Can Timber Buildings Help Reduce Global CO_2 Emissions?

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Summary

It is well known that trees absorb carbon from the atmosphere, some of which is retained in wood and wood products, and that carbon absorbed by forests can be used to offset emissions of carbon dioxide (CO_2) from burning of fossil fuels. Hence some countries are using commercial forestry to help meet their Kyoto Protocol commitments. This is controversial because of uncertainty about the amount of carbon sequestered and the duration of carbon retention before return to the atmosphere. Carbon retained in timber buildings or other wood products might also be used to offset CO_2 emissions from burning fossil fuels, except that this carbon is not normally counted in the Kyoto accounting system. This paper quantifies the reduction in global CO_2 emissions resulting from increased use of timber in buildings. The most tangible benefit is the smaller amount of fossil fuel energy required to manufacture wood compared with more energy intensive materials. The benefits of using timber in this way are described with reference to New Zealand, and generalised to other countries in a global context.

1. Introduction

Countries which have adopted the Kyoto Protocol are searching for ways to reduce emissions of carbon dioxide (CO_2) from burning of fossil fuels. For some of these countries, especially those with large plantation forests such as New Zealand, forestry is an important part of the efforts to meet Kyoto Protocol commitments [1].

It is well known that trees, as they grow, absorb carbon dioxide from the atmosphere in the process of photosynthesis, with the help of solar energy. Much of the absorbed carbon is converted to wood, which has a complex chemical structure consisting of about 50% carbon. The carbon absorbed by new forests can be used to offset emissions of CO_2 from burning of fossil fuels. Carbon which is chemically part of wood remains in the woody material, either in forest residues or any sort of wood-based products, until the material finally decays or burns or is eaten by insects.

2. What are the requirements of the Kyoto Protocol?

For signature countries to meet their obligations with the Kyoto Protocol, net national emissions for developed countries must be reduced in the first five-year commitment period (2008-2012), relative to 1990 emissions. The exact reductions vary from country to country with an average of about 5%. New Zealand is required to reduce emissions to 1990 levels. For this country the two main greenhouse gases are carbon dioxide (CO_2) which is mainly produced from burning of fossil fuel, and methane (CH_4) produced in agricultural activities, in roughly equal proportions. Only CO_2 is considered in this paper. It will be shown below that it is not easy to predict fossil fuel use, and much more difficult to predict the amount of CO_2 which can be accumulated in forests or forest products.

3. Why is forestry so important?

The contribution of forestry to the Kyoto Protocol is very small globally, but very important for forestry-intensive countries like New Zealand because the Kyoto Protocol allows increases in the carbon pool in plantation forests to offset carbon dioxide emissions from any other sources.

It is essential to use correct terminology. A growing tree is a carbon “sink” because it absorbs carbon dioxide from the atmosphere. After a tree is cut down it becomes a carbon “source” as the carbon is released to the atmosphere in the form of carbon dioxide when the wood is burned or decays or is eaten by insects. A standing tree contains a “pool” or “reservoir” of carbon in the chemical structure of its wood. The carbon pool in a whole forest depends on the sums of the sinks and sources from all the trees in the forest, which is difficult to quantify. To measure the increase or decrease of the carbon pool in a forest it is easiest to compare carbon inventories at the beginning and end of the period, rather than trying to calculate continuous flows of carbon into and out of the system [2].

There is confusion about the treatment of forest residues and forest products in Kyoto Protocol accounting. The most common crude assumption is that carbon in all harvested material is oxidised to CO_2 instantly. This assumption is clearly inaccurate, but for simplicity it has been used to date in most countries including New Zealand. For forest residues which are left to decay in the forest, it is possible to report delayed emissions of CO_2 to better reflect when the carbon is released. It is more difficult to allow for the life of carbon in forest products, but some countries are reporting this as emissions over time in the same way as for forest residues

One of the positive benefits of using more wood in buildings is the reduction in CO_2 emissions resulting from the smaller amount of fossil fuel energy required to manufacture wood compared with that needed to manufacture more energy intensive materials. The national benefit will be included in Kyoto accounting because fossil fuel use will be carefully measured and any reduction will be recorded. A similar benefit applies when wood waste is burned as a substitute for fossil fuel. However, when wood is used as a fuel, or stored, or used as a building material, there is disagreement on how to account for the stored carbon before the woody material eventually decays or is burned.

There are clearly global benefits from the use of wood in many applications, but there are difficulties assigning these benefits to private forest owners or related businesses within a country. These difficulties become even more complicated when forest products are exported to other countries, either as logs or manufactured products, where they may again be stored for an unknown time before being used as many different products or fuel.

4. Which forests are counted?

The year 1990 is an important year in Kyoto accounting. For any new forests planted on farmland since 1990, their absorbed carbon during the first commitment period will be counted as a carbon sink. Forests which were existing in 1990 are not necessarily counted unless the forest is actually removed during the commitment period, in which case the loss of carbon will be counted as a carbon source. Pre-1990 forests can be included if Parties elect Forest Management as an eligible activity under Article 3.4. but this has not yet happened in New Zealand.

In order to use forestry to offset fossil fuel emissions, it is necessary to maintain both new and existing forests in perpetuity, and also to continue to plant new forests on non-forested land. There are three major considerations:

1. A high proportion of existing forests must remain in place because the carbon pool in these forests is part of the Kyoto inventory. The size of the pool for a given forest will fluctuate about a steady state condition, depending on the type of forest, sometimes being a carbon sink and sometimes a carbon source. Carbon is contained in all forests including native forests and shrublands. Unmanaged mature natural forests (preservation forests) reach a steady state so that the carbon being absorbed each year is roughly equal to the carbon emitted through natural processes of decay and degradation of wood, leaves and soil. The forest will have fluctuations in

the size of the carbon pool due to natural causes including variations in climate, natural hazards and pests. A managed plantation forest will have fluctuations due to logging and replanting of parts of the forest estate. The long-term use of plantation forestry for carbon sequestration requires that all logged areas be replanted. An unmanaged natural forest will tend to have a higher carbon density (tonnes per square metre) than a managed forest [2], but the latter will have a higher sequestration rate and the harvested wood can be used for materials or fuel replacing other materials, hence reducing CO_2 emissions.

2. The planting of new forests on non-forested land must be continued every year in order to continually increase the total carbon pool, and offset carbon dioxide emissions from burning of fossil fuel. This new planting will require a continuing supply of land suitable for afforestation. This may become increasingly difficult to find as the required area becomes very large, after some decades of continual planting. The government may need to offer incentives for private planting of new forests if reliance on forestry carbon credits is to continue into the future.

3. Any deforestation resulting from clearing of new or existing forest land will have a serious negative impact on the national carbon credit balance. The carbon pool of a forest is eventually lost if the land is converted to agriculture or other non-forest uses. The New Zealand government is assuming the liability for any deforestation (unless it exceeds a very high level), so they may need to discourage forest owners from converting forest land to non-forest uses.

In summary, in order to maximize the benefit from the carbon pool in forests, it is not only necessary to make new plantings every year, but also necessary to ensure that existing forest cover remains in place in perpetuity, either managed for timber production or as a protected forest [2].

5. Problems of changing predictions

Carbon dioxide emissions have been increasing steadily in New Zealand, with the bulk of the increase from liquid fuels in the transportation sector. In 1990, total national emissions of CO_2 were about 62 million tonnes per year, which increased by 15 million tonnes by 2005, to 77 million tonnes per year. Predictions are very difficult. A few years ago, the New Zealand government had planned for these emissions to be reduced through policy incentives to an average of 72 for the first commitment period, but the current 'most likely' estimate has now grown to 80.9 million tonnes per year [3].

Further, the amount of CO_2 predicted to be absorbed in forests has also dropped significantly, such that the national credit surplus of 55 million tonnes over the commitment period (projected in 2003) dropped to a surplus of 33 million tonnes (projected in 2004) and then much further to a net deficit of 36 million tonnes (projected in 2005). The government is struggling to find politically realistic strategies to manage this predicted deficit. A major government review [4] helps to explain the accounting, but does not help much with future strategy.

The change in the prediction of carbon sequestration in forests from 2003 to 2005 was the result of important changes in forestry activity and changes in methods of accounting [3]. The main changes are:

- Reduced areas of new planting
- Increased conversion of forest to farmland
- New planting into existing shrublands that already meet the Kyoto definition of forest
- Uncertainty about loss of carbon from soils after deforestation
- Carbon in natural scrub no longer being counted

The expected benefits of forestry in New Zealand for the first commitment period are positive, but much less than predicted a few years ago. Demographic changes in the plantation forests may result in the forest estate becoming a net source rather than a sink in the third and some subsequent periods [2], which could be of great concern to future governments and forest owners. On the other hand, a resumption of new forestry planting to over 60,000 hectares per year (as achieved in the 1990s) would place New Zealand in a very positive position.

6. Who gets the benefits from carbon stored in forests?

The New Zealand government has retained the carbon credits from nearly all plantation forestry in the country, regardless of ownership, so that the benefits of carbon sequestration flow to the government rather than to the owners of the trees. This has caused great concern to the forest owners because of the enormous potential value of carbon credits, and partly explains recent reductions in new forest planting.

The value of the national carbon credit has changed enormously from 2003 to 2005 with the changes described above. The price of carbon credits will float as they are traded on international markets, but the current price on the European futures market is over 25 Euros ($NZ50) per tonne, so New Zealand's initial estimated surplus of 55 million tonnes over the first five-year commitment period (predicted in 2003) had a potential positive value of $NZ2.7 billion which might have been sold on the international market, but this has now changed to a negative value of $NZ1.8 billion (predicted in 2005) which the government is struggling to deal with.

It is clearly in the national interest for there to be a large and increasing investment in plantation forestry, with most of those forests remaining as production forests in perpetuity. There are currently major discussions between the government and the forest owners to try to find market-related measures to make this happen [5]. A wide range of current proposals includes the following:

- A comprehensive review of the national climate change policy.
- Shift ownership of carbon credits and liabilities from government to the owners of forests.
- Make the value of carbon credits to forest owners represent the amount of carbon removed from the atmosphere, over the life of the forest and forest products.
- Remove the planned "deforestation cap" which is essentially a tax on deforestation.
- Allow for the benefits of greater timber use in New Zealand, by measures such as:
    - Encouraging greater use of timber as a building material
    - Reporting delayed emissions
- Encourage new forest planting by measures such as:
    - Paying for the costs of new planting
    - Removing local disincentives for forestry
    - Payment for beneficial externalities (clean water, environment, etc)
- Adoption of a new inventory and accounting system, to more accurately reflect the carbon flows to and from the atmosphere.

7. What are the benefits of using more wood in buildings?

Considering global CO_2 emissions, the main benefits of using more timber as a building material are:

- An increase in the pool of carbon in wood and wood products
- Reduction of fossil fuel use in manufacturing wood rather than more energy intensive materials such as steel, concrete and aluminium
- Displacement of fossil fuel by burning of wood waste materials
- Reduced use of fossil fuel for heating and cooling over the life of the building

This paper concentrates on the second bullet point above, but others [6] suggest that there are even larger benefits to be obtained from the third point. The fourth point is extremely important because of the large amount of energy used for heating and cooling of inefficient buildings.

8. How much carbon is stored in buildings?

This question has two meanings because of the ambiguity of the word “stored”. The first question is “how big is the pool of carbon in existing buildings?” and the second question is “how much is this pool of carbon changing annually (or how large is the annual net sink)?”

The answer to the first question will change over time because of variations in the carbon sink resulting from new buildings and the carbon source resulting from demolition or other disposal of old buildings. In a steady state economy the number of new buildings being built would approximately equal those being demolished and the carbon pool would remain roughly constant. The size of the national wood carbon pool in existing buildings has not been quantified accurately for many countries.

The second question requires a calculation of the amount of carbon in the materials of new buildings, less the carbon released from materials of demolished buildings. Estimates for the embodied energy and carbon dioxide emissions for building materials in New Zealand [7] were converted into quantities for different types of buildings [8], showing that the carbon sink for wood and wood products in new New Zealand buildings is roughly half a million tonnes of CO_2 per year. A similar study is available for new house construction in the United States [9]. Wood requires much less energy to process than other materials because it is a natural material already embodying a large amount of solar energy. Carbon in buildings remains for the life of the building, which may be 50 years or more. This is not a cumulative benefit because the carbon returns to the atmosphere when timber buildings are finally demolished, and the wood decays or is burned.

Some authors state that there will be benefits if wood is used in long-life products, but it is the size of the pool, not the life of products which is most important [2]. If the Kyoto accounting system counted the pool of wood products, the total size of the pool would be more important than the flow of carbon through the pool, i.e. wood ownership would be more important than wood consumption.

9. How much fossil fuel is used to manufacture building materials?

It is difficult to estimate how much fossil fuel energy is used to manufacture the materials in buildings, although this has been a topic of research for about 20 years [10]. The total fossil fuel energy used to construct new buildings in New Zealand during the 1990s was about 32 PJ per year, being about 7% of the national total fossil fuel energy consumption at that time [8]. This will have been considerably greater in the last decade because of a building boom.

10. How much CO_2 is emitted from building construction?

CO_2 is emitted to the atmosphere from burning of fossil fuel to provide heat or electricity for processing of materials. A small amount of carbon dioxide released to the atmosphere during the manufacture of cement from limestone. The total CO_2 emissions associated with construction of buildings in New Zealand is over 2 million tonnes each year [8]. This number is relatively lower than in many other countries because New Zealand generates about three quarters of its electricity from renewable hydro-electricity. Any increased use of renewable sources of energy such as wind power, hydro power, or burning of wood or wood waste for electricity generation or heat will directly reduce the amount of fossil fuel being burned, leading to a benefit in the Kyoto system.

Energy used for heating, cooling and lighting over the life of a building is much larger than the energy needed to manufacture the materials, resulting in further carbon dioxide emissions. This energy can be assessed through a Life Cycle Assessment (LCA) of the building. Some building designers are taking a lot of effort to reduce fossil fuel energy use for heating and cooling, supported by organisations such as the Green Building Council [11]. More research is needed into innovative methods of reducing the energy required for heating and cooling in timber and all other buildings, utilising high thermal insulation, passive solar architecture and other techniques.

11. Which buildings could be constructed with more wood?

Houses make up about half the new buildings constructed in New Zealand. Most are on a concrete slab with timber framing, clad with bricks or other materials and lined inside with gypsum plasterboard. Opportunities for using more wood in houses are as cladding, flooring, windows and joinery.

Most apartments, hotels, motels and hostel type buildings are made from reinforced concrete or steel framing where timber could be used. Factories and industrial buildings are nearly all made with steel cladding on steel frames, with concrete floors and walls. It is not possible to economically use wood for large scale roof cladding or industrial floors, but there are many possibilities for using engineered wood products for structural members. The structural components of most office buildings are reinforced concrete, with increasing use of structural steel. There are significant opportunities for timber structures in low to medium rise office buildings, often combined with concrete or steel in composite construction. However, no significant change is likely to eventuate without incentives.

A recent report by BRANZ [12] investigated the potential for greater use of timber in government and private sector buildings in New Zealand, identifying half a million square metres floor area of eligible projects each year, with modest carbon dioxide emission savings of 64,000 tonnes per year. An earlier investigation [8] considered a scenario where up to half of all New Zealand apartment, hotel and motel buildings are constructed with light timber framing, ten percent of commercial office buildings are built with glulam or LVL frames, half of industrial buildings have a timber structure, and at least half of all new houses have increased use of timber in floors, windows and other components. This scenario results in reduced CO_2 emissions, over three quarters of that from house construction, most from displacement of energy intensive brick cladding and aluminium windows with wood products, the balance being displacement of steel and concrete structural members by wood in a variety of buildings. The scenario assumed no changes in the energy used for heating and cooling of buildings.

This scenario has a 20% decrease in energy needed for manufacture of building materials, with the 6.7 PJ decrease in fossil fuel use being 1.5% of the total national consumption. The predicted 500,000 tonne reduction in atmospheric carbon dioxide emissions is 20% of that used for the manufacture of building materials, but only 0.8% of the national total emissions of 62 million tonnes, or 1.4% of the projected national annual deficit of 36 million tonnes described earlier, small but a step in the right direction.

This scenario requires a 17% increase wood use and results in a corresponding 17% increase in temporary carbon storage. The additional wood needed for construction could easily be made available from current exports which are about half of national production and increasing steadily.

12. Approximate global estimate

The numbers shown above can be multiplied by 500 to give a rough global extrapolation, assuming that the mixes of forest products, building types, building materials and manufacturing energy in New Zealand are representative of the rest of the world [8]. New Zealand may be a reasonable global model because it is a lightly industrialised developed country, intermediate between industrialised and developing countries. The carbon coefficient of building materials will be greater in countries where more electricity is generated from fossil fuel rather than renewables.

This extrapolation gives a global scenario with a 20% reduction in energy for manufacturing building materials, hence a 20% decrease in carbon emissions. This scenario would require a 17% increase in global usage of wood products and a corresponding 17% increase in carbon storage. The predicted energy reduction of 3350 PJ is almost 1% of 1998 global energy production of 365,000 PJ and the reduction of 250 million tonnes of CO_2 emissions is just over 1% of the global emissions of 23 billion tonnes at the time of the study [13].

These scenarios have implications for global forestry and forest products industries. The 59 million cubic metres (17%) increase in wood use in buildings would require an increase in forest harvesting of about 120 million cubic metres of logs (assuming 50% conversion from roundwood to solid product), which is over 3.5% of the total global harvest of 3400 million cubic metres, or 8% of the global industrial roundwood harvest of 1500 million cubic metres [14]. To be viable in the long term, the increase in harvesting would require new forest areas to be planted or brought into production, and all production forests continuously re-planted for sustained yield. Other pressures on the global forest estate (including possible biomass fuel production) must also be considered.

13. What incentives are needed for more timber to be used in buildings?

Construction is a major industry with strong traditions and well established procedures. There is strong competition between major materials, so changes occur slowly without strong incentives. Some parts of the building industry may be reluctant to use more timber following recent problems relating to weathertightness and wood quality, which have been dealt with by government agencies in New Zealand. Most buildings are constructed with borrowed money, so the lending institutions and the insurance industry have to be comfortable with the security of their investments.

A significant increase in the use of timber in new buildings will not happen without a serious co-ordinated investment in education, research and promotional activities. Education must include professional engineers and architects as well as young students. Promotional activities by industry are essential. Leading-edge research is needed into building performance issues including wind, fire and earthquake resistance, noise control, thermal behaviour, passive solar architecture and durability, accompanied by design aids [15]. If New Zealand had gone ahead with the carbon tax proposed in 2005, this would have provided a significant incentive to use biological materials such as wood rather than fossil-fuel-intensive materials.

14. What are the other benefits of more timber buildings?

In addition to benefits accruing from the carbon credits described above, greater use of timber in buildings in a country like New Zealand will be accompanied by reduced dependence on imported materials and fossil fuels, increased opportunities for adding value to wood products, export potential for engineered wood products and prefabricated buildings, creation of new employment opportunities, and development of export markets. Export markets for timber buildings mean that the global benefits could be an order of magnitude greater than projected above, using New Zealand grown timber.

Additional benefits are increased investment in plantation forestry, leading to further increases in the Kyoto carbon pool in forests and wood products, and increased benefits from substitution of materials for building, fuel and many other uses.

15. Acknowledgements and References

Many thanks to Piers Maclaren, Justin Ford-Robertson and Peter Weir for helpful comments and suggestions.

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Note: Most of these references quantify carbon sinks and flows in tonnes of *carbon*, which have been converted to tonnes of *carbon dioxide equivalent* in this paper in line with current convention.