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Opportunities and challenges for terrestrial carbon offsetting and marketing, with some implications for forestry in the UK

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Abstract

Background and purpose:
Climate change and its mitigation have become increasingly high profile issues since the late 1990s, with the potential of forestry in carbon sequestration a particular focus. The purpose of this paper is to outline the importance of socio-economic considerations in this area. Opportunities for forestry to sequester carbon and the role of terrestrial carbon uptake credits in climate change negotiations are addressed, together with the feasibility of bringing terrestrial carbon offsets into the regulatory emission trading scheme. The paper discusses whether or not significant carbon offsetting and trading will occur on a large scale in the UK or internationally.

Materials and methods:
The paper reviews the literature on the socio-economic aspects of climate change mitigation via forestry (including the authors' research on this topic) to assess the potential for carbon offsetting and trading, and the likely scale of action.

Results and conclusions:
We conclude that the development of appropriate socio-economic framework conditions (e.g. policies, tenure rights, including forest carbon ownership, and markets) and incentives for creating and trading terrestrial carbon credits are important in mitigating climate change through forestry projects, and we make suggestions for future research that would be required to support such developments.

Keywords:
forestry, climate policy, carbon sequestration, carbon trading, the Clean Development Mechanism

INTRODUCTION

Since the Kyoto Protocol of 1997, climate change has become one of the most important global environmental policy issues. Its various aspects have been widely discussed in the literature, and have been major items on the agendas of numerous international conferences and meetings.

In the light of recent international agreements on climate change, Annex I countries (developed and transition economies that are signatories to the Kyoto Protocol) are striving to reduce their greenhouse gas (GHG) emissions, and/or to remove CO_2 from the atmosphere. Since the Conference of the Parties (COP-7) in 2001, afforestation, reforestation and forest management have become eligible policy measures to address climate change. The Annex I countries are allowed to meet part of their targets through the use of Land Use, Land Use Change and Forestry (LULUCF) 'sinks'.

Each country has been allocated a number of tonnes of carbon sequestration that can be used to progress its emissions target through forestry. The Stern Review [1] increased awareness of the socio-economic aspects of climate change, placing scientific observations in a conventional economic framework. It showed that the extent to which the mitigative role of forests can be enhanced is mediated by externalities and uncertainties and is shaped by a range of market signals, policies and governance structures, as well as public attitudes and behaviour patterns.

The UK, in general, and Scotland in particular, have put in place some of the most far-reaching greenhouse gas reduction policies of any country in the world. Emissions reductions targets of 80% (of the 1990 baseline figure) by 2050 have been set for the UK as a whole in the 2008 Climate Change Act. These reductions were to be overseen by an independent monitoring body: the Committee for Climate Change. In Scotland, in the Climate Change (Scotland) Act (2009) a more robust definition of emissions is used and an interim target of 42% emissions reduction on the 1990 baseline is set for 2020. Progress towards the reduced emissions target is also guided by the UK Climate Change Committee [2].

The last decade has seen an upsurge in the number of papers addressing forestry and climate change in the UK. Some studies have focused on the physical potential in terms of climate change mitigation, addressing sequestration in trees and in timber products, or mitigation benefits offered by the use of wood as fuel [3, 4, 5, 6]. They show that UK forests contain 150 MtC (roughly a year of emissions) and have sequestered between 12 and 16 $MtCO_2$ per year since 1990. Timber products have also been shown as a significant carbon stock also contributing to reducing emissions, either as a substitute for fossil fuels (energy generation) or for carbon intensive materials (concrete, steel, aluminium). Other studies have focused on the economic dimension of carbon sequestration in forests [7, 8, 9, 10], estimating the costs of carbon sequestration and the social value of carbon sequestered in trees and timber products. These papers stress that socio-economic issues are important in determining the amount and type of land available for forestry development [11, 12, 13, 14]; that the main difficulties associated with the use of wood for energy and in wood products have been socio-economic [15]; and, further, that comparative indicators of the cost-effectiveness of climate change mitigation strategies are needed to achieve the carbon reduction targets at least cost [16]. The role of forestry in climate change mitigation is especially relevant in those regions that have good potential for forestry-based carbon sequestration activities, especially in Scotland within the UK, where consideration of biophysical conditions and of institutional and economic aspects of carbon offsetting merit special attention. This paper discusses the opportunities and challenges of forest-based carbon offsetting and trading, and the implications for carbon forestry from a UK perspective, and suggests future research that would be required to support the extension of such activity.

RURAL POLICY DIMENSIONS

In spite of the acceptance by governments that climate change is a serious problem [17, 18] and notwithstanding the interventions through mechanisms such as the Climate Challenge Fund and the efforts of the Turner Committee [19], Giddens [20] argues that there is currently no effective politics of climate change. It is certainly questionable whether there are appropriate governance mechanisms in place to support the development of the mitigative capacities of forests, both in the UK and elsewhere.

The optimum carbon offset forestry projects will likely be those which link long-term carbon capture and storage with long-term substitution opportunities (of low-embodied carbon products for high-embodied carbon products), and of using wood for fuel [4] capable of bridging existing gaps between rural development policy priorities and those of climate policy [17]. In remote rural areas with timber-growing possibilities, forestry development could generate win-win outcomes [21], providing benefits to the environment, people and the economy [22]. Because of the wide range of benefits it delivers to different stakeholders, multi-functional forestry, which has both carbon sequestering and other functions, is expected to be more popular than purely carbon and/or timber production oriented forests [23].

There is necessarily a difference, however, between the wider benefits provided by forests and the financial benefits that arise to forest developers. In the EU, intra-European credits from activities enhancing carbon sequestration are not included in the regulatory schemes [24]. Therefore, establishment of tree plantations for carbon sequestration, principally driven by grant aid, requires appropriate institutional settings, sources of investment and sound incentives. For example, as part of the Scottish Rural Development Programme, grant support will now be delivered through a number of options, both forestry-specific (e.g. short rotation timber plantations of willow or poplar) and non-specific (e.g. support for renewable energy projects relating to forestry), including those of carbon sequestration [25] To date the Mid-term Evaluation of the Scottish Rural Development Plan indicates 60 forestry challenge fund bids having been supported [26]. Carbon sequestration is only one of the purposes but was rated highly by respondents as a reason for adopting the forestry measures.

Forestry with carbon sequestration as a motive (and forestry more generally) is likely to be inhibited where high farm policy payments are capitalised into land values and where, if grant-aided farm woodland planting occurs, farm subsidies are lost to the occupier. In the UK, rural land use decisions are likely to have been shaped less by market signals and more by the distortions generated by public policy measures. There is evidence [25] that low rates of tree-planting have been in part a function of the subsidies to farming.

Moreover, it is not only in production support that grant aid can influence afforestation for carbon sequestration. Guyomard et al. [25] analyse the effects of agri-environmental policies on land allocation decisions and the effects of general tax and monetary policies on agricultural land prices, all of which have had a significant impact on forestry [26]. Rural policy and environmental drivers, e.g. the reform of CAP, will frame future possibilities [27].

There is evidence that forest and woodland development is related to landowners' willingness to take on forestry-based carbon credits rather than the biophysical possibilities for carbon capture and storage [28]. Therefore the diversity of forest owners' values must be acknowledged in new governance mechanisms [29]. Landowner preferences for carbon sequestration measures are likely to be influenced by institutional arrangements, by available information concerning potential profits, and by landowners' eligibility for grants. If forest-based activities are neither financially viable nor desired land management options, there can be little likelihood of large-scale carbon offsetting [30].

The complexity of landowners' motives to adopt forestry-based carbon credits, institutional and policy arrangements and potential for profitability require an improving of transparency, accountability, and equity in forestry within and among public sector, private sector, and civil society initiatives. Adger et al. [31] argue that governments could create deliberative processes, involving stakeholders who acknowledge different values, for implementing climate change mitigating measures.

There is a need for information campaigns, training facilities, pilot schemes and mutual learning, especially of the type that generates contagious (viral) diffusion processes, to demonstrate forestry sector-based opportunities for carbon sequestration, and make them attractive for forest land-owners and managers. It is important to consult people to get to know which climate policy alternatives are desirable for them, and why, as well as developing understanding of public perspectives on the role and place of forestry in mitigating climate change.

ECONOMICS OF CARBON SEQUESTRATION

Carbon sequestration through forestry is commonly considered: as cost-efficient [32]; synergistic (when incorporated in multifunctional forestry, it can co-deliver a variety of ecosystem services, providing concurrently economic incentives for sustainable forest management, [33]); technically feasible (most countries have a legacy of tree-growing); effective in the short term (providing an almost immediate effect after tree-planting); and a low resource/energy consuming climate policy measure. However, a meta-analysis of 68 studies to estimate carbon sequestration costs, with a total of 1047 observations worldwide, has identified huge variability of estimates of sequestration costs across countries. Van Kooten et al. [34] show that the costs of carbon sink in forests range from €35 – €199 per tonne of carbon and, when opportunity costs are taken into account, they range from €89 - €1069/tC. These costs suggest that by no means can all forestry be seen as cost-effective carbon sequestration.

To assess whether forestry development offers an economic opportunity for carbon sequestration, marginal costs per tonne of sequestered carbon have been computed across a number of countries [35, 36, 8, 23, 37]. This is explored in the McKinsey Report [38] by comparing marginal abatement costs. Research demonstrates that even if all carbon sink pools (i.e. carbon savings) are taken into account, it is unlikely that 'additional' forestry in an EU country will be a cost-effective means for mitigating climate change [39]. Tree-planting in Europe generally is costly, opportunity costs of land are high, and distant returns to forestry make the investment unprofitable [40]. Slangen et al. [41] and Pussinen et al. [42] show that the costs of carbon sequestration in EU forests seldom fall below €65 - €202/tC. However, despite high-cost estimates of carbon sink in some EU regions [40] large amounts of carbon may be sequestered by forestry at low costs elsewhere (e.g. in some regions in transition and developing countries, and even in some localities in Europe, including the UK [32, 43, 23].

The stock change approach has been used to estimate carbon capture and storage in UK forests, under the requirements of DEFRA [44]. The carbon sequestration costs appear to range from £30.5 per tonne of carbon (afforestation of sheep grazing areas) to £174.9 per tonne of carbon (agro-productive land) at a discount rate of 3.5% [10]. According to Global Atmosphere Division [45], average costs of carbon sequestration in the UK range from €72 - €116/tC. These estimates provide some evidence in support of prospective afforestation of some marginal land in the UK. However, large-scale afforestation is hardly an option in the UK at aggregate country level. The scope for carbon capture is thus likely to be concentrated on particular areas of land, where opportunity costs are lowest (e.g. lightly stocked hill farm land with low-carbon soils and high tree growth potential).

In the UK, it is clear that alleviation of climate change through carbon sequestration in forests is now a significant rationale [46, 47]. Given the extensive agricultural and sporting use and the prevalence of less favoured areas in Scotland, the opportunity costs of afforestation with respect to other productive rural land uses ought to be relatively low in this country compared to more fertile areas of the UK. However, much depends on the impact of forestry on soil carbon, as many less favoured areas are characterised by high carbon soils, and that carbon may be lost by ground preparation for afforestation. Additionally, where forestry delivers multiple ecosystem services in more densely peopled areas, the desire for permanent forest cover may be greater and fit well with multifunctional forestry. However, either option needs to be supported by appropriate policy frameworks. Further, to date there is little comprehensive and spatially explicit evidence on the value of carbon sequestration in the UK, let alone the wider values of other non-market ecosystem services, which might guide locational premia on grants for afforestation (for carbon sequestration or multiple forest benefits).

In forestry, many effects are long-lived, and growing forests provide some of their benefits far into the future. Mitigative capacity for forests in relation to climate change varies across the territory, and the aggregated costs are likely to increase over time. Tackling climate change, therefore, should include strategies that are pre-determined by long-term carbon stabilisation targets in the atmosphere, which take into account dynamic and scale effects, and which consider both potential damages from the changing climate and the co-benefits related to mitigation-adaptation linkages within rural land use. The choice of location for carbon sequestration projects, and of appropriate tree species and management regimes to be applied, are important factors in ascertaining cost effective climate policy actions [12].

In addition to the question of whether forestry offers a generally cost-efficient option for mitigation, it may be desirable to construct spatially explicit cost-benefit analysis (CBA) of climate policy scenarios for forestry-based projects. The scenario analysis could identify: (i) which options are economically sound; and (ii) which regions are likely to benefit most (or be most adversely affected) from forestry development. The basic forestry options that merit attention are: (1) carbon capture and storage in forests, (2) production of wood for energy, (3) wood products, and (4) tree-planting/growing for the provision of multiple ecosystem services, including sequestration, e.g. floodplain tree-planting.

Some of these scenarios have been economically assessed across several countries, including the UK [41, 8, 48, 12, 10]. However, the multifunctional nature of forestry requires careful scenario design that reflects the realistic possibilities for delivering multiple ecosystem services through well designed forestry projects at local and regional scales.

In England, for example, tree-planting for multiple purposes rather than solely for carbon sequestration commonly enlarges social benefits and helps to address potential conflicts relating to trade-offs, e.g. between biodiversity and carbon sequestration, or between landscape amenity values and those of climate change mitigation [49]. Although multi-functional forestry may result in lower rates of carbon sequestration, it is expected to be more attractive to people, because of the provision of multiple ecosystem services and contribution to sustainable development [24]. The answer as to whether it is pertinent to consider forest multi-functionality in a vertical sense (with each lot of land or forest stand fulfilling two or more functions, [50]), or horizontally (when "effective multiple use is merely organized and coordinated specialization" on different areas of land [51]) depends on the case and scale of observation and on the issue in question. The question then would arise as to the type of woodland we want to create, and where, and how it is to be managed to maximise the total ecosystem services output at lowest costs.

In addition to afforestation, it is also possible to increase carbon density at the stand level. This can be achieved by maintaining a permanent forest cover; increasing rotation lengths; minimising soil carbon losses; increasing growth rates; and managing drainage. However, lengthening of rotations reduces opportunities to use wood for energy generation and/or wood substitution for GHG-intensive materials [52, 10]. The effects of avoiding carbon release to the atmosphere through a continual cycle of forest harvesting, regeneration, and replacing carbon intensive materials and/or fossil fuels with wood, are repeatable, and locally, therefore, more sustainable. The social benefits of wood product and bio-energy scenarios in the long run are expected to be higher than those arising from the strategy of carbon fixation alone [30]. However, the rising demand for wood fuel and wood products could result in the increase in timber harvesting elsewhere, for example, in the tropics. Therefore, a holistic view, with consideration of displacement effects and of possible "leakages" is needed. Estimating the carbon sink must take into account the carbon debit from land use changes and timber harvesting, carbon stored in wood product sinks (not considered under the Kyoto Protocol), various carbon "leakages", and additional carbon sequestered as a result of forest management.

In the UK, forestry projects for carbon sequestration combined with wood production and/or renewable energy strategies offer better opportunities for innovation, employment, development of markets and enhancement of rural economies than narrowly based carbon sequestration forests [13]. In some localities, short-rotation plantations for bioenergy might generate cost-effective emissions reductions [30]. However, it is important that measures for carbon sequestration in forests are considered within spatial planning; in relation to forest, agricultural and rural policies; and as part of measures for sustainable energy systems and sustainable rural development [24]. This will save costs, deliver cost-effective outcomes and assist in coping with environmental problems associated with climate change.

CARBON OFFSETTING AND MARKETING

The Kyoto Protocol flexibility mechanisms provide opportunities for countries to tackle climate change from an economic perspective [53]. However, it is unlikely that credit and permit (allowance) trading will occur on a large scale internationally, and even nationally [54]. While voluntary (e.g. not regulated through the Kyoto Protocol flexibility mechanisms) carbon offsetting and trading schemes involving forestry are spreading, "carbon trading so far appears ineffective in terms of actually reducing GHGs" [55]. Moreover, in future, countries are likely to have even fewer incentives than nowadays to commit themselves to international agreements, due to undefined yet potential damages/losses from climate change, and because of either unwillingness or inability of some countries to meet their emission reduction targets. Among the reasons for such failures is the proclivity of countries to rely primarily on administrative measures and voluntary actions, based on common values and norms, and on behavioural changes [30]. The administrative measures and voluntary actions are very important, indeed. However, consequently, the costs of climate change mitigation appear to be higher than they need to be, and these high costs reduce the efficiency of policy implementation, setting the stage for more difficult negotiations on emissions reduction in the future. Carbon trading presumes transfers of credits, allowances, permits and quotas, all of which have to be linked directly to GHG emissions reduction. It is important here to distinguish between permit trading and credit trading. Permit trading is where the authority sets an emissions quota and issues tradable permits for that amount (or sells them at auction). This is true cap-and-trade. Credit trading occurs when the government mandates that each emitter reduces emissions by a certain amount. Firms that reduce emissions below the required target point receive credits that can be sold to firms that cannot meet their targets. However, credit trading could result in countries satisfying the Kyoto Protocol but with growing emissions, e.g. when new firms enter the market as the economy expands. Credits might be created by carbon sequestration in terrestrial ecosystems and traded for emission reduction credits. The Kyoto Protocol therefore permits countries to achieve illusory emission reductions in ways that did not actually reduce GHG emissions [30].

The cap-and-trade system designed to reduce mitigation costs now includes carbon offsets from forestry [54]. However, under the regulatory scheme of the Clean Development Mechanisms (CDM), the share of forestry projects in total expected CERs (certified emission reductions) until 2012 comprises less than 1%. There are 17 such projects, compared to total number of over 2400 registered CDM projects [56]. Although the biophysical potential to sequester carbon through afforestation is high in some countries, the tree-planting activities are constrained by numerous internal economic, social and environmental factors in these countries (e.g. land use planning; economic development; or financial consideration). Further, the potential of regulatory carbon offset trading is limited to carbon balances, resulting from the eligible mitigation forestry projects subject to cap, as well as by the costs of GHG inventory preparation [53], and too high transaction costs.

The evidence on institutional considerations of terrestrial carbon offset trading is very complicated. European investors are clearly showing interest in investing in Joint Implementation (JI) and CDM projects. However, the potential gains from international projects are seldom seen as priorities for land use and climate policies in the host countries. Therefore, unless the necessary institutional infrastructure is developed and the barriers for investment are identified and addressed, the UK cannot expect to benefit widely from crediting JI and CDM systems. In order to utilise the potential of forests to contribute to mitigation of climate change effectively and efficiently, it is imperative to clarify international agreements and rules on forest carbon capture and storage accounting, to increase technical effectiveness and accuracy, and to develop further policies, tenure rights (e.g. forest carbon ownership), economic incentives, and where possible, carbon markets.

Regulatory trading schemes (as compared with voluntary markets) largely fail not because of lack of interest, but primarily from negative economic conditions (market and governance failures), including imperfect information and too high transaction costs [57]. "Corporate power also is shown to be a major force affecting emissions market operation and design. The potential for manipulation to achieve financial gain, while showing little regard for environmental or social consequences, is evident as markets have extended internationally and via trading offsets" [55]. An obstacle to emissions trading at international level is that many countries have low capacity in terms of social capital and institutions to develop effective market systems. Also, regulatory trading schemes address only a small proportion of potential global emissions and there is no effective international penalty for non-compliance.

Moreover, as shown by Van Kooten [30], the cap-and-trade system that includes carbon offsets from forestry faces challenges in the creation and acceptability of carbon trading exchanges. The costs per tonne of carbon removed must be compared with the costs of decreasing carbon stocks in the atmosphere in ways other than through forestry (e.g. through emission reductions). When CO_2 emissions are considered, the emissions cap is set at the same level as the emissions reduction target. In addition, where carbon offsets by forestry are concerned, a cap is not only required on emissions, but also on permissible offsets. Therefore, in the light of carbon trade negotiations, the conversion factor or exchange rate between emission reductions and carbon offsets needs to be set. Also, there is concern that countries have been given sink credits for ongoing activities, so that credits can be claimed even though there has been no additional carbon sequestration [30].

Carbon offsetting from forestry, and numerous problems with its inclusion into regulatory emission trading schemes, are caused largely by: the challenges of ensuring "additionality" and permanence of forestry projects; setting the level of baseline emissions; coping with "leakages" that may occur when the CO2 emissions which a project is meant to sequester are displaced beyond its boundaries; reliable measurement, assessment and monitoring of carbon sequestration and of the costs; concerns over double counting; acceptability of carbon trading; establishment of proper carbon offset certification and of its "conversion" into emission permits; assurance that actual carbon sequestration has taken place; development of both property rights and institutions for exchanging carbon offsets; and the legal aspects and verification of sustainable development requirements, particularly when CDM afforestation projects are concerned [57, 30, 14, 11].

Many of these challenges are also pertinent to voluntary carbon offsetting and marketing. However, the voluntary carbon market is less regulated and less costly. In the UK, the current focus is on implementing climate policy measures within its national boundaries. Therefore, the Kyoto Protocol cap-and-trade system is hardly applicable to the forestry sector. However, various carbon capture and storage projects that adapt voluntary carbon offsetting schemes are now performing successfully [58], including in the UK. The voluntary carbon market is becoming popular worldwide and comprises 37% of total voluntary transactions by the forestry sector [59]. The founders are government and non-government organisations (NGOs), businesses, and individuals. Projects include tree-planting and forest conservation, and in the majority of cases these offer cheap carbon savings [60]. However, evaluation and inclusion of carbon offset credits in a trading system remain difficult because of the difficulties in assessing and monitoring terrestrial carbon, due to its (usually) temporary and ephemeral nature [30], and for other already mentioned reasons. Discussions of opportunities and challenges pertaining to terrestrial carbon offsetting and marketing, both regulatory and voluntary [55], and to the mechanisms for assuring that the associated emissions reductions in forestry are relatively long-lived and are not double-counted by the countries, are available in the literature [57, 61, 62, 30, 63]. The temporary nature of terrestrial carbon, which is eventually released back into the atmosphere through wood decay or burning may be addressed through partial credits accounting for the perceived risk of carbon release; insurance coverage against the destruction or degradation of forest sinks; assurance that the temporary activity will be followed by one that results in permanent emission reductions (e.g. always through replanting after harvesting); and using a conversion factor to translate years of temporary carbon storage in forest into a permanent equivalent, etc. It is possible to cope with "leakages", for example, by expanding the scope of the system to internalize "leakages" or to design the project so as to be "leakage"-neutralizing [57]. Some studies [30, 13] provide evidence that, although carbon capture and storage in a tree is carbon neutral in the long-run (at 0% discount rate for carbon uptake benefits), terrestrial carbon sequestration assists in delaying climate impacts and in avoiding and/ or reducing damage caused by global warming. Carbon sequestration forestry projects are particularly relevant, when represent a low-cost measure of coping with the changing climate and when offer multiple benefits. For doing this, carbon sequestration forestry projects need to be coherent, effective, cost-efficient, widely acceptable by the public, and consistent with other aspects of sustainable development policy.

New insights are needed into the connection between climate policies and strategies to promote sustainable forestry and to enhance integrated sustainable land use. Efficient and feasible forestry-based carbon sequestration initiatives need to be well embedded into existing policy areas, and if flexible mechanisms are implemented, then considerable scope exists for multifunctional land use systems and win-win solutions for sustainable regional development.

However, any assumption that forestry-based carbon sequestration is a universal remedy may discourage other efforts to address GHG emissions reductions [64, 55]. Terrestrial carbon offsetting does not always complement economic growth, and large-scale afforestation and short-rotation plantations may result in negative environmental and social consequences through other ecosystem services being compromised or reduced. These challenges are often further multiplied by a great number of institutional challenges and uncertainties associated with land/forest tenure and with property rights on carbon offsets, as well as with managerial aspects, particularly concerning large-scale afforestation and carbon trading. Changes in government policies, market fluctuations, and social norms and behaviour patterns contribute to uncertainties, and the extent to which the strategies can be justified on efficiency grounds also depends on the rate of discounting employed in the economic evaluation of forestry-based climate policy projects.

Among motivating research topics for socio-economists to consider are: who is responsible for carbon sequestration after the Kyoto Protocol commitment period of 2012; what is the value of (temporary) terrestrial carbon sinks, and how will this value change, as markets develop and institutions evolve to handle numerous uncertainty aspects affecting terrestrial carbon capture and storage. Further critical research questions relate to the relative weight of carbon sequestration in different regions where multifunctional forestry is practiced (in particular, spatially explicit cost-benefit modelling for multifunctional forestry) and to the policy design challenges that enable appropriate and cost-effective policies, low transaction costs and uptake of measures on appropriate land.

CONCLUSIONS AND DISCUSSION

Forestry contributes modestly to climate change mitigation, even though large amounts of carbon are locked up in forests. There are many uncertainties and challenges pertaining to carbon sequestration in forests. However, forestry-based projects have considerable relevance for national carbon budgeting in countries where wooded cover has potential to expand significantly. They are also important in the context of reducing collective carbon emissions at least cost by trading carbon offsets across countries. The prevailing vision is that carbon sequestration in forests is important as it may be a relatively low-cost option and, further, it postpones and reduces climate change, allowing time for adaptation, learning and technological innovation.

New forest development is an important carbon sequestration activity, especially when combined with substitution of wood for fossil fuels and construction materials (some of which may be particularly GHG-intensive). The current UK policy context acknowledges this potential and gives an important role to forestry in the search of cost efficient options to tackle climate change.

The UK Biomass Strategy [65] considers forestry as an important source of fuel for the future, for both heat and electricity generation purposes. This is reinforced in more recent, and also more general policy documents, like the UK low carbon transition plan [66] and the UK Renewable Energy Strategy [67]. Some incentive mechanisms are put in place, both on the supply side (e.g. the Carbon Code) and on the demand side. In Scotland, the Scottish Forestry Strategy [46] aims to increase the forest cover from 17% currently up to 25% by the second half of the century.

That is considered as an ambitious target as this would involve for Scotland the plantation of 650,000 hectares over the period (in the last decade, the afforestation rate in the UK was ca. 11,000 hectares per year [68]). A rationale for woodland expansion has been published by the Forestry Commission [69]. It justifies the Forestry Strategy (amongst other reasons) on the grounds of carbon sequestration in trees and also the substitution potential of timber products (fuels and wood materials).

The UK Climate Change Committee recently produced guidance for the Scottish Government [70] in which they highlight both new afforestation and more biomass heating as two key areas in the non-traded emissions with the potential to significantly reduce carbon emissions. They note in particular that 'Scotland has a particular advantage in access to local forestry for biomass and with rural homes off the mains gas grid that may currently have emissions-intensive heating systems.'

However, it is unlikely that the most effective type of forest from the perspective of carbon sequestration (like mono specific even aged conifers plantations or production of wood energy) will fit well with other environmental amenities. An interesting example of that relates to the afforestation of the Flow Country in Northern Scotland, in the late 1970s. Plantation of large areas of conifers (involving construction of drainage, soil preparation etc.) has caused the drying of the peat, and subsequently a loss of habitat for birds etc. To perpetuate the environmental amenities of these areas, some land has even been bought by RSPB (Royal Society for the Protection of Birds) and trees have been removed.

Further, the high non-market values of forestry for recreation, landscape and biodiversity in more densely populated areas makes multifunctional forestry with carbon sequestration a plausible option in areas such as those where community forests have been promoted in the UK. These policy options and the spatially variable suite of ecosystem services need to be analysed further. Accounting challenges for carbon storage in wood products need to be resolved. Incentives and mechanisms to combat deforestation in some regions of the world, particularly in the tropics, also need to be addressed.

The Kyoto flexibility mechanisms (e.g. CDM) provide opportunities for countries to improve the cost-effectiveness of climate change mitigation. However, our analysis indicates it is unlikely that either credit or permit (allowance) trading will occur on a large scale. The primary reasons are the unsupportive economic and market conditions, especially imperfect information and excessive transaction costs. The development of carbon trading systems involving forestry requires the solution of these problems and the reduction of transaction costs associated with terrestrial carbon offsetting and marketing. Concerns about overestimation of carbon sequestration through forestry development focus on the following considerations:

- Carbon sequestration in forestry is not equivalent to permanent emissions reduction. Often, terrestrial carbon sinks are relatively short-lived, and this makes it difficult to compare them with more permanent emission reductions (but the techniques to do so exist [30]).
- Wider use and promotion of offsetting may distract the attention of policy makers and practitioners away from emission reductions and from the development and application of novel means of climate change alleviation, including technological innovation. According to Spash [55] "...there is the potential for emissions trading to have undesirable ethical and psychological impacts and to crowd out voluntary actions...the focus on such markets is creating a distraction from the need for changing human behaviour, institutions and infrastructure". Identification of a baseline scenario and additionality of carbon sequestration activities is difficult, as is the avoidance of carbon "leakages" (e.g. displacement) and of double-counting.

Moreover, it is often unclear how to translate sustainability requirements for woody biomass production into rural policy guidelines; how to implement flexibility mechanisms for more effective and cost-efficient use of forestry opportunities to mitigate climate change; how to overcome market limitations and institutional obstacles for terrestrial carbon offsetting and trading; and how to develop incentive mechanisms and governance structures to implement carbon offsetting projects and make them acceptable/desirable to the different stakeholders. Another important matter is the question of scale. It is clear that, in the search for means to tackle climate change and to supply fossil fuel free energy, forestry has an important part to play. If the scope for large-scale afforestation is limited, the scope for smaller scale projects will also influence the range of forest types, as well as the goods and services they provide:

- at the regional scale, depending on the current intensity of land use and competition with agricultural activities, which will be affected by changes in the CAP;
- at the local scale to decentralise energy production (community forests for district heating, or public buildings such as schools and hospitals etc.); or provide amenity spaces (suburban forests).
- at the individual holding scale, planting trees on farms could become an "offset-generating" option if a cap-and-trade mechanism (or a tax) on GHG emissions was put in place. In this case, forestry would reduce the burden in farmers, as a carbon market without offsets would affect negatively farm profits [71]. Forests could also be used to generate energy on the farm, which should help farmers diversify their activities while reducing the reliance on fossil fuels.

However, norms, values and behaviours of key actors will influence the development of forestry. On the "supply side", there is often an innate resistance to forestry-based carbon sequestration by the farming community, and on the "demand side", for many people, there are advantages to having "clean" and easy energy systems based on gas or oil. Decisions to change behaviour patterns are also influenced by price and other economic incentives, e.g. subsidies, and other considerations (discussed in [13]). Behaviour may also be shaped by citizen values, and the drivers of change are thus many and varied. There is a need for "viral" social processes to help diffuse changes to help nurture low-carbon lifestyles. Currently, there is only modest evidence of these changes taking place. Voluntary offset schemes provide an example of individuals or organisations choosing to offset their carbon use, and there may be scope for greater citizen engagement if their interests are embodied in offset options on offer. It is evident that leadership and innovation have greatest effect where there are strong partnerships between the public sector, research organisations and private sector interests [72].

In the National Assessment of the potential of the UK forestry to mitigate climate change (known as the Read Report, [13]), the authors of the current paper extended the socio-economic analysis of climate change mitigation forestry options for the UK, emphasising the need to widen research on the cost-effectiveness of terrestrial carbon sequestration, as well as on carbon offsetting and marketing. Forestry will necessarily remain a legitimate object of attention with regard to land-based carbon sequestration, but until the technical, policy, institutional and behavioural obstacles are effectively addressed, progress is likely to be limited.

However, we consider that the opportunities for effective carbon sequestration in forestry may be considerable and cost effective in some parts of the UK (and other countries), especially when connected to a multifunctional vision of forestry that is properly supported by spatially explicit benefit models.

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