Lifecycle carbon dioxide emission and stock of domestic wood resources using material flow analysis and life cycle assessment

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Abstract Lifecycle greenhouse gas emission and carbon stock of domestic wood resources and products were evaluated using material flow analysis and life cycle assessment. Carbon storage and material substitution effect was analysed for a single residential wooden house substituting typical concrete house. The embodied greenhouse gas emission of wooden type was lower than that of concrete type by 54.3 tCO_2e. Furthermore, the wooden house stored 38.3 tCO_2 in the wood material used for the house until the end of life of the house. To promote greenhouse gas mitigation potential of forest sector, the application of life cycle assessment and material flow analysis of wood products is required. Wood biomass such as demolition wood or wood pellet can reduce greenhouse gas emission when used for energy source by substituting fossil fuel consumption. Better option and increasing wood use for material and energy substitution can be a strategy to cope with climate change in forest sector.

1 Introduction

Wood is potentially a carbon neutral material if produced in a sustainable way. There is a growing concern for the mitigation of global warming by wood use increase such as increasing construction of wooden building. Building sector is a major energy and material consumer as well as a major consumer of wood products. Wood can substitute energy intensive materials such as concrete and steel. When wood and wood wastes are used for biomass energy substituting fossil fuels, greenhouse gas emission can be reduced because burning of wood does not increase atmospheric carbon dioxide in the atmosphere. Wood building products including framing lumber and plywood are sequestering carbon dioxide for a long time until the end of life of a building.

This study analyzes life-cycle greenhouse gas emissions of a conventional two-story single family house comparing wood frame and concrete frame. Greenhouse gas emissions (CO_2, CH_4, and N_2O) are estimated for the life-cycle stages of the house, that is, raw material extraction, transportation, building operation, maintenance, and final disposal. For this purpose Life cycle assessment (LCA) methodology, a tool to evaluate potential environmental impact of a product or a service, with the mechanism of analyzing input and output of material and energy of the system boundary.

Comparison between wooden- and concrete- framed houses have found that wood material based houses have low embodied energy and low greenhouse gas emission than concrete or steel based houses [3]. An LCA study done in the U.S. by CORRIM (Consortium for Research on Renewable Industrial Materials) found that life-cycle carbon dioxide emissions of wood framed houses are smaller than steel framed design by 17% and than reinforced concrete design by 31% [7]. In Japan, where the proportion of wooden house construction is more than 70% of the residential house, the life-cycle carbon emission of reinforced concrete house is about 23% greater than wooden house [4].

While around two thirds of land is covered by forest, Korea is a net importer of wood products. This is because most of the forest resources are not matured and the production cost of domestic wood is high. From the growing concern form mitigate global warming, increasing portion of renewable energy is an important environmetal issue of Korea. However wood biomass is a carbon neutral energy, it requires some energy during collection, production, and transportation of the fuel. Wood resides in the forest, which amount to one third of roundwood production in South Korea are not collected and used for material or energy source for economic reason. As a result, the important renewable low carbon energy is abandoned and becomes potential greenhouse gas emitter. We study the opportunities to increase the carbon stock and to reduce greenhouse gas emission by increasing the use of uncollected wood biomass as a fuel and wood material substitution in forest sector. Wood pellet LCA study was done to know the GHG mitigation potential of wood biomass. The production and use of wood pellets has been increased greatly in the South Korea. Wood pellets are recognized as carbon neutral energy and can be made from the wood resources of sawmill residues, roundwood, and wood residues collected from forestry practices. The embodied energy use and greenhouse gas emission were compared among three types of wood biomass sources for pellet production. The wood material life-span of domestically produced wood is rather short compared to imported wood, which is mostly used for long lived wood products such as lumber in wooden house. About sixty percent of domestic wood is used for pulp production and medium density fiberboard production, which are rather short life-cycle. In conclusion, greenhouse

gas reduction potential of domestic wood can be achieved by increasing use of long lived wood products storing carbon and substituting fossil intensive materials and by using more wood biomass for fuel substituting fossil fuel.

2 Materials and methods

2.1 Life cycle assessment of wooden house

Life cycle assessment (LCA), a useful tool to assess overall potential environmental impact of a product or a service, was used in this study to compare life-cycle greenhouse gas emissions between wooden house and concrete house alternative. The goal of the study is to estimate life-cycle global warming impact of a single family house focused on greenhouse gas emissions related to life cycle of a house, from raw material extraction to final disposal of a house. The three main greenhouse gases, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) were included for the GHG estimation in mass of carbon dioxide equivalent(tCO_2-eq.).

The studied wooden house, HANGREEN, is a two-story single family house(floor area: 190m^2) constructed in South Korea. The system boundary of the study consists of five life-cycle stages, such as, building material production including transportation, on-site construction with heavy machinery, house operation for 50 years, maintenance during house use, and final disposal of house.

2.2 Material flow analysis of wood

Wood products can displace more fossil-fuel intensive construction materials such as concrete, steel, aluminum, and plastics, which can result in significant emission reductions [8]. Material flow analysis helps to understand societal metabolism of sustainable production and consumption of staple resources [2]. There are some studies of material flow analysis of wood products including paper [5].

In 2009, Korea consumed 26,607,000 cubic meter of wood and wood products. Among them, 23,431,000 m^3 was imported, and 3,176,000 m^3 was from domestic rounwood supply. 10,967,000 m^3 (41.2%) was used for pulp and chip, 5,852,000 m^3 (22.0%) was used for lumber, 3,061,000 m^3 (11.5%) was used for plywood and veneer, and 2,472,000 m^3 (9.3%) was used for particle board and MDF. In 2009, 819,000 m^3 of wood was collected after forest tending, among which, 199,000 m^3

(24%) was used for roundwood resources. Korea exported 7,000 m^3 of plywood in the year 2009 [6].

Forest stock of South Korea was 659,120,000 m^3 at the end of 2008 and 696,828,000 m^3 at the end of 2009. Therefore, 37,708,000 m^3 of forest stock was increased during the year of 2009. From the MFA and LCA of domestic wood products, greenhouse gas reduction potential of wood material substitution effect can be measured. Carbon stock in forest sector of Korea is increasing.

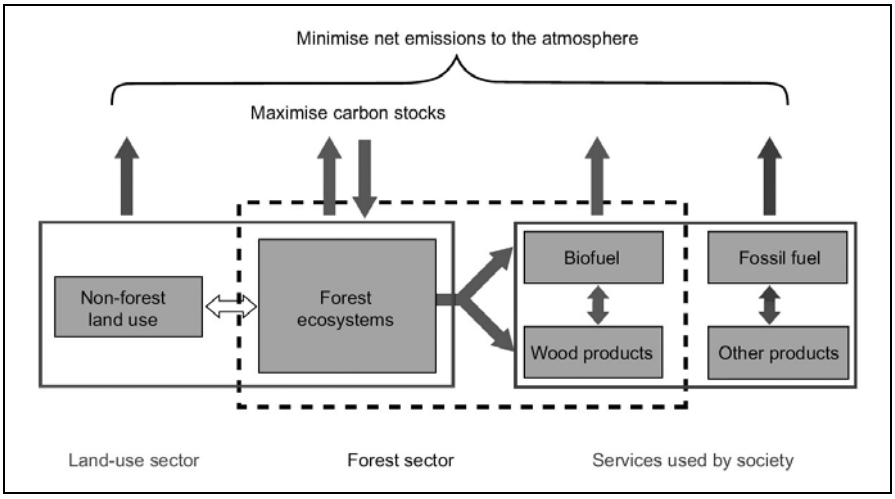

Fig.1: Forest sector mitigation strategies need to be assessed with regard to their impacts on carbon storage in forest ecosystems on sustainable harvest rates and on net GHG emissions across all sectors. (Source: IPCC Fourth Assessment Report)

3 Results

3.1 Greenhouse gas reduction effect of wooden house

3.1.1 Embodied GHG emissions

The embodied GHG emission of a house is total greenhouse gas emissions from construction material production, transportation, and construction activities. Total material input of the wooden house was 209.6 ton, while concrete house used 499.7 ton of construction material. GHG emissions of production and

transportation of construction material of wooden house and concrete house were 51.27 tCO_2e and 104.61 tCO_2e, respectively. GHG emissions from fossil fuel consumption of heavy construction machinery are 1.05 tCO_2e for the wooden house and 1.97 tCO_2e for the concrete house. Embodied GHG emission of wooden house was 52.33 tCO_2e and that of concrete house was 106.59 tCO_2e. The embodied GHG emissions of wooden house was lower than that of concrete house by 54.3 tCO_2e.

3.1.2 GHG emissions during house use

The service life of 50 years was assumed for lifetime of the studied houses. The service life of 50 years has been chosen for many other LCA studies on building regardless of framing material [1]. GHG emission from consumption of natural gas and electricity used during the service life of the studied houses was estimated 421.45 tCO_2e regardless of house type owing to the same thermal capacity assumption. GHG emission from maintenanace of the houses were 6.95 tCO_2e for wooden house and 8.17 tCO_2e for concrete house.

3.1.3 GHG emissions from house disposal

Dismantling of the house and transportation of demolished material to the waste management site are included for the estimation of greenhouse gas emission of disposal stage. GHG emissions from machinery use in disposal stage were 3.11 tCO_2e for wooden house and 5.25 tCO_2e for the concrete house.

3.2 Greenhouse gas reduction scenario

3.2.1 Life-cycle GHG emissions

The baseline life-cycle GHG emissions, which includes material, construction, operation, maintenance, and disposal were 483.84 tCO_2e for wooden house and 541.46 tCO_2e for concrete house. The emission difference of the two houses was 57.62 tCO_2e. This implies if wooden house is constructed instead of concrete house, 57.62 tCO_2e is reduced.

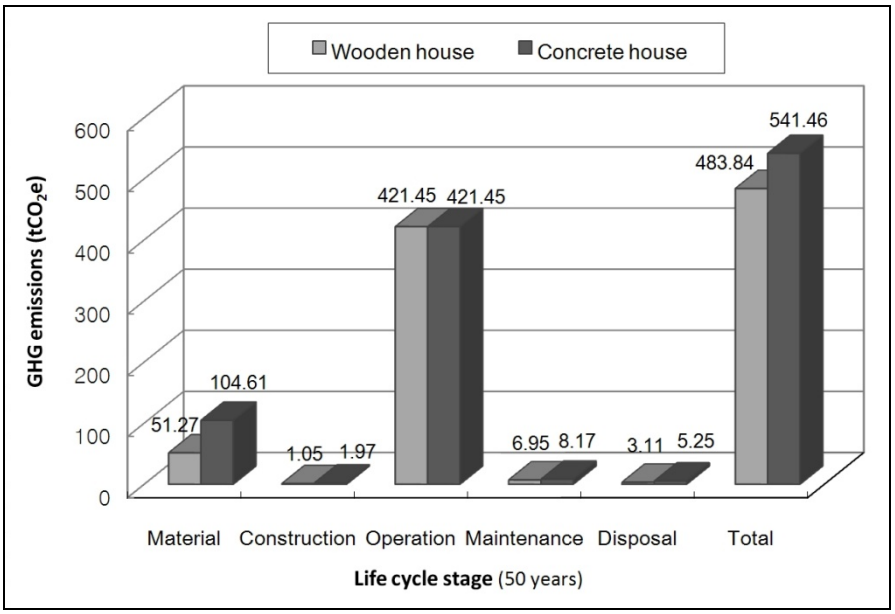

Fig.2: Life-cycle greenhouse gas emission of wooden and concrete house

3.2.2 Energy saving in use phase

About 80% of life-cycle GHG emissions result from fossil fuel consumption in use phase of 50 years. The GHG reduction potential of energy saving by 10%, 20%, and 30% are 42.2 tCO_2e, 84.3 tCO_2e, and 126.5 tCO_2e respectively. Photo voltaic system installed on roof of the house can substitute purchased electricity. Considering emission factor of PV system. The reduction potential of using PV system per 1kWh is 0.419 $kgCO_2e$. Using this factor, we assumed we get electricity from PV system by 30% and 50%. The reduction potential is 24.5 tCO_2e and 40.8 tCO_2e respectively.

3.2.3 Carbon storage and fossil fuel substitution

Harvested wood products (HWP) store carbon dioxide during the use. Wooden house uses a great amount of wood products for building components, such as framing wood of wall, roof and flooring. In the study, wooden house used 38.4 m^3 of HWP and stored 38.3 tCO_2, while concrete house used 1.8 m^3 of HWP and stored 1.8 tCO_2. Waste wood from demolished wooden house can substitute fossil fuel consumption when used as energy source at combined heat and power

generation. If wood substitute bunker C oil and LNG in CHP, 21.8 tCO_2e and 18.1 tCO_2e can be reduced from using carbon-neutral biomass, wood.

3.2.4 Wood pellet use for boiler

From the life-cycle assessment of wood pellet production system in South Korea, 0.27 $kgCO_2e$/Mcal and 0.24 $kgCO_2e$/Mcal were estimated to be reduced by using wood pellet boiler instead of using diesel and natural gas, respectively. In the use pahse of the studied house, annual energy required for heating was estimated 24,950 Mcal/year. When substituting natural gas boiler with wood pellet boiler, it comes out that about 6 ton of carbon dioxide can be reduced annually.

4 Discussion

While 6.4 million ha of forests in South Korea, which accounts for 64% of total land cover, sequester carbon dioxide, harvested wood products can help to increase carbon pool of forest sector including wood products carbon pool. The mitigation effect of biomass use is direct and permanent on condition that the biomass source was come from sustainably managed forests.

The production and use of wood pellets has been increased greatly in South Korea. Wood pellets are carbon neutral energy and can be made from the wood resources of sawmill residues, roundwood, and wood residues collected from forestry practices. The LCA study showed that the use of wood pellets as biofuels substituting fossil fuels such as natural gas and kerosene for boilers has positive effects both in reducing greenhouse gas emissions and in decreasing cost for house heating. The life-cycle environmental impacts of wood pellets were mainly from the transportation of wood resources and pellet products to the final consumer. Better utilization of forest residues which have not been collected and used much for biomass, increasing pellet-boiler efficiency, and improving regional biomass utilization system such as decrease in transportation distance can be measures to reduce greenhouse gas emissions in forestry sector for climate change mitigation.

The result shows that wooden house construction has a potential of mitigating climate change. The total GHG emissions of wooden house was lower than that of concrete house over the life-cycle of the studied single family house such as raw material extraction, manufacture of building materials, on-site construction, operation and maintenance, and final disposal of house.

At present, demolished construction materials are landfilled or incinerated as well as recycled as recycled concrete gravel or as wood resource for particle board

production. When recovered wood materials from demolished buildings are used as biomass energy substituting for fossil fuels, greenhouse gas emissions could be more reduced. Increasing wooden house construction instead of concrete or steel house would be an effective measure to reduce fossil fuel consumption and green house gas emissions.

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6 References

[1] Adalberth, K., Almgren, A. and Petersen, EH. Life cycle assessment of four multi-family buildings, *Int J Low Energy Sustainable Build*,Vol. 2, 2001.

[2] Bringezu S. Comparison of the material basis of industrial economies, In: Bringezu S, Fischer-Kowalski M, Kleijn R, Palm V, editors. Analysis for Action, Support for Policy towards Sustainability by Material Flow Accounting, Proceedings of the ConAccount Conference 11–12 September 1997, Wuppertal, Germany, 1997.

[3] Buchanan, A. and Honey, B. Energy and carbon dioxide implications of building construction, *Energy and Buildings*,Vol. 20, No. 3, 1994, pp. 205-217.

[4] Gerilla, G.P., Teknomo, K., Hokao, K., An environmental assessment of wood and steel reinforced concrete housing construction. *Building and Environment*,Vol. 42, 2007, pp. 2778-2784.

[5] Hekkert, M.P. Joosten L.A.J. and Worrell, E. Analysis of the paper and wood flow in The Netherlands, *Resources Conservation and Recycling*,Vol. 30, 2000, pp. 29-48.

[6] KFS, Statistical yearbook of Korean forestry, Korea Forest Service, 2010.

[7] Lippke, B., J. Wilson, J. Perez-Garcia, J. Bowyer, and J. Meil. CORRIM: Life-cycle environmental building materials. *Forest Prod. J.*,Vol. 54, No. 6. 2004, pp. 8-19.

[8] Petersen, A.K. and B. Solberg, Greenhouse gas emissions, life-cycle inventory and cost-efficiency of using laminated wood instead of steel construction. -Case: beams at Gardermoen airport, *Environmental Science and Policy*, Vol. 5, 2002, pp. 169-182.