IEA Bioenergy

Task 38

Greenhouse Gas Balances of Biomass and Bioenergy Systems

BIOMITRE

Greenhouse Gas Balance of bioenergy systems based on Integrated plantation forestry in North East New South Wales, Australia

Summary

Australia is heavily reliant on fossil fuels, particularly coal, for electricity production, but is now encouraging expansion of renewable energy to reduce greenhouse gas (GHG) emissions. Plantation forests are a potential source of biomass for renewable bioenergy. This study examines the potential GHG emission reduction from bioenergy utilising thinning, harvest and sawmill residues from plantation forests in northern New South Wales (NSW). Two alternative energy conversion options are compared: co-firing in black coal power plants located distant from the plantation region, or in stand-alone wood-fired plants located within the plantation region. Emission reduction per ha, and per unit electricity produced were calculated for two levels of plantation productivity. The potential emission reduction from forestry in Northern NSW was estimated using published predictions of future expansion of plantations in this region.

Biomass fired CHP plant in Ostersund, Sweden.

Co-firing gave higher emissions reduction per ha, and per unit of biomass, due to the greater efficiency of energy conversion by co-firing. However, co-firing gave lower emissions reduction per MWh, compared with the wood-fired option, due to the greater fossil fuel input required for transport. The emission reduction benefits of the wood-fired plants would increase, and possibly surpass the co-fired option, if high efficiency IGCC technology were employed.

Eucalypt plantation near Coffs Harbour, NSW. (Photo: A. Cowie)

The potential biomass production from 180 000 ha plantations in northern NSW was estimated to be 2.03 Mt dry matter per annum. The potential power output was estimated at 3090 GWh_e per annum from co-firing, or 2120 GWh_e pa for the wood-fired option, giving net GHG emission reduction of 2.63 Mt CO_2-equivalent (CO_2e) and 1.93 Mt CO_2e per annum for the co-fired and wood-fired alternatives, respectively.

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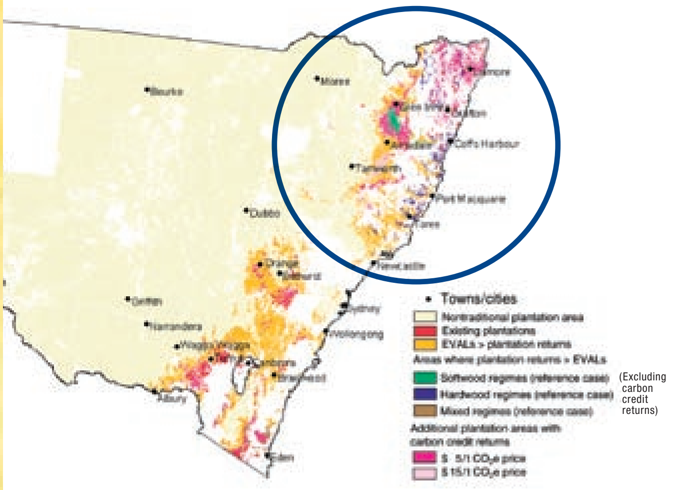
Scope



Note: Data are presented for broadscale assessment purposes only

Figure 1. Predicted expansion of plantations in NSW. Study area circled. Assessment based on comparison of forestry returns with estimated value of agricultural land (EVAL). (ABARE/BRS, 2001)

Australia is heavily reliant on coal for electricity production, and biomass accounts for less than 5 % of the electricity supply. New policy measures to reduce emissions of greenhouse gases are stimulating interest in renewable fuels: federal legislation has set a target of increasing renewable energy by 9 500 GWh p.a. by 2010, and in the state of New South Wales, mandatory emission reduction targets have been imposed on electricity retailers. Renewable energy sources under consideration include bioenergy from forestry residues.

Currently, in NSW eucalypt plantations, residues from thinning are left on the forest floor to decay, residues from harvest of sawlogs are windrowed and burned in the forest, and mill residues are often burned to waste. Potentially, each of these three residue resources could be utilised for renewable energy.

This study investigates the greenhouse mitigation potential of bioenergy based on residues from plantation forestry in northern NSW. Two alternative bioenergy conversion systems are compared: co-firing in existing coal-fired power stations, and the development of new wood-fired power stations within forestry regions.

Method

A study of potential plantation expansion by the Australian Bureau of Agricultural and Resource Economics and Bureau of Rural Sciences (ABARE/BRS 2001) predicted the future plantation area on the basis of competitiveness of agricultural production in comparison with plantations, and impact of returns from carbon trading (Figure 1). The study predicted that, at a price of AUS$ 5 (~ € 3) per tonne CO_2, the area of plantations in northern NSW is likely to expand from 68 000 ha (in 2001) to 180 000 ha. All plantation expansion in the northern region was predicted to occur on sites of Productivity Class 1 (assumed mean annual increment (MAI) of 22 m^3) or Class 2 (MAI 18 m^3).

Calculation of GHG balance

The FullCAM model of carbon dynamics (Richards, 2001) was used to calculate the greenhouse gas balance of bioenergy and conventional forestry systems.

Project case

The project case is a theoretical bioenergy system based on biomass production from conventional hardwood plantation forestry, with biomass obtained from thinning, harvest and sawmill residues from 68 000 ha existing and 111 000 ha newly established hardwood plantations. Two options for energy generation are included:
a) 30 MW wood-fired power stations to be constructed within the plantation region, or
b) co-firing in existing 500 MW black coal-fired power stations located outside the major plantation region.

Reference case

The reference system to which the bioenergy system is compared represents current practice, in which electricity is generated from 500 MW black coal fired power stations; thinning residues decay on the forest floor, harvest residues are windrowed and burned in the field, and sawmill residues that are not utilised in drying timber are burned to waste at the mill.

System boundary: In each case the system boundary includes the power generation system, 68 000 ha existing plantation, and 111 000 ha grazing land newly converted to plantation. The same quantity of sawn timber is produced, and the same quantity of carbon is sequestered. GHG emissions, including non-CO_2 greenhouse gases, from fossil fuel consumption and fertiliser manufacture and application are included, as are emissions due to power plant construction.

Functional unit

The analysis is expressed in terms of GHG mitigation per hectare of plantation (difference between reference and project case), for each plantation productivity class, and for each of the energy conversion options. Net GHG emission reduction per MWh_e of bioelectricity for each productivity class and each conversion option are also presented. The calculation period is 100 years, to cover several rotations.

Regional analysis

The regional analysis was undertaken by multiplying the GHG mitigation per hectare with the area of plantation in each productivity class, for each Local Government Area (LGA). For the wood-fired option, a transport distance of 100 km was assumed for all plantation locations, based on the assumption that new power stations will be distributed across the region. For the co-firing option, biomass was assumed to be transported to the existing coal-fired power stations. A spatial analysis was undertaken to determine the mean distance, by existing road network, from each LGA to the closest coal-fired power station (Figure 2); the average distance over which biomass was transported was 360 km.

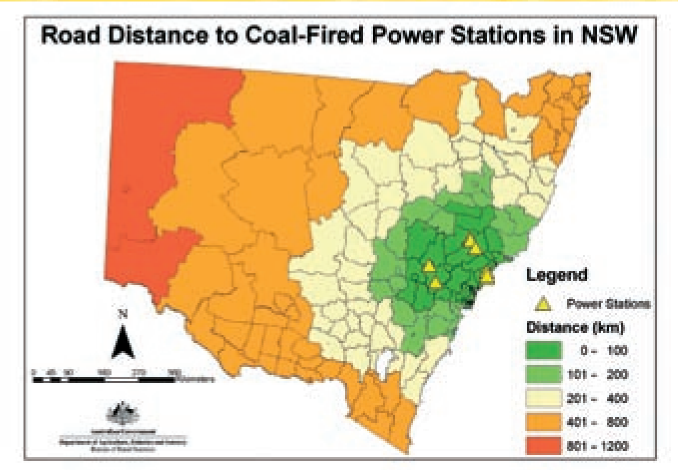


Figure 2. Average road distance to closest coal-fired power station from each local government area in NSW.

Table 1. Assumptions.

Plantation management	Productivity class 1	Productivity class 2
Rotation length [years]	28	30
MAI [m^3 ha^{-1} $year^{-1}$]	22	18
Thinning [age in years], ([% biomass removed])		
Thinning 1	10 (50)	12 (50)
Thinning 2	18 (50)	20 (50)
Emissions from biomass production, processing and transport	GHG emission	
Management (plantation establishment and maintenance) [t CO_2e $ha^{-1}$$year^{-1}$]	0.037	
Harvest [t CO_2e per t C in biomass harvested]	0.073	
Chipping and local transport [t CO_2e per t C in biomass processed]	0.037	
Long-distance transport [t CO_2e per t C in biomass transported per km]	0.00073	
Emissions factor diesel [g CO_2e MJ^{-1}]	78.1	
Emissions factor NSW black coal [g CO_2e MJ^{-1}]	98.1	
Power station assumptions	Wood-fired	Co-fired
Technology	Circulating fluidised bed boiler, steam turbine	Pulverised fuel black coal boiler, steam turbine. 5 % co-fired biomass, by weight
Capacity	30 MW	500 MW
Biomass moisture [%]	55	55
Efficiency of conversion [%]	20[2]	29[2]
Displacement factor[1]	0.57[2]	0.83[2]
Emissions due to construction [kg C MW_he^{-1}]	3.27	0.627[3]

[1] Displacement factor = (efficiency of bioenergy system / efficiency of fossil fuel system) x (CO_2 emissions of fossil system / CO_2 from bioenergy)

[2] The efficiency of conversion and displacement factors are low due to the high moisture content of the biomass.

[3] Considering only additional facilities required to receive biomass and deliver it to the coal conveyor

Assumptions

Key assumptions are listed in Table 1; see Cowie (2004) for further detail. For the bioenergy case it was assumed that 30 % of branch mass, 100 % leaf and root mass, and 3 % stem mass (representing the stump), remained as litter; at thinning, 100 % of the biomass removed from the forest was utilised for bioenergy, while at final harvest, 90 % was used for bioenergy and the remainder was retained in sawn wood products. It was assumed that 3.5 % of the carbon from mill residues was utilised to dry the sawn timber.

It was assumed that biomass was utilised directly from the field rather than being dried prior to combustion; the high moisture content lead to low efficiency of conversion. For the co-firing option, the analysis considered only the biomass component of the system: construction relates to additional facilities required to receive biomass and deliver it to the coal conveyor; the electricity generated and fossil fuel emissions relate only to the biomass combusted.

Results and discussion

The forest and product carbon pools, and “bioenergy credit” due to displaced fossil fuel emissions, over 100 years, are exemplified in Figure 3, and the biomass production system is compared with the reference forestry system in Table 2. There was a substantial decline in soil carbon predicted for the reference and bioenergy cases, for newly established forests. Reviews of soil carbon dynamics under afforestation have concluded that loss of soil carbon commonly occurs where plantations replace pasture, though large losses are limited to situations where high levels of fertilisation have built up a large pool of labile soil carbon. The rate of decline in soil C was greater under the bioenergy system; this is to be expected, because removal of branch biomass reduces the quantity of biomass C in the litter pool that interacts with the soil C pool. Nevertheless, changes in the soil C pool are small compared with the accumulation of C in tree biomass over the first rotation, and the growing pools of products. Over several rotations displaced fossil fuel carbon becomes the dominant pool.

By definition, the tree carbon and ‘products in landfill’ did not differ between the bioenergy and reference cases. The product stock is slightly higher in the bioenergy case due to C stock in the biomass pool.

The net GHG emission reduction for the co-firing option at the highest plantation productivity was 1610 t CO_2e ha^{-1}, 36 % higher than the wood-fired option (Table 2). This difference was due to the higher efficiency of the co-firing system, which was partly offset by higher transport emissions due to the longer transport distance to coal fired power stations. The emissions from construction, though 3.5 times higher in the wood-fired plant, had very little impact. The total fossil fuel emissions were higher, relative to the power output, for the co-fired option compared with the wood-fired system. Including stock change in the plantation (that is, relative loss of soil carbon compared with the reference system), fuel used in biomass production and transport, and plant construction, the emissions were 130 g CO_2e kWh^{-1} and 70 g CO_2e kWh^{-1} for the co-firing and wood-fired systems, respectively. In comparison, emissions for electricity production from the reference NSW black coal power stations were 980 g CO_2e kWh^{-1}.

The potential biomass production from 180 000 ha plantations in northern NSW was estimated to be 2.03 Mt per annum. The potential power output was estimated at 3090 GWh_e per annum from co-firing, or 2120 GWh_e per annum for the wood-fired option, displacing, respectively, 3.03 Mt CO_2e or 2.08 Mt CO_2e. (Table 3). The net GHG emission reduction was 2.63 Mt CO_2e and 1.93 Mt CO_2e per annum for the co-fired and wood-fired alternatives, respectively, which represents 6.0 % and 4.4 %, respectively, of the 1990 NSW greenhouse gas emissions due to electricity production. The total GHG emission in NSW for 1990 was 126.9 Mt CO_2e; thus, the co-firing option could deliver GHG emission reduction of 2 % of this total, while the wood-fired option could give 1.5 %. The estimated total quantity of biomass produced is sufficient to supply about ten 30 MW power plants.

Table 2. Change in carbon stock of the forest and product pools, credit due to displaced fossil fuel emissions, and GHG emissions reduction, calculated over 100 years. Positive values indicate a gain, negative values a decline.

		[1]Productivity class 1 MAI 22 $[m^3 ha^{-1} year^{-1}]$		Bioenergy case – Reference case			
		Reference		Class 1		Class 2	
		Existing plantation	New plantation	Co-fired	Wood-fired	Co-fired	Wood-fired
Soil[2]	$[t C ha^{-1}]$	-9	-19	-15	-15	-12	-12
Litter[3]	$[t C ha^{-1}]$	5	5	-3	-3	-2	-2
Tree[2]	$[t C ha^{-1}]$	81	81	0	0	0	0
Net Forest C	$[t C ha^{-1}]$	**77**	**67**	**-18**	**-18**	**-15**	**-15**
Products in use[2]	$[t C ha^{-1}]$	22	22	3	3	3	3
Products in landfill[4]	$[t C ha^{-1}]$	22	22	0	0	0	0
Total Product C	$[t C ha^{-1}]$	44	44	**3**	**3**	**3**	**3**
Fuel used in biomass production[5]	$[t CO_2e ha^{-1}]$	-51	-51	-183	-24	-150	-18

		Reference	Co-fired	Wood-fired	Class 1 Co-fired	Class 1 Wood-fired	Class 2 Co-fired	Class 2 Wood-fired
Biomass produced	$[t\ dm\ ha^{-1}]$	0	1240	1240	1240	1240	1030	1030
Green Electricity generated	$[MWh_e]$	**0**	**1890**	**1300**	**1890**	**1300**	**1560**	**1075**
Grid electricity[6]	$[MWh_e]$	1889	0	0				
Net stock change forest+product	$[t CO_2e ha^{-1}]$	407	352	352	-55	-55	-44	-44
Fossil fuel displaced	$[t CO_2e ha]$	0	1853	1273	1853	1273	1534	1055
Power plant construction emissions	$[t CO_2e ha^{-1}]$	0	-4.4	-15.6	-4.4	-15.6	-3.7	-12.8
Total fossil fuel emissions	$[t CO_2e ha^{-1}]$	-1904	-242	-92	1661	1233	1376	1022
Emissions reduction	$[t CO_2e ha^{-1}]$				**1610**	**1180**	**1335**	**980**
Emissions reduction	$[kg CO_2e t biomass^{-1}]$				**1300**	**950**	**1300**	**950**
Emissions reduction	$[kg CO_2e MWh_e^{-1}]$				**850**	**910**	**850**	**910**

[1] Productivity Class 1 only presented, as example.
[2] Value at 100 years determined from fitted trend line, to overcome influence of fluctuating pool size.
[3] Value at 100 years determined from average carbon stock of pool over the period.
[4] Total carbon stock of pool at 100 years.
[5] Includes forestry operations, processing and transport. In the co-firing option, fossil fuel emissions due to transport are calculated for a distance of 360 km, which is the average distance from local government area to the closest coal-fired power station, weighted by area of plantations in each LGA.
[6] Value given for co-firing option, as example.

Table 3. Potential annual greenhouse mitigation benefit from bioenergy based on plantations in northern NSW

Plantation productivity		**Class 1**		**Class 2**		**Total 1 + 2**	
		Co-fired	Wood-fired	Co-fired	Wood-fired	Co-fired	Wood-fired
Forest + product stock change	[kt C pa]	-13	-13	-11	-11	-24	-24
Fossil fuel spent	$[kt CO_2e pa]$	-173	-36	-135	-27	-307	-63
Biomass produced	[kt DM pa]	1140	1140	893	893	2033	2033
Fossil fuel emissions displaced	$[kt CO_2e pa]$	1701	1170	1331	917	3032	2083
Net GHG emission reduction	$[kt CO_2e pa]$	1463	1082	1166	851	2636	1932
Electricity produced	$[GWh_e pa]$	1733	1191	1358	933	3091	2124

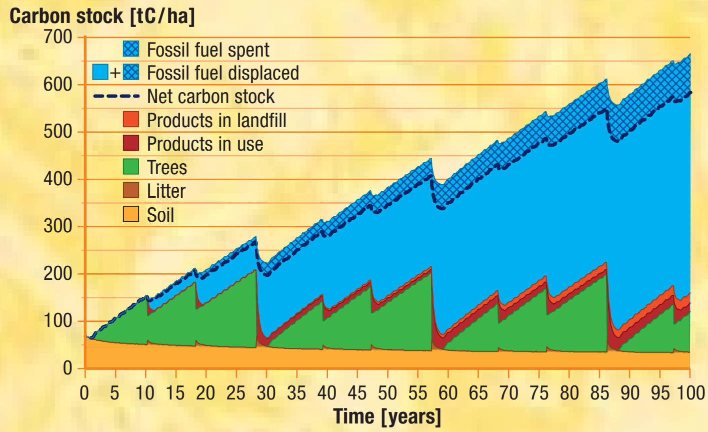


Figure 3. Carbon stock of all forest and product pools, displaced fossil fuel and fossil fuel spent for the Productivity Class 1, co-fired option, with 600 km transport distance. Fossil fuel spent reduces the total carbon stock to the net carbon stock indicated by the broken line.

Uncertainties

The assumed efficiency of electricity generation in the wood-fired power plant was fairly low, representative of a circulating fluidised bed boiler with steam turbine, utilising green forest residues. Increasing the assumed efficiency of the wood-fired power plant from 20 to 25 % gave a corresponding increase in avoided fossil fuel emissions, and increased the emission reduction by just over 25 %, to 2.46 Mt CO_2e per annum, approaching that of the co-fired option (Figure 4). With advanced integrated gasification combined cycle (IGCC) technology, the efficiency achieved could be as high as that of co-firing; the emissions reduction benefit of the wood-fired option would then surpass that of co-firing, due to reduced transport emissions.

The regional analysis of potential for bioenergy from northern NSW is directly dependent on the predicted area and productivity of plantations obtained from the ABARE / BRS study, and therefore strongly influenced by the assumptions behind that study. Growth rates predicted in the ABARE / BRS study are optimistic in comparison with recent estimates of average plantation growth rates in the region (State Forests NSW, unpublished), though they are achievable with appropriate species-site matching and optimal management. Assuming reduced productivity of MAI18 for Class 1 and MAI15 for Class 2, the potential biomass production and emission reduction benefits are reduced by nearly 20 % (Figure 4).

The ABARE / BRS study analysed three options for the price of carbon; the lowest price of $ 5 per t CO_2 was utilised in this analysis. Recently, a market for carbon sequestration has been established in NSW through the NSW Greenhouse Gas Abatement Scheme, which imposes mandatory targets for emissions reduction on electricity retailers in NSW. The value of carbon in this market is about AUS$ 15 per t CO_2, based on the after-tax penalty for non-compliance. Therefore, the analysis was repeated using the plantation area predicted for AUS$ 15 per t CO_2: 222 500 ha. This area could produce 2.54 Mt biomass per annum, from which 3 870 GWh green electricity may be generated by co-firing or 2 660 GWh_e from wood-fired power plants (Figure 4).

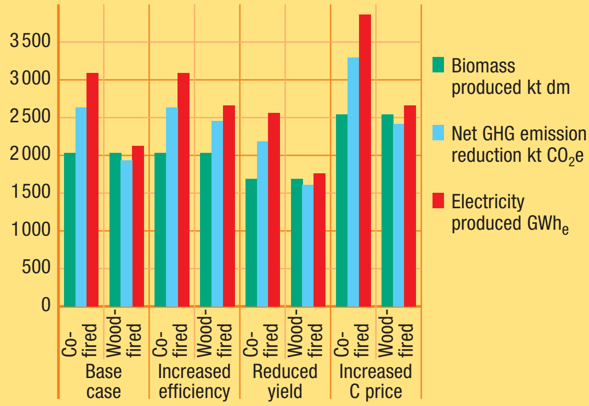


Figure 4. Sensitivity analysis: Biomass produced, GHG emission reduction and electricity produced per annum with increased efficiency of wood-fired combustion, reduced plantation yield and increased carbon price (see text for details).

Conclusion

The expanding plantation industry clearly has potential to contribute significantly to reducing GHG emissions in NSW through supply of biomass for bioenergy: from 180 000 ha plantations, through co-firing in existing coal-fired plants, emissions reduction of 2.63 Mt CO_2e per annum is predicted. The emission reduction benefits are 26 % lower for wood-fired power plants, due to the greater efficiency of co-firing. This conclusion is dependent on the technology of the wood-fired plant; new generation IGCC technology may achieve similar efficiency to co-firing. See Cowie (2004) for full report.

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IEA Bioenergy
Task 38

IEA Bioenergy (www.ieabioenergy.com) is an international collaborative agreement, set up in 1978 by the International Energy Agency (IEA) to improve international cooperation and information exchange between national bioenergy research, development and demonstration (RD & D) programs. IEA Bioenergy aims to realize the use of environmentally sound and cost-competitive bioenergy on a sustainable basis, thereby providing a substantial contribution to meeting future energy demands.

IEA Bioenergy Task 38 brings together the work of national programs in 13 participating countries on GHG Balances for a wide range of biomass systems, bioenergy technologies and terrestrial carbon sequestration. As one example of work, case studies have been conducted by applying the standard methodology developed by the Task 38. The case studies have assessed and compared GHG balances of different bioenergy and carbon sequestration projects in the participating countries, and the Australian case study is one example.

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