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MODELLING BIO-ENERGY WITH CARBON STORAGE (BECS) IN A MULTI-REGION VERSION OF FLAMES

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ABSTRACT

Global FLAMES [1,2] demonstrates the potential of the combined evolution of the stock and flow effects from temporary sequestration and subsequent fossil fuel displacement due to plantation based bio-energy, in reducing greenhouse gas levels below those widely thought to be feasible [3]. This surprising effectiveness can be further enhanced by linking plantation bio-energy to carbon capture and storage [4]. Such 'BECS' technology yields, potentially, a negative emissions energy system and control of CO_2 levels on a few decade time-scale. The effect of BECS is illustrated using global FLAMES. To provide relevance to country level scenario building and decision taking, FLAMES has been developed [5] into a multi-region dynamic market model simulating trade in fossil fuel, biofuel, and timber products. Results are illustrated in the case of three notional regions, 'rich', 'landed' and 'popet' (populous with petroleum) – broadly equivalent to the 'North', South Sahara Africa with Southern America, and Asia plus OPEC

Introduction

This paper reports on work in progress in a model that simulates the main market impacts that arise from policy driven land allocations to two plantation activities. These are long rotations, which initially sequestrate carbon prior to later use of woody biomass as joint product timber and bio-energy raw material, and short rotations that lead to a larger proportion of bio-energy raw material in the joint product, with minimal sequestration over the short rotation. A key role is played by exogenous representation of technological advances, including with plantation productivity. This work builds on the previous development of the FLAMES model that simulates global (1-region) interactions in the markets for land, fuel and timber under the impact of model-user-selected allocations of land to the two activities. This paper explains the motivation for the further development of FLAMES and reports preliminary results.

Motivation

The long rotation activity creates a 'buffer stock' of carbon that can be used to decouple reductions of carbon in atmosphere (C_{at}) from change in the energy sector, cutting premature obsolescence costs – "stranded assets" – inherent in other urgent programmes of C_{at} reductions (whilst not diminishing the role of cost effective progress with renewable energy and energy efficiency). The potency of this low cost approach enables a return towards pre-industrial levels of C_{at} over half a century in a way that remains compatible with existing carbon-fuel-based infrastructure. And – should science eventually demonstrate that there is no need for concern in relation to C_{at} – it carries the option of maximising timber output (with bio-diversity benefits in terms of reduced 'mining' of natural forest timber reserves). To provide policy relevant output to facilitate the realisation of this potential, the earlier global FLAMES model has been developed to a multi-region version with trade, generating world and regional prices for fossil and biofuels and timber to support land allocation decisions at the national level.

Urgency arises potentially on account of concern for Abrupt Climate Change [6] the possibility of which "haunts the problem" [7] and provides the economic rationale for action by the developed countries – which are largely sheltered from the economic impacts of gradual climate change [8]. Obersteiner et al [4] suggest that BECS technology can provide a 'real option' in a risk management approach to such climate threats. Accordingly, FLAMES has been applied to a preliminary analysis of the potential for rapid response to a few decade time-scale Abrupt Climate Change. Furthermore it is argued [9] that a low cost 'buffer stock' approach to the FCCC Art 3.3 commitment to early action in response to threats of severe or irreversible damage may provide a basis for rapprochement between Kyoto Protocol Parties and other Annex 1 Parties.

Order of magnitude

Assuming 500GJ/Ha is produced over 500mHa globally by 2030, i.e. using half of the usable land described by the FAO as surplus to agricultural needs, then there is a supply of 250EJ annually which, with 50per cent efficient conversion, can displace 200EJ of crude oil (assumed five eighths transportation fuel fractions) annually. By 2100 14,000EJ of oil is displaced, equivalent to about 2.4 billions of millions of barrels, more than twice global proved reserves and renewable each century – plausibly sufficient to keep pace with rising demands for transportation fuels given continuing increases in plantation productivity and vehicle efficiency (e.g. with fuel cells and bio-methanol as hydrogen carrier). Regardless of C_{at} considerations, there would seem to be a significant case on security of supply grounds for growing fuel as well as drilling for it.

Caveats

The results generated by the FLAMES model are the direct outcome of the assumptions made in the baseline or reference scenarios and of the quantities of land allocated to policy-desired uses. Three baselines have been simulated: first, 'business as usual' (b.a.u., reflecting a median IS92 no policy scenario); second, 'fossil free energy scenario' (f.f.e.s., reflecting the Tellus Institute's 1993 study funded by Greenpeace); and third, 'Kyoto' (broadly half way between the first two). Both the first two embody rather little land use change or bio-energy and the third reflects the view that the Kyoto Protocol approach to gradual climate change is unlikely to achieve C_{at} stability – let alone reductions – during this century. It should be noted that, although the focus of the FLAMES model is on the additional impact of policy driven land allocations, the surprisingly low C_{at} levels noted previously (see above) that result from large scale land allocations are only reached with the simultaneous application of the low and zero emissions energy technologies involved in the f.f.e.s.: in other words, the large scale policy-driven land use allocations illustrated in this paper are a necessary but not sufficient condition for the achievement of the low C_{at} levels mentioned above. By the same token, for the below pre-industrial C_{at} levels illustrated in this paper, large scale negative emissions, through widespread application of BECS technology, is a necessary but not sufficient condition.

Additionally, it should be noted that the very large land allocations that have been used in the FLAMES model are taken to be 'maximal'. No decision taken this decade can finally determine land allocations some decades ahead and the implication of modelling large allocations at such a time is that the initial phases of the programme are successful in meeting socio-economic and environmental constraints and hence stimulating – or at least not inhibiting – the sequence of decisions that is represented by such a maximal programme. Thus such maximal allocations are a representation of the maximum amount of land that might be used for policy-desirable activities if the appropriate incentives were put in place, and sustained, to reward current landlords and land users so as to ensure they engage continuingly in such policy-desirable land use. Implicitly it is assumed that they desist from current land-profligate slash and burn subsistence, nomadic herding, forest clearance, etc., investing their rewards so as to meet their food and other land based needs better than at present, and more sustainably. Conceptually the modelled allocations are intended to represent the maximum possible policy-induced effect, constituting a 'flip' in the trend of land use change and the following of a new path, starting from a near-future bifurcation in the evolution of land use policy and technology towards stewardship rather than exploitation. And, implicitly, no degree of policy urgency can accelerate land use allocations defined as maximal: if pushed too fast then disaffected communities will simply set fire to the plantations. This is not to claim that the land allocations modelled here are empirically maximal in this sense: if a better estimate of what is maximal can be made, then that estimate should replace the pattern modelled here.

Methodology of FLAMES and N-region FLAMES

Investigation of market impacts in the context of ongoing technological transition (which is inconsistent with competitive general equilibrium) is most transparent within a demand and supply framework. Three markets – for fuel (with perfectly substitutable bio-fuel and fossil fuel), for timber products and for land – are simulated at a high level of aggregation, as three simultaneous equations in four variables, producer prices for fossil fuel, bio-fuel, and timber, and the opportunity cost of land (rent). Output from the two policy-driven plantation activities is determined by plantings one rotation earlier and allocated to joint-products timber and bio-fuel as a function of their relative price and of the rotation length, with a rapid transition from maximum timber to nil timber near a price difference that represents the cost of processing to timber products. Closure is by a fourth equation for a tax on fossil fuel CO_2 emissions (equal to the difference in producer prices for fossil and bio-fuel) that is dedicated to financing the excess cost of biofuel over fossil fuel (including rent). In the multi-region (N-region) case, additional export demands arise for fossil and bio-fuel, and for timber products, proportional to differences between regional and world prices, with the latter determined in a set of trade balance equations setting total exports equal to total imports. A fossil fuel tax is set globally to cover global policy costs and a transfer equation for each region determines the additional subsidy from importing to exporting countries needed to compensate for 'profit taking at sea' (the 'law of one price' does not apply).

A final equation, currently independent but capable of including CO_2 fertilisation effects and, if so, requiring simultaneous solution with the other 4N+4[1], simulates the impact on C_{at} , under the chosen reference scenario, of emission and absorption in the energy, forest product and land use sectors, and in the oceans, as the consequence of user selected (or policy-driven) land allocations to the two activities. In the market equations, per capita demands for fuel, timber products and farmland grow exponentially (but could be driven by an economic growth model) and are inhibited by the fossil fuel tax. Under b.a.u., supplies of fossil fuel grow to match demand but emissions grow more slowly in order to represent increased energy efficiency and use of non-fuel energy sources. Under f.f.e.s., there is accelerated technological progress (TP) in these areas – and correspondingly slower TP with 'discouraged' fossil fuel. Reference case supplies of woody biomass are derived from harvesting an area of managed forest that is distinguished from conservation forest, which is treated as unavailable for exploitation. Both these supplies and supplies from policy driven land allocations provide timber and bio-fuel raw material as joint products, with the proportions dependant on relative prices at the time of felling, and on rotation length. Long rotation forestry technology is treated as 'mature', with zero TP, while short rotation productivity rises threefold over 70 years, eventually reaching current achieved results in experimental plots in Brazil. Supplies of exploitable land represent all land that is not barren or conservation forest and rents rise as the reciprocal of the area left to wilderness, after meeting demands for farming, for managed forest and for policy-driven activities. For a detailed description of the 1-region model, see Read (1999).

Parameters in the market equations are initialised to a broad representation of current conditions and then shifted over time at user-selected rates to achieve a broad match with the time-path of C_{at} in the chosen reference scenario. Then the impact of user-selected land allocations (see Figure 1, top panel) to, first, a time-path of short rotation plantations and, second, the same pattern of short rotation plantations but preceded by a time-path of long rotation plantations, is superposed on the reference case (with a user-specified responsive reduction in conventional forestry). Model outputs are generated as the time-paths for C_{at} (see Figure 1, bottom panel) and for the various prices in the model (see Fig 2).

BECS and precautionary policy

It is envisaged that BECS technology would be mobilised in response to bad scientific news regarding near term risks of precipitating an Abrupt Climate Change event as a consequence of continued elevated C_{at} levels. Global-FLAMES may be used to assess the effectiveness of BECS (with other measures – see caveat above) under a 'game with nature' framework in which policy is assumed to be either 'Kyoto' or 'Precautionary' and nature to be 'Nice or Horrid' hence yielding a regret matrix [KN, KH; PN, PH][2]. 'H' is taken to correspond to bad news in, say, 20 years time (i.e. 15 years after the initiation of globally coordinated precautionary policy) and 'P' to measures extra to 'K', taken prior to the bad news, specifically,

[1] Three market equations plus a transfer equation for each region, three world price equations plus the global tax equation.

[2] Unfortunately the lap-top on which that work was done was stolen during preparation of this paper. Graphical results that had been transmitted to a colleague and are displayed in Fig 1 cannot at present be reproduced, as the coding was not transmitted at the same time. At the time of the theft, the KH case had yet to be modelled.

a learning-by-doing programme with carbon capture and storage technology (CCS) applied to fossil fuels, and a human capital development-cum-plantation programme in line with the short plus long rotation plantations described above. Under PH, the decade after bad news is devoted to a crash programme of converting long rotations land to short rotations, accelerating technological progress with non-fuel energy and efficiency in line with the f.f.e.s. scenario, and applying CCS to both fossil fuels and to bio-fuels. Under KH the same crash programme is attempted but without the benefit of experience with CCS technology from 2005 to 2020, or of low cost pre 2020 C_{at} reductions, or of ready availability of plantation land in 2020, all arising from the precautionary policy measures.

Technical Progress

All scenarios are developed from the same initial conditions, with 300EJ of final global demand for fuel supplied by raw fossil fuel at 2$/GJ, 2.5Gtons timber supplied at 150$ per ton and 1.9Gha of food-land having an opportunity cost of 10$/Ha[3]. Different scenarios arise as the consequence of different exogenously imposed rates of technological progress that yield neutral price shifts over the time horizon under b.a.u., (in line with broad historic experience save for the 1970's oil price hikes). Thus technological progress embodied in capacity expansion broadly keeps pace with demand growth under b.a.u., for which final per capita fuel demand is assumed to grow at 3.5%p.a. and emissions at 1.5%p.a. (where the difference represents decarbonisation of energy due to increased end use efficiency, renewables and fuel switching). Under f.f.e.s., policy signals induce two effects on TP: firstly investment in fossil fuel R&D is discouraged so that fossil fuel expansion falls to 2%p.a. and secondly accelerated technological progress in decarbonisation occurs over the second and third decades modelled. Consequently fossil fuel prices initially rise due to reduced supply but eventually fall due to more-reduced demand. Over the remaining four decades modelled TP with decarbonisation slows so that aggregate TP at the time horizon is the same as under b.a.u. – this represents an assumed physical limit in TP in relation to, for instance, thermal efficiency.

In relation to land use, where policy induced change occurs, the productivity of long rotations (an old technology) is assumed constant at 6 oven dry tons/Ha-yr while the productivity of short rotations rises from 12 o.d.t/Ha-yr to 36 o.d.t/Ha-yr over the 70 year time horizon.

Results

Outcomes are illustrated in Figures 1 and 2. Figure 1 shows land allocations proposed and the resulting C_{at} effects, for three reference scenarios (b.a.u., f.f.e.s. and 'Kyoto' and for the 'Precautionary' scenario first with no ACC and second with response to bad news in 2020 (i.e. the PH scenario). Figure 2 illustrates market price movements in fossil and bio-fuel prices, in timber prices and land rents under policy-driven land allocations to both biofuel and a long rotation buffer stock (i.e. the PH scenario).

Comments and further research

The outcome of the PH scenario, as illustrated in Figure 1 suggests that a return to below pre-industrial C_{at} levels by 2050 is, if necessary, feasible given that appropriate precautionary measures are undertaken. Clearly there is a need to model the KH case (i.e. the consequences of maximal land use change and other aspects of the precautionary policy initiated only after news of ACC becomes available) and the costs of policy under the alternative scenarios, along with recoding of the PH case to enable repetition of current results (and estimation of policy costs).

Prior to this work there is a need to achieve more realistic analysis of landowner behaviour in response to price expectations illustrated in Figure 2: clearly the prospect of sharp price drops as the long rotation approaches maturity will induce a profit maximising land-owner to fell early. Whatever policy may induce the establishment of these plantations can hardly determine the behaviour of landowners exposed to commercial discount rates a generation later. Thus an incentive-compatible version of FLAMES is currently under development to provide a more realistic picture of the long-term C_{at} impacts of policy driven land

[3] In the 3-region model, these initial values are the world prices, with regional prices for Rich, Landed and Popet [2.5, 3, 1.5] and exports [, ,] for fossil fuel and [0,0,0] for biofuel, and with regional prices [180, 150, 1??] and exports [, 0 ,] for timber. These initial values yield trade coefficients for fuels and for timber in the three regions as exports/ (world – regional price), with the coefficients for fossil and bio-fuel assumed equal.

allocations. In the long run it is envisaged this model may reveal the optimal pattern of land allocations in relation to a risk-averse precautionary policy criterion focused on ACC.

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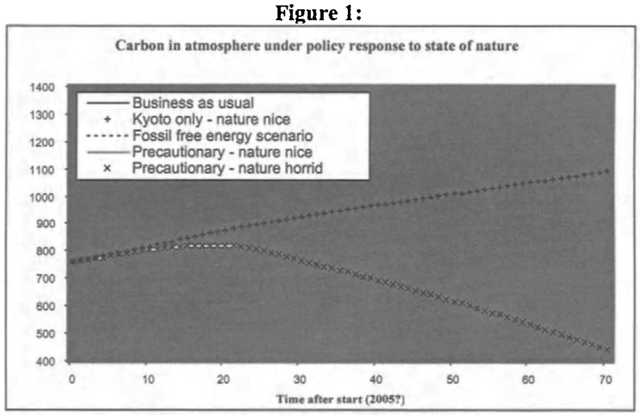
Figure 1:



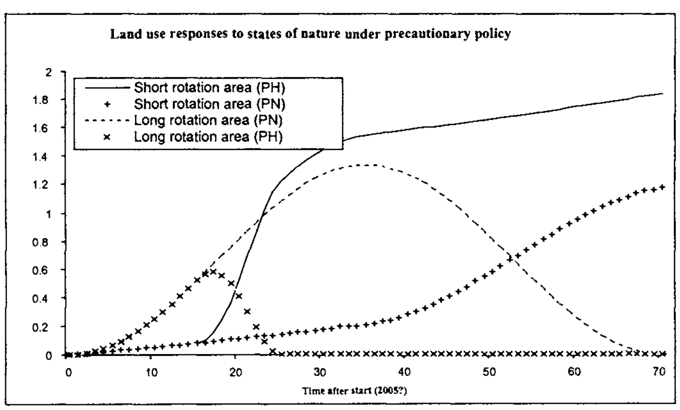


Figure 2: Regional and world price movements 'Kyoto' plus biofuel plus buffer-stock scenario.