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Can Carbon Offset Trading Promote Economic Development in Forest-Dependent and First Nations Communities?

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Abstract

Forest-dependent, rural communities often experience declining populations and prosperity because technological changes related to harvesting, transportation and processing of wood fiber occur more rapidly than technical improvements in fiber availability – in forest growth. How then can communities where forest resources are the primary economic driver increase wealth that might then be used for economic development? Answers to this question are explored by examining the potential of different management regimes to create greater employment and wealth, particularly management options that include carbon values. Our application is to an interior forest region of British Columbia, the province where First Nations control the most timber supply and the region that produces the greatest volume and value of lumber for export. We examine the trade-offs between revenue as measured by net present value, employment and carbon in forest ecosystems, where the latter is a proxy for the ecological health of the forest. We conclude from the analysis that no management strategy is able to satisfy all of the technical, environmental and social/cultural constraints and, at the same time, offer forest-based economic development that will prevent the decline of rural communities. Nonetheless, given knowledge of tradeoffs, there are management options that can improve upon current employment, wealth and/or ecological health of the forest.

Keywords: carbon accounting; climate mitigation and forestry; forest-dependent rural communities

JEL Categories: R11, Q23, Q01, C61

Can Carbon Offset Trading Promote Economic Development in First Nations Communities?

1. INTRODUCTION

In Canada, governments have historically promoted economic development in rural regions by promoting exploitation of natural resources, including forest resources. Many rural communities depend on the forest industry, with a significant number reliant on forestry for more than 50% of household income. Indeed, forest resources are an economic development driver in many of the more than 80% of native communities located in forest regions.[1] Forests also provide aboriginal people with cultural and spiritual values, and non-timber forest amenities (e.g., biodiversity, wildlife harvests for meat and fur, etc.), that may be incompatible with timber exploitation; these values are important when considering the health and sustainability of forest-dependent, native communities (Beckley et al. 2002). However, while these non-market amenities are important for First Nations peoples, high rates of unemployment and low incomes often characterize forest-dependent native communities, leading to poverty and general misery as aspirations of people cannot be met. For example, 42.9 percent of dwellings on First Nations' lands, which include forest-dependent communities, have defective plumbing or electric wiring and/or need structural repairs to walls, floors or ceilings. Therefore, it is necessary to determine means by which forest resources can be used to increase community incomes and employment (Krcmar et al. 2005; Krcmar and van Kooten 2008).

Statistic Canada's 2011 National Household Survey found that there were 1.4 million aboriginal people living in Canada, representing 4.3% of the country's total population. This was up from 3.8% of the population in the 2006 Census, 3.3% in 2001, and 2.8% in 1996. However, rates of unemployment among aboriginal peoples in Canada are significantly higher than they are for Canadians as a whole. This is demonstrated in Figure 1, where unemployment rates are provided for Canada as a whole plus the two provinces that have the greatest proportion of natives in the population, Saskatchewan and Manitoba. Unemployment rates in more remote, forest-dependent communities, and particularly native communities, are much higher, sometimes over 50%

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[1] Unless otherwise indicated, data provided in the Introduction come from Statistics Canada's National Household Survey, 2011.

especially among those under age 25, while labor force participation rates are much lower thereby indicating that actual unemployment is likely even higher – potential workers became discouraged by their employment prospects and simply dropped out of the labor force. In 2011, the off-reserve unemployment rate for aboriginals was 34% percent, but it was 53% for those living on reserves.

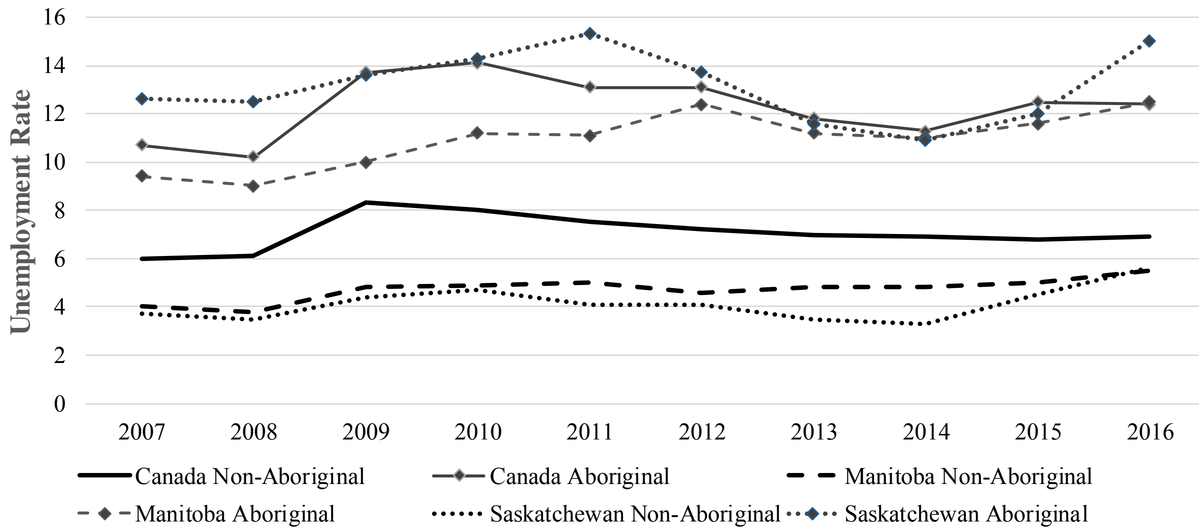

Figure 1: Unemployment Rates for Non-Aboriginal and Aboriginal People, Canada and Selected Provinces, 2007-2016
(Source: Statistics Canada, Labour Force Survey, CANSIM Table 282-0226)

Governments have sought to address poverty on reserves, especially forest-dependent aboriginal communities, by allocating greater control over timber harvests to First Nations. Between 2003 and 2014, the proportion of the sustainable timber harvest in Canada allocated to First Nations increased from 4.7% to 10.4%, as indicated in Table 1. At the same time, efforts are underway to provide aboriginal peoples with the skills needed to work in the forest sector in occupations ranging from forest management, silviculture and harvesting to mill operations, manufacturing and marketing, supplanting many workers who will retire in the near future (Forest Products Sector Council 2011).[2] Already aboriginals account for 17,000 direct and indirect jobs in the forest sector (or 5.3% of the total compared to 3% on average in other sectors), while aboriginal forest enterprises now number between 1200 to 1400, or some 15% of all forestry enterprises.

[2] See http://www.nrcan.gc.ca/forests/canada/aboriginal/13173 [accessed February 20, 2018].

Table 1: National Allocation of Forest Tenure Volume to First Nations, Selected Years, 2003-2014

Region	Total Harvest Allocation (million m^3/yr) 2003	2006	2014	Proportion Native (%) 2003	2006	2014	% of Total Native Allocation[a]
Quebec	35.7	31.8	17.2	1.8	2.7	6.4	7.3
Ontario	30.5	22.6	29.2	3.6	5.7	22.3	11.0
Manitoba	3.5	3.5	2.5	3.8	4.5	2.0	1.3
Saskatchewan	6.8	8.1	8.3	16.8	24.3	18.8	16.9
Alberta	24.1	24.6	32.0	4.1	4.7	5.5	9.8
British Columbia	61.3	82.6	81.7	6.1	7.3	47.8	51.4
Rest of Canada	8.7	9.7	13.4	0.03	0.03	0.04	2.3
Total Canada	170.6	182.8	184.2	4.7	6.4	10.4	100.0

[a] Proportion of the total Canadian timber volume allocated to First Nations in 2006 (11,685,474 m^3) attributed to the jurisdiction in the left column.
Source: Compiled from data provided by the National Aboriginal Forestry Association (2015).

The purpose of the current paper is to investigate a particular aspect of the role that forestry has in providing income, ecological and environmental benefits (e.g., of a cultural nature), and employment in logging and transportation. Of course, income and employment are important to forest-dependent, aboriginal communities, without which First Nation peoples cannot benefit from the forest ecology. Further, whereas income and employment can easily be measured, ecological and environmental benefits are of a non-market nature. In the current application, we use measures of net carbon uptake as a proxy for such benefits; in essence, we equate the environmental benefits accruing to First Nations with the role their local forest ecosystems play in mitigating climate change. We do this despite the fact that sale of carbon offset credits constitutes an income benefit; as we demonstrate below, these are not identical objectives.

While others have examined the importance of forest-sector employment in First Nations and even considered the role of forests in mitigating climate change (e.g., Krcmar and van Kooten 2008), the current research employs a much more sophisticated and realistic model of carbon fluxes. By taking into account the benefits of selling carbon offset credits in carbon markets, First Nation forest managers can examine directly the tradeoff between employment and income. A secondary question relates to whether employment in the forest sector or net forest rents are adequate enough to support populations in remote, forest-dependent communities.

A forest management model is developed to maximize net discounted returns to commercial timber operations plus the benefits of managing carbon fluxes; carbon in living trees, organic matter and post-harvest carbon pools, plus avoided emissions from substituting wood for non-wood in construction or bioenergy for fossil fuels, are tracked. Constraints ensure that forest management is sustainable, while carbon prices ensure efficient mitigation of climate change. The research finds that forest-dependent, rural communities can benefit greatly in terms of increased net income when the price of carbon offset credits is used to incentivize lower CO_2 emissions and increase sequestration of carbon through forestry activities. Prospects for reducing poverty in forest-dependent, First-Nation communities through better management of forests are less optimistic, partly because of rapid population growth. It is not clear, however, that strategies to protect forests to take advantage of sale of carbon offset credits would yield significant financial benefits that could be used to reduce poverty.

2. METHODS AND MATERIALS

In this section, we adapt a holistic forest management model by van Kooten (2018) that accounts for carbon flows. The objective is to maximize the net present value of commercial forest operations plus the financial benefits from creating carbon offset credits to sell in carbon markets. Alternative objectives are to maximize the sustainable level of employment and the net carbon sequestered. We then determine trade-offs between the financial objective and the employment and environmental objectives, and where a compromise solution might lie. The results are then used to determine the potential for forestry to sustain forest-dependent communities.

The results of the analysis depend to a large degree on assumptions regarding the creation of carbon offset credits. This decision is a political one that depends on what activities can be used to create carbon offsets and what substitutions are permitted and how these are counted – that is, can one claim carbon credits for fossil fuel emissions avoided when wood biomass is used to generate electricity or emissions associated with production of steel and cement when wood substitutes for non-wood materials in construction? It also depends on how urgent the need is to address climate change and the rate used to discount future carbon fluxes (see Johnston and van Kooten 2015; Schlamadinger and Marland, 1999; Richards 1997). The application is to the Quesnel Timber Supply Area in the interior of British Columbia, as the majority of aboriginal harvest occurs in

British Columbia's interior even though this region represents a more productive forest than the boreal forest where many First Nations' forest-dependent communities are found.

2.1 Forest Management Model

The forest management model employed here is described in van Kooten (2018) and is built on an earlier version for a different region by van Kooten et al. (2015). The forest management model consists of a constrained optimization problem formulated as a linear programming model with the following objective:

$$(1)\ \text{NPV} = \sum_{t=1}^{T} \beta^t \left[\left(\sum_{j=1}^{N} p_j \varepsilon_j \right) H_t - K_t - p_C \left(E_t - C_t - S_t \right) \right],$$

where p_c refers to the price of carbon ($/t$CO_2$), p_j to the price of forest product j ($/m^3), ε_j is the proportion of the harvest processed into product j, and $\beta = 1/(1+r)$ is the discount factor, with r the discount rate on monetary values. For simplicity and given fixed product prices and proportions ε_j, it is assumed that the price of logs ($/m^3) is the value of interest in the objective function (1). That is, logs are processed into lumber, with wood chips and other residues used to make pulp, manufacture engineered wood products (e.g., oriented strand board or OSB, and fiber board), and wood pellets for energy; these products are assumed to be produced in fixed proportions. Further, K_t refers to the costs of forest management, silviculture, harvesting, hauling, processing and administration costs – the costs of processing logs into wood products and creating carbon offset credits. Then E_t refers to the emissions released as a result of forestry activities. Finally, C_t and S_t refer, respectively, to the carbon flux and emissions avoided because of the reduced production of cement and steel if wood substitutes for these materials in construction, or if wood biomass substitutes for fossil fuels in the generation of electricity. Carbon flux and substitution (avoided emissions) are measured in metric tons of carbon dioxide (tCO_2).

The measurement of CO_2 fluxes at time t needs further explanation. Suppose a forest site is harvested, the logs hauled to a sawmill, and then processed only into lumber and wood pellets. The emissions related to harvest, hauling and processing are taken into account by the term E_t in equation (1). Changes in the ecosystem carbon are taken into account using the Canadian Forest Service's Carbon Budget Model (Kull et al. 2011), although these are explicitly embodied in the

BC government's growth and yield calculator, TIPSY.[3] These carbon fluxes are included in the C_t term in equation (1). The remaining components of C_t depend on the final disposition of logs.

When trees are harvested, it is assumed that all of the carbon stored in the trees is immediately (at time of harvest *t*) released to the atmosphere. Of course, this is not the case; if timber is processed into lumber, the carbon is stored and only slowly released into the atmosphere. If carbon is released to the atmosphere from a wood product 80 or more years after the time of harvest, it has little if any impact on climate change. Therefore, its contribution to global warming and today's carbon flux is insignificant, and should be weighted much less than if that same amount of carbon was released (in the form of CO_2) one year after harvest. Future carbon flux from production of lumber or another long-lived wood product must be discounted to the common year of harvest, and the rate used to do this depends on the urgency with which society wishes to address climate change. If there is some urgency to address climate change, then current CO_2 emissions are more dangerous than future ones and current carbon uptake is more beneficial than future sequestration. The more urgent the need to address climate change, the higher must be the rate used to discount future physical carbon uptake from and release to the atmosphere.

The weighted current carbon released from and stored in a post-harvest wood product pool at time of harvest *t* is given by (van Kooten 2018):

(2) $C_{t,release} = \left(\frac{d}{r_c + d}\right)\varepsilon C$ and $C_{t,stored} = \left(\frac{r_c}{r_c + d}\right)\varepsilon C$,

where d is the rate at which the wood decays, C is the amount of carbon in harvested timber and ε is the proportion the timber entering the product pool. If d=0 (no decay) then the amount of carbon released from products is also zero and all the carbon is retained regardless of the rate used to weight carbon. If r_c=0, no carbon is stored because it is all released. The same reasoning applies to biomass burning and subsequent uptake through new growth, except this is taken into account within the model by new plantings and subsequent uptake of carbon from the atmosphere. The choice of r_c is clearly a political one as it depends on the urgency with which society wishes to

[3] TIPSY (Table Interpolation Program for Stand Yields) is a growth and yield model developed by the BC Ministry of Forests that provides yield tables for stands under different management regimes using TASS (Tree and Stand Simulator) and economic data using SYLVER (Silviculture on Yield, Lumber Value, and Economic Return) (BC MFLNRO 2016).

address climate change, as opposed to the choice of the discount rate used to discount monetary values (including the value of carbon offset credits), which depends on market outcomes.

The CO_2 emissions avoided when wood pellets substitute for fossil fuels in the generation of electricity, or the emissions avoided in producing steel and concrete when wood substitutes for these materials in construction, might also be counted as savings attributable to the forestry activities. In both cases, however, these emissions reductions might more appropriately be counted in other sectors of the economy. Again, the decision to provide carbon offset credits for emissions avoided, and the degree of substitution, is a political one.

Finally, the model also includes various technical constraints; these relate to the limits on harvest imposed by the available inventories in any period, based on tree species, bio-geoclimatic zones, slope classes and age characteristics; there is a total area constraint; constraints on growth from one period to the next (which are affected by management practices); reforestation options; limits on the minimal merchantable volume that must be stocked before harvest can occur; sustainability constraints (viz., sustainable management certification standards); non-negativity constraints; and other constraints relating to the scenarios that are investigated. The constrained optimization model is constructed in GAMS (General Algebraic Modeling System) and solved using the CPLEX solver (Rosenthal 2008).

2.2 Study Area and Data Description

British Columbia is Canada's most important timber producing province with 95 million ha of forestland (27.3% of Canada's total), a harvest of 66.5 million m^3 (43.4%), and exports of more than $10.8 billion (50.4%) (Natural Resources Canada–Canadian Forest Service 2016). It is no wonder that the majority of the timber made available to aboriginal peoples is located in the province (see Table 1). The Quesnel TSA is located in the Northern Cariboo Forest Region in the Southern Interior of BC and covers some 1.4 million ha, of which 965,700 ha are in the harvest land base, consisting of Lodgepole pine (85%), spruce (10%), Douglas-fir (3%) and a variety of other species (Snetsinger 2011).

To keep the model manageable, we identified 538 sites in the Quesnel TSA, but there was no information about the proportions of major and secondary species. Therefore, the proportions of major and secondary species were randomly derived and the TIPSY model used to simulate growth and yield for 200 years (using a decadal time step) and for two treatments after harvest – stands regenerated with genetically-enhanced stems planted over a two-year period or regenerated with natural growing stock (basic silviculture) within six years of harvest. This resulted in a forest with 6,205 stands covering an area of 20,266.4 ha that was most representative of the Quesnel TSA. As noted earlier, the Canadian Forest Service's Carbon Budget Model was used within TIPSY to track carbon fluxes and stocks in living and dead biomass in the forest ecosystem over time.

In 2014, total timber harvest in the BC interior amounted to 46.92 million m^3; this translated into 18.2 million m^3 of lumber. Sawmill residues constituted 21.3 million m^3, with the remaining 7.4 million m^3 consisting of logs that were chipped directly or made into a variety of engineered wood products. The recovery of lumber varies by size and species of trees, and is taken into account in the growth and yield data from TIPSY. Fixed proportions are assumed for the disposition of residues, however. While some residues (particularly sawdust) are burned at mills for heat and electricity, and/or converted to wood pellets, the majority of residuals are used to make pulp. Based on a 2014 survey of interior BC mills (BC MFLNRO 2015), it is assumed that 15.1% of residues are used to manufacture various wood products, 69.7% is directed to pulp mills, and the remaining 15.2% is used to produce biofuels, mainly wood pellets.

The costs of converting standing trees into lumber, sawmill residues and chips is the sum of the harvesting costs, road and infrastructure costs, transportation costs, manufacturing costs, and costs of post-harvest treatment of the site; these are summarized in Appendix Table A1. Also summarized in Table A1 are the price and cost data used in the study. Lastly, rates of CO_2 emissions and decay rates for various forest carbon pools are provided in Appendix Table A2.

The CO_2 released when producing a megawatt hour (MWh) of electricity varies by fuel type. Natural gas releases 0.55 tCO_2/MWh of power, while coal releases 0.94 tCO_2/MWh. On average, wood biomass with a moisture content of 40% would generate 1.83 MWh of electricity per m^3 (Kofman 2010). Burning wood in lieu of natural gas would save 1.01 tCO_2/m^3, and 1.72 tCO_2/m^3 if bioenergy replaced coal. Wood burning is considered carbon neutral in legislation, so emission reductions from burning wood in lieu of a 50-50 mix of natural gas and coal to generate electricity amount to 1.365 tCO_2/m^3 (van Kooten 2018). Finally, if wood substitutes for non-wood materials in construction, the emissions avoided from not producing steel and concrete could be as high as

3.3 tCO_2/m^3 (Hennigar et al. 2008), although we use an average of 2.75 tCO_2/m^3.

3. RESULTS AND DISCUSSION

Nine scenarios were examined, including a baseline scenario where carbon is unpriced. In each scenario, we found the maximum NPV and associated employment and carbon uptake, the maximum potential employment and associated NPV and carbon uptake, and the maximum carbon uptake and associated NPV and employment. The results are provided in Tables 2 and 3 for carbon prices of \$50/tCO_2 and \$100/tCO_2, respectively. The maximum values of the objectives are in bold in each scenario. This then allowed us to determine the opportunity cost of creating additional direct plus indirect aboriginal jobs in terms of potential net discounted returns that the aboriginal forest owner could make over the 200-year life of the forest.[4] We also found the marginal cost (MC) of our crude environmental benefit in terms of the NPV that would be forgone to ensure the greatest possible carbon uptake. This was measured in terms of \$/tCO_2. These results are provided in Table 4.

It is not unusual for governments to focus on jobs rather than net revenues, and that managing a forest for its net discounted commercial benefits reduces employment. What might the required monetary sacrifice entail? Given the results in Table 2, we find that the sacrifice varies from less than about \$800 per job to as much as \$11,270, where the sacrifice might include the benefits the landowner would have received from sale of carbon offset credits. Assuming an average annual income of \$50,000, the cost of creating extra jobs varies from 1.6 percent to 22.5 percent of earnings; the former is likely acceptable in First Nations' communities, while the latter is harder pill to swallow.

[4] This assumes that 1,000 m^3 of harvest leads to one direct plus indirect job.

Table 2: Trade-offs When Maximizing Net Present Value, Employment and Net Carbon Uptake, Objective Values, Baseline and Various Scenarios where P_{carbon} = \$50/tCO$_2$[a]

Objective that is maximized	Value of Objectives: NPV (\$ mil)	Employment ('000s)	Discounted Carbon (Mt CO_2)
	Baseline: Pcarbon = \$0/tCO₂		
NPV	**159.20**	10.77	2.776
Employment	145.32	**16.52**	3.317
Carbon Uptake	102.86	5.63	**3.891**
	No substitution		
NPV	**176.51**	10.03	3.503
Employment	171.27	**16.52**	3.317
Carbon Uptake	153.53	5.63	**3.891**
	Substitute for fossil fuel burning; count emissions avoided		
NPV	**190.79**	9.99	3.967
Employment	185.09	**16.52**	3.848
Carbon Uptake	179.59	7.36	**4.239**
	Substitute wood for non-wood in construction; count emissions avoided		
NPV	**350.77**	14.01	9.181
Employment	336.62	**16.52**	9.531
Carbon Uptake	343.05	16.36	**9.612**
	Substitute biomass for fossil fuels in electricity & wood for non-wood in construction; count emissions avoided		
NPV	**365.79**	14.18	9.724
Employment	350.45	**16.52**	10.063
Carbon Uptake	357.90	16.35	**10.151**

[a] Numbers in bold indicate the maximum value of the objective. Net carbon uptake would equal the number of carbon offsets created.
Source: Authors' calculations

Surprisingly, the lowest cost of creating jobs occurs when the policymaker permits no carbon credits to be issued for substitution of fossil fuel emissions avoided in other sectors, or when the forester can count emissions avoided from substituting biomass (wood pellets) for fossil fuels in the generation of electricity. This is the case regardless of the fact that more carbon offset credits are created in these two instances when NPV is maximized rather than employment (see Table 3). Yet, when carbon credits are provided for the fossil fuel emissions avoided when wood substitutes for steel and concrete in construction, the costs of creating additional jobs is at its greatest. This is surprising even though net discounted emissions of carbon – carbon offset credits created – are lower when NPV is maximized than when employment is maximized. Indeed, the cost of additional jobs then accounts for about one-fifth of total earnings.

Table 3: Trade-offs When Maximizing Net Present Value, Employment and Net Carbon Uptake, Objective Values, P_{carbon} = \$100/tCO_2, Various Scenarios[a]

Objective that is maximized	Value of Objectives: NPV (\$ mil)	Employment ('000s)	Discounted Carbon (Mt CO_2)
	No substitution		
NPV	**210.05**	8.39	3.791
Employment	197.22	**16.52**	3.317
Carbon Uptake	204.21	5.63	**3.891**
	Substitute for fossil fuel burning; count emissions avoided		
NPV	**233.87**	9.73	4.141
Employment	224.86	**16.52**	3.848
Carbon Uptake	231.15	7.36	**4.239**
	Substitute wood for non-wood in construction; count emissions avoided		
NPV	**545.88**	14.82	9.353
Employment	527.92	**16.52**	9.531
Carbon Uptake	539.25	16.36	**9.612**
	Substitute biomass for fossil fuels in electricity & wood for non-wood in construction; count emissions avoided		
NPV	**575.29**	14.77	9.887
Employment	555.57	**16.52**	10.063
Carbon Uptake	568.02	16.35	**10.151**

[a] Numbers in bold indicate the maximum value of the objective. Net carbon uptake would equal the number of carbon offsets created.
Source: Authors' calculations

When the objective is to maximize employment, which turns out to be the same as maximizing timber harvests, commercial harvests increase by between 12 percent (under a high price of carbon and when carbon offset credits include fossil fuel emissions avoided when wood biomass is burned for electricity and when less concrete and steel is used when wood substitutes for non-wood in construction) and 96 percent (high price of carbon but no carbon offsets permitted from substitution). While greater utilization of the forest is inevitably linked to forest degradation, this does not appear to be the case here, at least if ecosystem carbon is any indication (see Table 5). Greater utilization not only leads to more jobs, but it also appears to lead to more ecosystem carbon – more vegetation and soil carbon, but at an increased cost in net discounted revenues.

Table 4: Trade-offs between Net Present Value Objective and (i) Employment and (ii) Environmental Objectives, Opportunity Cost of Job Creation and Carbon Sequestration, Various Scenarios

Scenario	Cost of job ($'000s)	MC carbon ($/t$CO_2$)	Cost of job ($'000s)	MC carbon ($/t$CO_2$)
Baseline	2.41	50.53		
	P_{carbon} = $50/t$CO_2$		**P_{carbon} = $100/t$CO_2$**	
- No substitution	0.81	59.23	1.58	58.40
- Substitute for fossil fuel burning; count emissions avoided	0.87	41.18	1.33	27.76
- Substitute wood for non-wood in construction; count emissions avoided	5.64	17.91	10.56	25.60
- Substitute biomass for fossil fuels in electricity & wood for non-wood in construction; count emissions avoided	6.56	18.48	11.27	27.54

Source: Authors' calculations

Not surprisingly, when CO_2 emissions avoided in other sectors cannot be attributed to forestry activities, or when credit is given only in the case where biomass is used to generate electricity, the carbon stored in the product pool is lower under the NPV scenarios than otherwise. When avoided emissions from reduced production of steel and concrete are taken into account, there will be greater substitution of wood for non-wood materials in construction, thereby leading to more carbon stored in products under the NPV scenario (Table 5).

4. CONCLUDING DISCUSSION

In this paper, we examined the potential for forest resources to be a driver of economic development in forest-dependent, aboriginal communities in Canada. In doing so, we investigated the role that carbon accounting could play in improving the prospects for development, either through greater forest-based activities that create jobs or via the additional wealth that is created from the creation of carbon offset credits. Indeed, the creation of carbon offsets often leads to greater storage of carbon in the forest ecosystem, thereby enhancing non-market environmental and cultural values.

Table 5: Carbon Savings due to Forestry Activities, Net Total, Ecosystem and Stored in Products at Carbon Prices of $50/t$CO_2$ and $100/t$CO_2$, Mt CO_2[a]

	Net Total			Ecosystem			Stored in Products		
Scenario / Objective →	NPV	Employ	Carbon	NPV	Employ	Carbon	NPV	Employ	Carbon
Baseline	2.776	3.317	3.891	5.627	6.284	5.751	1.238	1.308	0.831
P_{carbon} = $50/t$CO_2$									
No substitution	3.503	3.317	3.891	6.257	6.284	5.751	1.212	1.308	0.831
Substitute for fossil fuel burning	3.967	3.848	4.239	6.229	6.284	6.087	1.215	1.308	0.993
Substitute wood for non-wood in construction	9.181	9.531	9.612	6.013	6.284	6.308	1.332	1.308	1.327
Substitute both	9.724	10.063	10.151	5.994	6.284	6.307	1.335	1.308	1.331
P_{carbon} = $100/t$CO_2$									
No substitution	3.791	3.317	3.891	6.079	6.284	5.751	1.020	1.308	0.831
Substitute for fossil fuel burning	4.141	3.848	4.239	6.261	6.284	6.087	1.140	1.308	0.993
Substitute wood for non-wood in construction	9.353	9.531	9.612	6.112	6.284	6.308	1.343	1.308	1.327
Substitute both	9.887	10.063	10.151	6.093	6.284	6.307	1.344	1.308	1.331

[a] The values in the table are discounted carbon flows.

Source: Author calculations

The results of our analysis indicate that carbon in ecosystems is greatest when the aboriginal landowner maximizes net carbon sequestration and, at the same time, policymakers incentivize the landowner to take into account the CO_2 emissions saved when wood substitutes for non-wood in construction. Otherwise, ecosystem carbon is maximized when the decision maker maximizes employment. This is surprising because employment and protection of the environment are often seen as contradictory objectives; but, in this case, they are not.

In our model, we imposed a sustainable harvest constraint by requiring an even flow management. We do this by requiring harvest in each decade to be within plus or minus 10% of the harvest in the first decade, where the harvest in the first decade (and subsequent ones) is endogenously determined. In that sense, it represents sustainable forestry. When the even-flow constraint is not imposed, harvests vary greatly from one decade to the next, which is what is expected when one begins with an uneven-age forest. If you impose a sustainable harvest constraint, the model harvests nearly the same each period, regardless of the objective you choose. Compared to the case of even-flow management, the objective values for NPV, employment and net carbon removed from the atmosphere are all higher when there is no sustainability constraint. The even-flow results are provided in Appendix Tables A3 through A6.

With even-flow management, the employment is much lower at 13,800 jobs per year than if harvests are allowed to vary over time, so that investment in new forests can occur; in that case, 16,200 jobs are provided each year on average. Of course, this does not account for potential changes in technology that reduce the number of workers supported by 1,000 m^3 of harvest from one (as assumed here) to a smaller number.

Regardless of what strategy is adopted, forestry is unable to be an engine of economic growth for remote communities. At best \$206.6 million of NPV can be created, but, when spread over a very long time horizon, it amounts to \$8 million to no more than \$20 million annually (depending on the discount rate employed) and then under the condition that the decision maker (aboriginal owner) manages timber to maximize NPV. If the aboriginal owners is concerned about community sustainability, in which case an even-flow directive is generally followed, the maximum NPV that sale of carbon credits would realize is \$187.1 million, or \$7.5 to 18.7 million annually. While these sums are not insignificant, they come about only from sale of carbon offset credits that might be considered double-counted.

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APPENDIX TABLES

Table A1: Price, Cost, Harvest and Other Parameters, Quesnel TSA

General parameters		**Transportation**	
Monetary discount rate (%)	2.5%	Fixed costs (\$/ha)	295.0
Carbon discount rate (%)	0, 1.5, 15	Hauling (\$/m^3 per cycle hour)	6.67
Price lumber (\$/m^3)	160.0	Hauling distance (km)	150
Price engineered products (\$/m^3)	200.0	Speed of trucks (km/hour)	50
Price chips (\$/m^3)	145.0	**Silviculture regeneration (\$/ha)**	
Price of fuel (\$/m^3)	155.0	Basic (SBPS, MS)	1000, 1200
		Enhanced (SBPS, MS)	1500, 1800
Logging costs (\$/m^3)		**Manufacturing costs (\$/m^3)**[b]	
Non-variable:	22.20	Sawmilling per harvested log	72.00
Variable: $2.04 – 0.005V$ if $V < 251$ m^3; $0.79 – 0.001V$ if $V \geq 251$ m^3		Engineered products (over-and-above sawmilling costs)	50.00

[a] Source: van Kooten (2018)

Table A2: Rates of CO_2 emissions and decay rates for various forest carbon pools

Carbon emissions	Value	Item	Value
Activity (tCO_2/m^3)		**Decay rate of:**	
Harvesting (tCO_2/m^3)	0.01173	Dead organic matter	0.0718
Trucking (tCO_2/m^3)	0.000078	Softwood lumber	0.0082
Production of:		Engineered wood products	0.0080
Sawlogs (tCO_2/m^3)	0.0293	Chips and pulp wood	0.0234
Engineered wood (tCO_2/m^3)	0.0660	Fuel	1.0
Pulp wood (tCO_2/m^3)	0.1000	Biofuel	0.7

Source: van Kooten (2018)

Table A.3: Trade-offs When Maximizing Net Present Value, Employment and Net Carbon Uptake, Objective Values, Baseline and Various Scenarios under Even Flow Management, P_{carbon} = $50/t$CO_2$[a,b]

	Value of Objectives		
Objective that is maximized	NPV ($ mil)	Employment ('000s)	Discounted Carbon (Mt CO_2)
	Baseline: Pcarbon = $0/t$CO_2$		
NPV	**116.05**	12.77	2.83
Employment	107.47	**13.88**	3.03
Carbon Uptake	77.77	8.64	**3.66**
	No substitution		
NPV	**158.33**	12.66	3.16
Employment	154.30	**13.88**	3.03
Carbon Uptake	137.76	8.64	**3.66**
	Substitute for fossil fuel burning; count emissions avoided		
NPV	**168.77**	12.67	3.59
Employment	164.22	**13.88**	3.52
Carbon Uptake	153.11	9.76	**3.99**
	Substitute wood for non-wood in construction; count emissions avoided		
NPV	**292.53**	12.9	8.65
Employment	280.88	**13.88**	8.78
Carbon Uptake	285.78	13.17	**8.97**
	Substitute biomass for fossil fuels in electricity & wood for non-wood in construction; count emissions avoided		
NPV	**303.11**	12.9	9.13
Employment	290.80	**13.88**	9.26
Carbon Uptake	296.35	13.26	**9.43**

[a] Numbers in bold indicate the maximum value of the objective. Net carbon uptake would equal the number of carbon offsets created.
[b] Even flow forest management is defined as: Harvests in each decade must be within ± 10% of the harvest in the first decade, where the harvest in the first decade (and subsequent ones) is endogenously determined.
Source: Authors' calculations

Table A.4: Trade-offs When Maximizing Net Present Value, Employment and Net Carbon Uptake, Objective Values, P_{carbon} = \$100/tCO_2, Various Scenarios under Even Flow Management[a]

Objective that is maximized	Value of Objectives		
	NPV ($ mil)	Employment ('000s)	Discounted Carbon (Mt CO_2)
	No substitution		
NPV	**206.48**	11.38	3.51
Employment	201.14	**13.88**	3.03
Carbon Uptake	197.74	8.64	**3.66**
	Substitute for fossil fuel burning; count emissions avoided		
NPV	**225.44**	11.95	3.86
Employment	220.97	**13.88**	3.52
Carbon Uptake	217.88	9.76	**3.99**
	Substitute wood for non-wood in construction; count emissions avoided		
NPV	**470.35**	13.07	8.74
Employment	454.30	**13.88**	8.78
Carbon Uptake	462.88	13.17	**8.97**
	Substitute biomass for fossil fuels in electricity & wood for non-wood in construction; count emissions avoided		
NPV	**491.39**	13.08	9.20
Employment	474.13	**13.88**	9.26
Carbon Uptake	483.46	13.26	**9.43**

[a] See notes on Table A3.
Source: Authors' calculations

Table A.5: Trade-offs between Net Present Value Objective and (i) Employment and (ii) Environmental Objectives, Opportunity Cost of Job Creation and Carbon Sequestration, Various Scenarios under Even-Flow Management

Scenario	Cost of job ($'000s)	MC carbon ($/$tCO_2$)	Cost of job ($'000s)	MC carbon ($/$tCO_2$)
Baseline	7.73	46.16		
	P_{carbon} = $50/$tCO_2$		**P_{carbon} = $100/$tCO_2$**	
- No substitution	3.30	41.51	2.14	60.06
- Substitute for fossil fuel burning; count emissions avoided	3.77	39.55	2.32	59.93
- Substitute wood for non-wood in construction; count emissions avoided	11.88	21.59	19.82	33.50
- Substitute biomass for fossil fuels in electricity & wood for non-wood in construction; count emissions avoided	12.56	22.41	21.58	34.64

Source: Authors' calculations

Table A.6: Carbon Savings due to Forestry Activities, Net Total, Ecosystem and Stored in Products under Even-Flow Management, Carbon Prices of \$50/tCO_2 and \$100/tCO_2 (Mt CO_2)[a]

	Net Total			Ecosystem			Stored in Products		
Scenario / Objective →	NPV	Employ	Carbon	NPV	Employ	Carbon	NPV	Employ	Carbon
Baseline	2.826	3.032	3.656	5.558	5.757	5.511	1.199	1.204	0.833
	P_{carbon} = \$50/tCO_2								
No substitution	3.160	3.032	3.656	5.847	5.757	5.511	1.188	1.204	0.833
Substitute for fossil fuel burning	3.591	3.516	3.987	5.810	5.757	5.730	1.192	1.204	0.938
Substitute wood for non-wood in construction	8.653	8.775	8.965	5.674	5.757	5.933	1.205	1.204	1.180
Substitute both	9.129	9.260	9.430	5.661	5.757	5.924	1.205	1.204	1.186
	P_{carbon} = \$100/tCO_2								
No substitution	3.510	3.032	3.656	5.925	5.757	5.511	1.078	1.204	0.833
Substitute for fossil fuel burning	3.861	3.516	3.987	5.961	5.757	5.730	1.129	1.204	0.938
Substitute wood for non-wood in construction	8.742	8.775	8.965	5.737	5.757	5.933	1.207	1.204	1.180
Substitute both	9.201	9.260	9.430	5.711	5.757	5.924	1.208	1.204	1.186

[a] The values in the table are discounted carbon flows.

Source: Author calculations