An economic analysis of afforestation as a carbon sequestration strategy in southwestern Ontario, Canada

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Abstract

Afforestation, the establishment of trees in areas that have not been forested for at least 50 years, is one possible approach for carbon (C) sequestration to mitigate climate change. This study compares the costs and benefits of afforestation as a carbon sequestration strategy for Eden Mills, a village within Wellington County, Ontario, Canada aiming to achieve C neutrality. We provide net present value analyses for three potential planting schemes under subsidized and unsubsidized financial scenarios that aim to sequester 2012 tonnes of atmospheric carbon dioxide (CO₂) using traditional and novel calculations of C sequestration rates. We present the total project costs, the optimal price of C, and the potential for afforestation as a C sequestration tool in southern Ontario. Planting schemes employ mixtures of tree species common to the region. Unsubsidized schemes are projected to cost between \$617,976-\$1,499,904 (CAD) with the optimal price of CO₂ between \$6.15-\$14.91 per tonne of C sequestered. A deciduous-dominated planting scheme requiring 24 hectares of land resulted in the lowest cost for all scenarios. Our analyses suggest that: 1) fast-growing tree species make afforestation projects more cost-effective, reducing costs by 29-59%; and 2) land management subsidies available to the region reduce costs by approximately 10%. Future cost-benefit analyses for afforestation projects should consider site-specific C sequestration rates and parameter sensitivity analysis when quantifying C absorption.

Keywords: greenhouse gases; carbon sequestration; afforestation; cost-benefit analysis; net present value

Introduction

Forests are recognized as carbon sinks that offset greenhouse gas emissions (van Kooten et al., 1999). Afforestation, or the establishment of trees on land that has not been forested for at least 50 years, provides a means for atmospheric carbon (C) sequestration in biomass and soils (Newell & Stavins, 2000; Bird & Boysen, 2007). Atmospheric C capture starts with photophosphorylation, or the production of energy units from sunlight, in plant chloroplast cells. The products of photophosphorylation are used to fuel a metabolic cycle where atmospheric carbon dioxide (CO₂) is reduced to organic compounds. These organic compounds are partitioned into biomass and root production (Jansson et al., 2010). Globally, this assimilation of carbon from atmospheric CO₂ stores approximately 3.17×10^{15} kg of organic carbon in plant biomass in terrestrial systems (Jansson et al., 2010). The earth's forests hold more than half of terrestrial carbon and

represent approximately 80% of carbon exchange between terrestrial ecosystems and the atmosphere (Montagnini & Nair, 2004). Afforestation not only stores a substantial amount of carbon, but further provides numerous ecological services: purification of air and water; protection from erosion, flooding and wind; wildlife habitat; and microclimate regulation (Puttock, 2001; Kimmins, 2004). Agriculturally marginal lands in particular are often used for afforestation projects, where soil fertility is adequate for growth of tree species, and is often improved through rotations (Ohta, 1990).

Afforestation has been implemented in Ontario by various agencies and research groups, including the Ontario Ministry of Natural Resources, Canadian Forest Service, and the University of Guelph's Department of Food, Agriculture and Resource Economics. Currently, the 50 Million Tree Program, led by the Ontario Ministry of Natural Resources and Trees Ontario, is an afforestation plan with the goal of increasing carbon sequestration by planting 50 million trees in Ontario by 2025 (Parker et al., 2009). Federal divisions

such as the Canadian Forest Service have developed integrated models that encapsulate growth rate, wood yield, and economic return to aid in determining species selection for afforestation projects (Yemshanov et al., 2007). Cost-benefit analyses have focused on the feasibility of afforestation as a cost-effective carbon sequestration tool (McKenney et al., 2006; Yemshanov & McKenzie, 2008; Ramlal et al., 2009). Bird and Boysen (2007) estimated that if associated costs were subsidized, approximately 300,000 hectares of private land in Ontario would be available for afforestation, with a majority being located in southern Ontario. Landowners could profit from afforestation if potential carbon markets emerge (Gleeson et al., 2009).

Community grassroots initiatives to mitigate climate change have gained international popularity (Ashton Hayes, UK and Dawson Creek, CA) and have been heralded in their efforts to achieve carbon neutral status (Ashton Hayes, 2011; Sustainable Dawson Creek, 2011). In 2007, the village of Eden Mills, Wellington County, Ontario committed to achieving carbon neutrality. This involves reducing carbon emissions and sequestering an amount of carbon equal to that which the village collectively emits. Previous studies have calculated the carbon footprint of the community, which is the net balance of carbon emissions per person on an annual basis (Chen et al., 2008). Results demonstrate that the village produced 4,621 tonnes of CO₂ in 2007, 2,608 tonnes of which were absorbed by forests within the community (Sword & Hendry, 2011). To reach carbon neutrality, an additional 12 tonnes of atmospheric CO₂ must therefore be sequestered. Afforestation is one plausible method of carbon sequestration for Eden Mills with substantial promise to achieve carbon neutrality. The objective of this study was to produce a cost-benefit analysis for the afforestation of idle land in Wellington County as part of a carbon offset scheme for Eden Mills. In this report we: 1) evaluate suitable lands in Wellington County; 2) select appropriate tree species and present their carbon sequestration rates; 3) present project costs (seedlings, land preparation, planting, maintenance, land rental, and other associated costs); and 4) conduct a net present value (NPV) analysis for the proposed land use.

Methods

Study region

Wellington County, situated in southern Ontario (43° 40' 43.67" N, 80° 25' 57.04" W), is composed of mixed deciduous-evergreen wood plains and tolerant hardwood forests, including patches of Carolinian forest. The majority of the land area is occupied by farmland (Hoffman et al., 1963). Northern and southern portions of Wellington County contain till plains, broad oval hills with gradual slopes and drumlin-like characteristics. The till is calcareous in the

southern region of the county, derived mainly from dolomitic stone (Hoffman et al., 1963). Wellington County contains 39 soil series, the most dominant of which are Perth loam, Huron loam, Guelph loam, Harriston loam, and Dumfries loam. Approximately 58% of the soils in Wellington County are considered to have good drainage; 30% are considered to have imperfect drainage; and 13% of the soils have poor to very poor drainage properties. In general, these soils provide adequate depth for plant rooting and sufficient water storage for the implementation of afforestation. Geographical Information Systems (GIS) data was used to determine the total area of suitable land for afforestation within Wellington County. We required that prospective sites be both agriculturally marginal (CLI Agriculture Class 4 or higher) and idle for at least the past five years, avoiding the removal of agriculturally viable lands.

Dominant tree species found in Wellington County include *Acer rubrum* (Red Maple), *Acer saccharum* (Sugar Maple), *Juglans nigra* (Black Walnut), *Juniperus virginiana* (Eastern Red Cedar), *Picea glauca* (White Spruce), *Quercus alba* (White Oak), *Pinus resinosa* (Red Pine), and *Pinus strobus* (White Pine) (Taylor & Jones, 1985). *Picea abies* (Norway Spruce) has become naturalized within North America, and is another common tree species (Taylor & Jones, 1985).

Planting scenarios

Species selection was limited to those permitted within the seed zone of Wellington County (OMNR, 2011). Wellington County is located directly on the boundary delineating Zones 34 and 32¹. Additional considerations for species selection included soil texture and drainage, growth and performance, and survivorship. A previous study by Thevathasan et al.² provided information on sequestration rates for the three most abundant tree species in Wellington County: Sugar Maple, Norway Spruce and White Pine. These species were cross-referenced with Taylor and Jones (1985) to verify their suitability for the general soil characteristics present within the prospective sites.

Three different species planting scenarios are proposed for potential afforestation projects, as shown in **Table 1**: deciduous-dominant, coniferous-dominant, and mixed (deciduous and coniferous). For each scenario, 85% of the planting area was composed of either deciduous or coniferous species or both, with 15% composed of the remaining species. The remaining 15% should ideally be a mix of species that ensures an appropriate level of biological diversity according to Ontario legislation³. Major variables used in all planting scenarios have been explained in detail in the following sections (stocking density, timber production and price, and cost of rental land).

Table 1. Three afforestation schemes proposed for carbon sequestration in Southern Ontario. Proposed schemes include: deciduous-dominant, coniferous-dominant, and mixed.

Tree Species	Percent composition of species for planting scheme		
	Deciduous-dominant	Coniferous-dominant	Mixed
Sugar Maple	85	15	42.5
Norway Spruce	7.5	42.5	42.5
White Pine	7.5	42.5	15

Carbon sequestration

Species sequestration rates depend on biotic and abiotic factors that are extremely variable through space and time. Primary abiotic influences include seasonal precipitation, soil texture, nutrient content, date of snowmelt, maximum and minimum temperatures, and amount of incoming short wave radiation received. Primary biotic influences include stand density, mycorrhizae, insect abundance, tree diseases and pathogens, and so forth. (Horsley et al., 2002). These factors can affect tree growth of individuals separated by only a few meters (Rainus et al., 2008). For the purpose of this analysis, it is assumed that sequestration rates are constant, that abiotic and biotic influences remain homogenous, and that climatic changes are negligible within Wellington County.

Tree species' carbon sequestration rates are traditionally determined through use of allometric equations that approximate total carbon from estimates of living biomass. Living biomass is predicted from measurements of stem size for a given tree age, using a temperate species biomass equation such as $M = aD^b$, where a and b represent site specific growth parameters (Ter-Mikaelian & Korsukhin, 1997). Root biomass is assumed to represent 20% of the total above ground biomass. Total plant carbon is assumed to equal 50% of the total living biomass, which is the average proportion of carbon in dry plant biomass (Parker et al., 2009). Plant carbon is then multiplied by 3.67 to estimate total atmospheric CO₂ sequestration (Bird & Boysen, 2007; Parker et al. 2009). When this approach is applied to the average value of parameters in established biomass quantification studies for temperate tree species, sequestration rates are: 35.17 (± 5.75) t C ha⁻¹ per year for Sugar Maple; 15.080 (± 2.72) t C ha⁻¹ per year for White Pine, and 30.121 (± 3.47) t C ha⁻¹ per year for Norway Spruce, assuming a 30-40 year-old stand (Alemdag, 1983; Alemdag, 1984; Ter-Mikaelian & Korsukhin, 1997; Perala & Alban, 1994; Jokela et al., 1986). These traditional models provide adequate estimates of carbon sequestration rates using assumptions about proportion of carbon in living biomass; however, they lack the site-specific information necessary to elucidate accurate local sequestration rates.

Because the proportion of carbon in living biomass is variable between species and localities, we used in-situ measurements of plant carbon to quantify carbon sequestration rates of *A.saccharum*, *P. abies*, and *P. strobus* from sites in Eden Mills (Goodale et al., 2002). Total plant

carbon for each species was determined from destructive measurements on three year old seedlings which yielded the following carbon percentages: 44% for Sugar Maple, 50.5% for Norway Spruce, and 42.4% for White Pine. The proportion of carbon in living biomass was applied to the biomass equation, $M = aD^b$ to infer total carbon in biomass of 30-year-old trees (the common age in Eden Mills). Since a significant amount of carbon is stored in leaves, litterfall measurements were made for each species, and the amount of carbon was calculated by multiplying the proportion of carbon in leaves and needles of three year-old seedlings to the weight of litterfall in 30-year-old trees. Soil organic carbon, another contributor to carbon sequestration, was measured using a LECO CR12 Carbon Analyser. Carbon lost through soil respiration was measured and subtracted from total carbon sequestered in biomass and soil. Local sequestration rates for each species were calculated as: 96 t C ha⁻¹ per year for Sugar Maple; 22 t C ha⁻¹ per year for White Pine; and 25 t C ha⁻¹ per year for Norway Spruce.

Subsidies

There are three subsidised planting programs that this project qualifies for: Wellington County's Green Legacy Program, Trees Ontario's 50 Million Tree Program, and The Grand River Conservation Authority's Tree Planting Program. The Green Legacy Program, coordinated by the County of Wellington, is an option for landowners and community groups seeking financial compensation and volunteer support for local afforestation projects. This program supplies native trees to qualifying landowners free of charge, and provides a group of local volunteers to aid in the planting process. Since 2008, Eden Mills has received over 6,000 seedlings as well as potted stock through the Green Legacy Program. Trees Ontario, a non-profit organization, collaborates with local planting agencies in Ontario to help subsidize and implement afforestation projects. The goal of this program is to plant 50 million trees in Ontario by 2025; large-scale afforestation projects are the target of this program (Parker et al., 2009). The Grand River Conservation Authority has been leading a community tree planting initiative for over 50 years to increase tree cover within the watershed. Landowners wishing to plant trees on plots of land greater than one hectare are eligible for the following services: site visits to help plan the afforestation project; assistance selecting species based on site

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characteristics; sales of saplings and seedlings, incrementally priced by the number ordered (from appropriate seed zones that are within the Grand River Watershed); and volunteers to plant the trees.

Net present value model

Net present value (NPV) analysis was used to evaluate the economic viability of this project. Cost-benefit analyses have been performed to determine the potential viability of other afforestation projects (as cited by Torres et al., 2010). Net present value was estimated using the difference in total discounted benefits and costs over the duration of the project. For the purpose of this study, it is assumed that population growth throughout the duration of the sequestration scheme is negligible, and that the amount of carbon to be sequestered does not change.

The goal of this NPV analysis was to estimate the project cost and the optimal price of carbon, per unit of carbon (assuming a constant unit price), to achieve carbon neutrality for the community of Eden Mills. The NPV equation was set to zero, as the purpose of the afforestation project was not to generate income but to sequester carbon as efficiently and economically as possible. Two situations were examined through the NPV analysis: 1) a project using full costs for all variables; and, 2) an approach that included available subsidies for the region (no costs for trees). We also examined the cost to sequester 50 and 75% of Eden Mills' emissions, in order to characterize what sequestration might be accomplished under budgetary constraints. We developed the equation (Equation 1):

$$NPV = \sum_{t=1}^T \frac{A1 \times (C1 + C2 + C3 + C4 + C5 + (P1 \times S1) + (P2 \times A2))}{(1+r)^t}$$

where NPV = net present value of project; T = duration of the project (50 years); t = time in years (year 0-50); C1 = cost of land rent in \$ per ha (year 0-50); C2 = cost of land preparation in \$ per ha (year 0); C3 = cost of plants in \$ per ha (year 0); C4 = cost of planting in \$ per ha (year 0); C5 = cost of maintenance in \$ per ha (cleaning, thinning, etc.) (year 0-50); P1 = price of carbon dioxide in \$ tonne⁻¹ for residents of Eden Mills (year 0-50); P2 = price of lumber in \$ m⁻³ (year 50); A1 = area in ha (year 0-50); A2 = amount of lumber produced in m³ per ha (year 50); S1 = average carbon sequestered in tonnes per ha (0-50); and r = discount rate.

Data and assumptions for NPV

Values for agricultural land in Canada vary significantly, and depend mostly on climate, population, local economy and competing land uses (McKenney et al., 2006). Statistics Canada (2009) estimated the average cost of farmland within Wellington County to be \$11,779.26 per ha. These initial costs may be too high to attract investment, so a

land renting approach was applied for the NPV analysis. Equation 2 is the opportunity-based formula used to estimate land rental price:

$$R = P \times r$$

where R is the annual return to ownership, P is the land price, and r is the real rate of time preference. Data from Statistics Canada (2011) estimate that the average cost of marginal land within Wellington County is \$12,505.73 per ha. Information leading to the price of different land types was not available for this study. The real rate of time preference was assumed to be 5% (Kula, 1984). Land preparation and establishment costs (C2) for afforestation projects in southern Ontario are expected to cost approximately \$600 per ha, where most projects cost \$1,500 per ha (McKenney et al., 2006; Yemshanov et al., 2007). Seedling costs (C3) for a project in Eden Mills would cost \$1.50 per deciduous seedling and \$0.75 per coniferous seedling (Green Legacy, 2011). Planting costs (C4) in Southern Ontario without subsidies are typically \$470 per ha (Yemshanov et al., 2005). The price of carbon dioxide per tonne sequestered (P1) is the total project cost divided by the desired amount of carbon dioxide to be sequestered for the duration of the project (age). In our NPV analysis, we valued P1 as total project costs divided by 2012 (tonnes sequestered to reach neutrality), divided by 50 (total years of project). The price of lumber (P2) represents the average sale price of merchantable lumber (\$ m⁻³). The total hectares of the project (A1) and amount of merchantable timber produced in the project at year 50 (A2) are specific to growing conditions and sequestration aims.

The majority of prospective sites for this project are relatively productive for forestry, despite being classified as agriculturally marginal. CLI Forestry data includes estimates of productivity for each class, and since most of the prospective sites were situated on CLI Forestry Class 1-3 lands, an average of 7.0332 m³ per year was calculated from the projected productivity range (4.97-9.10 m³ per year) (Environment Canada, 1972). A 50-year rotation period was assumed, implying a 50-year land rental. The cost of land preparation, trees, and planting were accounted for in year zero. Seedling costs were obtained from several nurseries local to Eden Mills. Assuming adequate species selection, site preparation and maintenance, replanting should not be required⁴. The cost of renting land and the value of carbon were discounted for every year of the project as they were constant costs and benefits. The value of timber and the 4% discount rate followed McKenney et al. (2006), and was only considered in the final year of the project. We used subsidies outlined by Wellington County's Green Legacy Program, Trees Ontario's 50 Million Tree Program, and The Grand River Conservation Authority's Tree Planting Program.

Table 2 summarizes the estimated cost involved in each afforestation scenario, with and without subsidies.

Table 2. Economic assumptions for afforestation scenarios within Wellington County, Ontario. Parentheses indicate data sources.

Parameter	Unsubsidized scenario		Subsidized scenario
Annual discount rate	0.04		
	(McKenney et al., 2006)		
Rotation age	50 years		
Price of carbon	Break-even		
Timber production	7.0322 m ³ ha ⁻¹ year ⁻¹		
	(Environment Canada, 1972)		
Timber price	\$20 m ⁻³ for hardwood; \$18 m ⁻³ for softwood		
	(McKenney et al., 2006)		
Stocking density	2000 stems ha ⁻¹		
	(Personal Communication, N. Thevathasan)		
Cost of land rental	\$12,505.73 ha ⁻¹		
	(Statistics Canada, 2009)		
Cost of seedlings	\$1.50 per deciduous seedling \$0.75 per coniferous seedling		\$0
	(Green Legacy, 2011)		
Establishment costs	\$1,500 ha ⁻¹		
	(McKenney et al., 2006)		

Results

Total land area meeting the aforementioned criteria within Wellington County is 4590 ha (MNR, 2001). **Figure 1** depicts CLI-Agriculture information overlaid with the prospective sites. **Figure 2** depicts CLI-Forestry information overlaid with the prospective sites. **Table 3** summarizes the area of land required for Eden Mills to reach neutrality based on the three afforestation schemes.

The costs of alternative planting schemes, sequestering 100%, 75% and 50% of Eden Mills' remaining carbon, are demonstrated without and with subsidization in **Table 4**. For each scheme, the amount of trees and land area required are given, as well as the price of carbon per tonne for residents of Eden Mills, which results in a net present value of zero. Unsubsidized planting schemes are projected to cost between \$617,976.89 and \$1,499,904.45, while subsidized schemes are projected to cost between \$549,434.13 and \$1,361,365.36 (**Figure 3A; Table 4**). Optimal carbon prices range from \$6.15 and \$14.91 per tonne for unsubsidized schemes, and

from \$5.46 and \$13.53 per tonne for subsidized schemes (**Figure 3B; Table 4**). Total land required for planting schemes to sequester the 2012 tonnes of CO₂ required for Eden Mills to reach carbon neutrality is between 23 and 82 hectares (**Figure 4**). When traditional calculations of CO₂ sequestration rates are employed, unsubsidized planting schemes cost between \$564,099 and \$918,402, where optimal price of carbon ranges from \$3.43 to \$9.52 (**Figure 3A, B; Table 4**). The cost of the project can be substantially reduced depending on the planting scheme used and whether or not subsidies are available, with an unsubsidized coniferous planting scheme being the most costly, and a subsidized deciduous planting scheme the least costly. Without subsidies, a change from a coniferous or mixed planting scheme to a deciduous planting scheme represents a 59% and 35% reduction in costs, respectively. Subsidies reduce the cost of all three planting schemes by 9-11%. A change between the most expensive and least expensive scheme represents a cost reduction of 63.4%.

Figure 1. Map of CLI-Agriculture for Wellington County. Prospective sites have been overlaid, depicting areas where land is both agriculturally marginal and has been idle for 5+ years. In general, Wellington County soils are agriculturally productive, so prospective sites are correspondingly few.

Figure 2. Map of CLI-Forestry for Wellington County. Prospective sites have been overlaid, depicting areas where land is both agriculturally marginal and has been idle for 5+ years.

Figure 3. Total project costs (A) and price per tonne of CO₂ sequestered (B) for deciduous, coniferous, and mixed dominated afforestation schemes. Costs are represented for subsidized and unsubsidized projects; as well as for projects where costs are calculated using traditional sequestration values.

Figure 4. Land required (ha) for unsubsidized and traditionally calculated afforestation projects to sequester 2012 tonnes of carbon to achieve carbon neutrality.

Table 3. Calculation of area required for Eden Mills to achieve carbon neutrality using the three proposed afforestation schemes.

Afforestation scheme	Sequestration rate (tonnes CO ₂ ha ⁻¹ yr ⁻¹)	C to sequester (tonnes)	Total area required (ha)
Deciduous dominant	84.77	2012	23.73
Coniferous dominant	34.3	2012	58.67
Mixed forest	54.54	2012	36.89

Discussion

Site selection

CLI Agriculture rankings are different from CLI Forestry; the use of marginal and idle agricultural lands does not necessarily mean the expected timber yields will be reduced. CLI Agriculture rankings present a relative scale for estimating food crop productivity. CLI Forestry is a better indicator of the extent of succession already occurring on idle lands, and depends on the presence of seeds, litterfall,

organic carbon and nutrient additions from previous land use (Clark & Tilman, 2010). The time elapsed and extent of succession will influence the difficulty of planting on a given plot of land. Ideal land is that having been idle for the smallest amount of time and surrounded by other farm lands or idle lands⁵. Although our study used three species that would be appropriate for the proposed afforestation schemes, future afforestation projects would consider species suitability for given site characteristics, and especially implement naturally occurring combinations of species.

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Table 4. Costs for unsubsidized, subsidized, and traditional afforestation projects in Eden Mills for deciduous, coniferous or mixed dominated planting schemes. Costs, area and trees required for projects represent projects aiming to sequester 50%, 75%, or 100% of Eden Mill's excess carbon dioxide (2012 tonnes).

Scheme	% C sequestered	Trees required	Land required (ha)	Unsubsidized		Subsidized		Traditional	
				Price per tonne CO ₂ (\$)	Total project cost (\$)	Price per tonne CO ₂ (\$)	Total project cost (\$)	Price per tonne CO ₂ (\$)	Total project cost (\$)
Deciduous	100%	47,476	23.73	6.15	617,976.89	5.46	549,434.13	5.6	564,099
Deciduous	75%	35,607	17.8	4.6	463,482.68	5.46	412,075.60	4.21	423,074
Deciduous	50%	23,738	11.88	3.38	308,988.45	5.46	274,717.07	2.8	282,049
Coniferous	100%	117,282	58.67	14.91	1,499,904.45	13.53	1,361,365.36	10.77	1,084,069
Coniferous	75%	87,962	43.98	11.18	1,124,928.34	13.53	1,021,024.02	8.08	813,051
Coniferous	50%	58,641	29.32	8.2	749,952.23	13.53	680,682.68	5.39	542,034
Mixed	100%	73,778	36.89	9.52	957,746.99	8.5	855,380.48	9.12	918,402
Mixed	75%	55,334	27.67	7.14	718,310.24	8.5	641,535.36	6.85	688,801
Mixed	50%	36,889	18.45	4.76	478,873.50	8.5	427,690.24	4.56	459,201

Model sensitivity

The results reported here are established from a model that is sensitive to variation in numerous parameters that quantify carbon sequestration and project costs. The proportion of carbon in tree biomass is variable between species, and between sites (Goodale et al., 2002). Despite taking in-situ measures of the amount of carbon in living biomass, sequestration rates may differ across prospective sites in Wellington Country. Additionally, carbon emitted during harvest was not included in this study, but should be considered in future afforestation projects and frameworks for afforestation projects as potential carbon sinks (Yemshanov et al., 2007). Carbon emissions from timber harvesting can substantially affect NPV analysis for afforestation projects in southern Ontario (Richard & Stokes, 2004; Ralmal et al., 2009). In our analysis we assume a rotation age of 50 years. Total project costs, timber values, and the amount of CO₂ sequestered are dependent upon the age at which harvest occurs. The rotation age used in our study is suitable for White Pine and Norway Spruce which grow considerably faster than Sugar Maple in sites with low fertility and full sun (Beaudet et al., 2000; Bebbert et al., 2004; Grassi et al., 2004). Afforestation projects that utilize mid-tolerant deciduous species should consider longer rotation times. The productivity of land where afforestation projects are implemented will have drastic effects on NPV analysis. Afforestation projects on more productive lands will have faster growth rates, sequestering more carbon in a shorter amount of time, which will ultimately cost less than projects on less productive sites. Finally, total project costs are dependent on the price of merchantable lumber. Not only are lumber prices quite variable, but they are significantly different between species and ages (McKenney et al., 2006).

Schemes that produce high value timber will cost less than those of low production value and quality given similar growth and yield. Sensitivity analyses such as those by McCarthy et al. (1995), and McKenney et al. (2006) provide good examples of how to detect parameter influences on analyses used.

Cost considerations

The price of CO₂ is heavily debated and may range from \$2-80 per tonne (van Kooten & Sohngen, 2007). Due to the nature of net present value analyses, the value of the lumber will be minimal as it is discounted over a period of 50 years, decreasing its value depending on the chosen discount rate. The discount rate has been chosen using results from past studies, and is reasonable considering the duration of the proposed carbon neutrality project. Results show a promising and practical method of efficiently sequestering carbon for the community of Eden Mills. Analyzing the results of the three proposed species mixes, the deciduous planting scheme is the most cost efficient due to its high carbon sequestration capability. Due to input variability, this cost-benefit analysis can only provide estimates of the cost of carbon and total project costs for this proposed carbon offset project.

The full cost project requires a very large initial investment. This amount is equal to nearly one third of the cost of the entire project. One approach to easing the issue of high establishment costs would be to stagger the planting schedule and plant smaller areas over several years. This schedule may be more feasible if the total amount of trees planted is separated over multiple years versus one large initial planting. This would require lower initial investments and would spread costs out more effectively over time. Other methods for reducing project costs might involve community

members in the planting process; some government-subsidized programs encourage this approach. Other benefits may be derived through recreational activities within the plantation, including hiking and skiing.

Another solution to the scarcity of available land for carbon offset projects in Wellington County may be to rent a previously established woodlot. A community might offer to purchase the carbon offsets generated by such a woodlot. This approach would bypass the issues of finding land that is both marginal and idle and having to convince a landowner to agree to a long-term rental or land purchase. Compensation could be provided to the landowner on a yearly basis for the annual carbon sequestered by the woodlot. This may result in a more affordable method of carbon sequestration compared to the costs of completing a large-scale carbon offset project. End-use of the forest biomass presents a challenge, and would have to coincide with acceptable practices outlined by the Government of Canada (2008) regarding carbon offsets.

Environmental and economic benefits

Biomass produced from afforestation projects may be less energy-intensive than other building supplies, such as steel or aluminum (van Kooten et al., 1999). The decay rate of carbon in lumber products is around 1-1.24% and can represent substantial storage of carbon (Winjun et al., 1992). The implementation of afforestation provides additional environmental and economic benefits aside from carbon storage. Forests provide protection from soil erosion and the adverse effects of flooding, provide habitat, regulate microclimate, and produce biomass for energy or materials (Freedman et al., 2009; Parker et al., 2009). Afforestation may additionally restore soils with low fertility to historically productive soils through substantial nutrient and resource provisioning (Parker et al., 2001).

Conclusions

The objective of this study was to generate a cost-benefit analysis for a prospective afforestation project to offset the carbon footprint of Eden Mills, Wellington County, Ontario. We determined suitable sites where lands were both agriculturally marginal and idle, so as not to remove agriculturally viable lands from crop production. Soil and hydraulic characteristics of these sites were taken into consideration when selecting appropriate trees species for the analysis. Results of our cost-benefit analysis suggest that an afforestation project in Wellington County will cost between \$549,441.33 and \$1,499,904.45 (CAD). The optimal price of CO₂ per tonne ranges from \$5.46 to \$14.91. We outline important considerations for the input values used in the cost-benefit analysis, given that some of these values are subject to high variability (e.g. annual carbon sequestration by trees, land rental prices, price of lumber). Subsidies

currently available for afforestation projects in Wellington County will make the project more economically feasible; volunteer assistance in planting could further reduce project costs.

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Endnotes

1. Personal communication with B. Boysen.
2. Unpublished report by N. Thevasathan et al. (2010) entitled "A Short Report on Carbon Sequestration in Mixed Forest Vegetation of Eden Mills Village".
3. Personal communication with P. Williams.
4. Personal communication with N. Munn.
5. Personal communication with P. Williams.

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