving" of 50%.

So, if the objective of the policy of growing biofuels is to reduce global warming, yet growing biofuels will warm the planet between now and 2107, compared to not growing biofuels, why are they being subsidised by the taxpayer, and their use made mandatory, throughout the EU?

Nevertheless, let's proceed with our analysis.

Step 5: Are we really offsetting emissions?[7]

So far we've assumed that if we produce biofuel containing the energy equivalent to oil containing 1 tonne of carbon, that this will "displace" the fossil fuel, thereby "saving" 1 tonne of carbon emissions. But is this really the case? Are we really causing that oil to stay in the ground or are we simply freeing up the supply for someone else to use? Kyoto does not apply to every country, so there are at present no global restrictions on carbon emissions. There is therefore no reason to suppose we are able to displace fossil fuel burning rather than merely move it, perhaps from one country to another. At present, we simply can't get oil out of the ground and refine it into fuel fast enough to meet global demand, so if some is not used in Europe (for example) it merely becomes available for use somewhere else. Let's assume that half the time consumption is limited by supply – so we do not displace fossil fuel burning – and (optimistically) that half the time it isn't. We therefore need to halve the carbon saving attributable to our 1 hectare of biofuel feedstock.

Our 1 tonne carbon saving per hectare from Step 4 is therefore reduced to 0.5 tonnes and our payback period is now 200 years. It will still be hotter in 2200 if we grow biofuel crops in Europe, than it would be if we don't.

Step 6: Timing of emissions

There's one more little problem. If the decision to grow biofuel feedstock results in forest clearance, this will lead to immediate carbon emissions, whereas the biofuels will only produce GHG "savings" gradually over time. If this happens then the emissions from destroying forest will remain in the atmosphere, causing damage by heating the planet, until they are offset by all the years of growing biofuels on the same land. Only after double the payback period we have so far assumed would the tonne-years of greenhouse gases in the atmosphere be equal in the two scenarios of leaving a forest in place or growing biofuels. That is, if forest is cleared to provide land on which to produce biofuel feedstock, then, in order to compensate for the carbon emissions when the forest was destroyed, we have to grow biofuel crops for twice as long as if a forest was not initially destroyed.

Now, growing biofuels may not require the destruction of forest directly, though this may well be the case for biofuel crops in the tropics. However, even if biofuels are grown on land that is already cleared, this may simply cause the current users of the land, such as food producers or subsistence farmers, to clear more forest to compensate. This is very likely to be the case for several decades, since humans are still expanding into forest areas.

At present, set-aside land in Europe is being allocated to biofuels, so perhaps we should just keep our payback period for biofuel crops grown in Europe at 200 years. However, all the set-aside land will eventually be used up. Growing biofuel in Europe would then lead to the need to import more food, increasing pressure on the world's remaining forests. If growing biofuels did result in forest clearance to produce land for growing biofuel feedstock, then we would have to have to double our payback period.

Let's again make the simplifying assumption that growing biofuels leads to forest clearance half the time. We have to add another 50% to our payback period, which therefore increases from 200 years to 300 years.

A policy of growing biofuels will therefore ensure that the world will be warmer until after 2300, than if we don't grow biofuels.

Conclusions

The analysis presented in this paper is an example only, using figures of the order that apply to the main crops being grown at present in temperate regions, such as rapeseed, corn and wheat. However, generous assumptions have been made:

- the value of 100 tonnes per hectare of additional carbon stored in forested land compared to forested land is at the very low end of estimates (Step 1);
- no account has been taken of the loss of carbon from rich soils and peat which can occur when forested land is cleared and prepared for agriculture;
- the value of 2 tonnes of carbon per hectare of the content of fossil fuel displaced by a biofuel crop is very generous for biofuel crops grown in temperate regions (Step 2);
- we have ignored the persuasive arguments presented in Paul Crutzen's recent paper (Step 4). If Crutzen is right, the N_2O emissions from biofuel feedstock cultivation alone may have a greater global warming effect than the CO_2 emissions displaced (even assuming 100% displacement) when the biofuel is used.

Using the method presented in this paper, an accurate analysis may be carried out for any actual or potential biofuel feedstock grown in Europe or any other region.

But two preliminary conclusions are clear:

- growing the existing biofuel crops in Europe will not help prevent dangerous climate change this century;
- efficiency improvements of at least an order of magnitude[8] would be needed to justify policies to promote biofuels.

The policy of promoting biofuel use being followed by EU and national governments is dramatically inferior to an alternative policy agenda of a programme of preserving and regenerating natural carbon stores, such as forests. Even using optimistic assumptions, growing biofuels in Europe will not contribute to a reduction in global warming for hundreds of years.

Additional factors

There are a number of additional factors which weigh against a policy of growing biofuels. Some of these could be input into the calculation of the biofuel payback period.

1. If biofuel feedstock production doesn't make use of land that could support a natural ecosystem, or, worse (Step 6), is already supporting one, it will have to use land that is currently used for production of food for the world's growing population. In practice, market forces will divert biofuel production onto both existing farmland and unused land at the same time (and reallocation of farmland to biofuel production will also divert food production onto unused land[9]). There will therefore be competition for land between food and biofuel producers.

Promoting biofuels will inevitably reduce the availability of food worldwide and push up food prices. Since a quart won't fit in a pint pot, some of the world's poorest people will become even more malnourished. This in itself is sufficient reason to seriously question the policy of promoting biofuel use.

2. Due to the depletion of nutrients in soils, it is unlikely that biofuel feedstocks could be cultivated continuously on the same land for the payback period necessary to justify using the land for biofuel production rather than reforesting it. In practice, yields would gradually decline and fallow periods would be required, further extending the payback period. This is likely to be a particular problem in the tropics.[10]
3. Crops may require irrigation, but even if they don't, they nevertheless take up more water than forest, reducing river flows. This reduces water availability downstream and will contribute to the need for desalination plants to serve coastal cities! If the energy required to replace the water is taken into account this could further increase the payback period for the policy of growing biofuels.
4. At times of extreme rainfall, run-off is higher from cropland than from forest, causing more flooding.
5. Biofuel crops are monocultures, vulnerable to disease. This risk may reduce the average annual yield over a long period of time, further increasing the payback period for the policy of growing biofuels.
6. Growing biofuels or any other crop reduces biodiversity. This is a downside to a policy of growing biofuels, but cannot be quantified in terms of the payback period.
7. There are costs to human health (and in terms of biodiversity) of using the fertilizers, herbicides and pesticides that are required to grow biofuel crops.
8. Growing biofuels is a ludicrously expensive way to attempt to reduce GHG emissions.[11] If farm incomes are a consideration, it would be much cheaper, for example, to pay farmers to convert set-aside land to permanent woodland[12], since all the costs of producing biofuels (fertilizer, processing etc.) would then not be incurred.
9. Farmed land is not as available for leisure activities, such as walking, bird-watching and foraging as is reforested land.
10. Forest products such as berries, mushrooms and game are unavailable on farmed land. If these are quantified in terms of the energy and/or land elsewhere that would be necessary to produce substitute products, then the effect would be to extend the pay-back period of the policy to promote biofuels even further.
11. There are better policy alternatives, such as to promote the use of electricity in transport.[13]

Modification History

Version	Date	Status/comments
1.0	7/2/08	Issued
1.01	8/2/08	Single minor correction

[1] Though in some areas of the world, such as the UK, the ecological balance has been disturbed by extinctions, in particular of predators. For example, a programme of reforestation in the UK would be most successful if accompanied by the reintroduction of predators, such as wolves, and/or the protection of land from grazing animals.
[2] See for example, "Are biofuels sustainable?", House of Commons Environmental Audit Committee, First Report of Session 2007-08, ref. HC 76-I; "Sustainable biofuels: prospects and challenges", Policy document 01/08, The Royal Society, January 2008; "Carbon Sustainability Reporting Within the Renewable Transport Fuel Obligation, Requirements and Guidance, Government Recommendation to the Office of the Renewable Fuels Agency", DfT, January 2008.
[3] This is a very conservative assumption. Figures as high as 300 tonnes of carbon per hectare are often cited. Also, the figure of 100 tonnes per hectare takes no account of the additional soil carbon in undisturbed soils in forests, grassland or any other natural ecosystem.
[4] That is, carbon dioxide (CO_2) containing 2 tonnes of carbon, ignoring any other GHGs. I am using the older convention of calculating in terms of tonnes of carbon rather than CO_2 or CO_2 equivalent ($CO_{2\ eq}$), which has become popular since its use in the Stern Report, because I want to compare tonnes of carbon emitted to the atmosphere to tonnes of carbon stored in forests. The conversion is that 3.67 tonnes of CO_2 contain 1 tonne of carbon.
[5] "N_2O release from agro-biofuel production negates global warming by replacing fossil fuels", Atmos. Chem. Phys. Discuss., 7, 11191-11205, 2007, www.atmos-chem-phys-discuss.net/11191/2007. The paper points out that estimates of the proportion of the nitrogen (N) in fertilizer that ends up released as the GHG N_2O are based solely on that released from the cultivated area itself, and take no account of subsequent releases from the large proportion of fertilizer (and chemical derivatives) that runs off the cultivated and ends up in water-courses and elsewhere. The argument is persuasive because it explains a large discrepancy between global N_2O emissions and rates of emission of the GHG from field studies.
[6] "Are biofuels sustainable?", House of Commons Environmental Audit Committee report HC 76-I, published 21/1/08, p.8 which notes that the UK's Renewable Transport Fuel Obligation (RTFO) will target "annual GHG savings of fuel supplied" of 40% in 2008-9, 50% in 2009-10 and 60% in 2010-11.
[7] I have previously discussed this point in a little more detail in a note, "The Displacement Fallacy", available online at http://unchartedterritory.wordpress.com/2008/01/16/the-displacement-fallacy/ .
[8] i.e. at least 10 times.
[9] It is little wonder that deforestation rates worldwide are increasing, e.g. see "Brazil Amazon deforestation rate soars", BBC, 24/1/08, accessed online on 25/1/08 at http://news.bbc.co.uk/1/hi/world/americas/7206165.stm .
[10] See, for example, "Deforestation hits nutrient cycle", BBC, 19/12/07, accessed online on 24/1/08 at http://news.bbc.co.uk/1/hi/sci/tech/7148278.stm.
[11] E.g. see "Are biofuels sustainable?", op cit, p.9.
[12] Such a policy should reward farmers more for reforested land, the longer it has been set-aside (up to say a century). This would ensure that when additional land is needed for food production, the land that is used is that which is least valuable land in terms of the carbon stored on it, i.e. incentives would be geared to promote a "last in first out" policy for set-aside/reforested land.
[13] This point is developed a little more in my previous paper, "Biofuels Are Not the Answer", the latest version of which is available online at http://unchartedterritory.wordpress.com/2008/01/25/biofuels-are-not-the-answer/ .