University of Alberta

Afforestation in Alberta: A Case Study Evaluating the Economic Potential of Hybrid Poplar Plantations Given Bio-Energy and Carbon Sequestration Considerations

by

Lee. St. Arnaud

A thesis submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Master of Science
in
Forest Economics

Resource Economics and Environmental Sociology

Fall 2012
Edmonton, Alberta

Abstract

The investment viability of afforestation of hybrid poplar plantations on private land in the Province of Alberta was explored. Carbon credits from afforestation were included in the simulations. The base case showed relatively little potential for afforestation in the province. Substantial changes to the price for pulpwood and the price for carbon were required to initiate land use change on a large scale across the Province. The most important factor affecting land use was the permanent conversion factor that discounts carbon sequestration values because sequestration with wood fiber is not permanent. Land use change was the least sensitive to changes in carbon prices, assuming a permanent conversion factor of 0.1.

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Chapter 1: Introduction

In Canada, the performance of the forest industry has been lacklustre over the past decade. Mill closures and layoffs have been the norm; new start-ups and investment rare. Most firms appear to be operating at the margin and struggling to survive. In 2009, the average return on capital for the Canadian industry was 0.1%, falling from 7.9% in 1999 (Natural Resources Canada 2010). As of 2009, of the 70 mills and secondary forest product manufacturing centres located across the province of Alberta, 18 had shut down either permanently or indefinitely, and an additional 25 were operating at reduced capacity. Many firms initially believed that this new low would pass, and forest companies could continue operating under their traditional business models.

It was initially speculated that the reduction in the demand for wood products could largely be attributed to the cyclical nature of the industry. This view, however, was not congruent with the structural changes that had occurred in the global forest industry. Changes in consumer demand for traditional forest products in the main Canadian export markets, such as newsprint, are in decline (Mehrotra and Kant 2010). Weak U.S. demand for Canadian softwood, largely attributed to a strong Canadian dollar and a poor U.S. housing market, continues to plague the industry (Natural Resources Canada 2010). Industrial plantation forestry production in southern economies has altered the international timber supply. It is predicted that between 50 and 75% of global forestry production will be supplied through industrial plantation forestry by 2030 (FAO 2000). These short rotation plantations allow firms to reduce their operating costs significantly, largely through reducing the opportunity cost of holding land, as well as lowering transportation costs.

Finally, the Alberta forest industry is at risk of experiencing the largest insect outbreak since the outset of commercial timber operations in the province, threatening the current timber supply. The mountain pine beetle outbreak in British Columbia has advanced into the eastern slopes of the province and threatens the lodgepole and jack pine forests of the province (Schneider et al. 2010). In adjacent British Columbia, it was predicted that nearly 77% of pine volume would be killed over the duration of the outbreak (Walton et al. 2008).

The survival of the Alberta forest industry is critical for many communities across the province. According to the Alberta Forest Products Association (AFPA 1999) there are over 50 communities across the province that rely on the forest industry. In 2009, there were an estimated 33 279 workers employed directly in the industry in Alberta. The Alberta forest industry contributed approximately 19.9 billion dollars to national GDP (Natural Resources Canada 2010).

Fundamental adjustments to the past business model of firms are likely necessary for industry rejuvenation. There has been an increased focus from both government and industry on finding ways to increase the competiveness of the Canadian forest sector. The current paradigm of timber production for traditional forest products is being challenged. Increased interest in forest products as a source of bio-energy has spawned large research efforts, both in Canada and internationally. The government of Canada, in an effort to promote this fledgling industry, launched the Investment in Forest Industry Transformation (IFIT) program in August, 2010. This program aims at providing incentive for forest companies to develop, commercialize, and implement clean energy technologies in the pulp and paper sector (Natural Resources Canada 2010).

There have been a number of firms across Canada considering transitioning to industrial plantations in order to maintain competitiveness. Of the various species examined, hybrid poplar has emerged as promising for the Alberta forest industry. The short rotation crop can provide a reliable fibre supply within short haul distances from the mill (Anderson and Luckert 2007). Poplars are already used in pulping operations as well as in the production oriented strand board (OSB) in the province. Extensive breeding programs have resulted in various clones that can achieve high growth rates across many different ecotypes (Dominy et al. 2010). Moreover, poplar plantations have been shown to sequester atmospheric CO_2. Alberta's new atmospheric carbon cap and trade program could augment incentives for firms to plant hybrid poplars.

The question remains, will poplar plantations play an important role in the Alberta forest industry in the future? As it is illegal to practice plantation forestry with exotic species on public land in the province, decisions made by private landowners will determine if poplar plantations will become available to forest companies. Alberta Pacific Forest Industries Inc (AlPac), a pulp producer in North Eastern Alberta, has been experimenting with poplar plantations since 2002 on private land. This firm leases private land for 20 year periods in order to establish hybrid poplar plantations. AlPac is currently one third of the way towards establishing their target of 24,000 ha of plantations (AlPac 2012).

The factors affecting decisions landowners make when switching from one land use to another has been studied in depth (Lubowski et al 2006, Schatzi 2003). There are currently two schools of thought that have come to the forefront on how to best quantify these economic decisions. When there are large data sets available, it has been argued (see Lubowski 2006) that econometric models (revealed preference) are best suited for predicting land owner behaviour. There are, however, many areas where the quality or quantity of data is lacking. Econometric applications may not be the best approach under these circumstances. For example, Yemshanov et al. (*under review*) developed a bio-economic model that predicts land use change. Their model uses a combination of spatial data, land expectation values, and option values to predict land use change.

Elaborating on the model developed by Yemshanov et al. (*under review*) this analysis will evaluate the economic potential of poplar plantations within the province of Alberta. Additional to previous investigations, this study will also incorporate carbon credit markets and how they will affect the likelihood of poplar plantations being adopted on a province wide scale. Furthermore, specific consideration will be given to the effect that emerging bio-energy/bio-fuel technologies will play in altering the competiveness of plantation forestry when measured against traditional agriculture. The goal of this research is to investigate the following questions by creating policy scenarios for the land use change model:

1. How will prospective carbon markets affect the investment viability of poplar plantations and bio-fuel/bio-energy production to landowners and forestry firms within the province?

2. To what extent will bio-fuel/bio-energy play an important role in Alberta's future forest industry?

In order to pursue these questions, I will first review past research conducted on land use change and also on carbon sequestration. The third chapter will discuss the methods used in the analysis. The fourth chapter will discuss the scenarios used in the analysis as well as the results of the model. The final chapter will dedicated to discussion and general conclusions.

Chapter 2: Land Use Change and Carbon Sequestration: A Review

Two main themes have emerged from the literature pertaining to land use decisions with respect to agriculture and forestry. The factors that influence an agent's decision to either keep land in its current use, or switch to another, have received a great deal of attention (e.g. Platinga 1996, Schatzki 2003, Lubowski et al. 2006). The other theme is the impact of the costs of carbon sequestration (Parks and Hardie 1995, Alig et al. 1997, McKenney et al. 2004).

Land use decisions have the ability to affect global atmospheric carbon levels. It is estimated that two thirds of global greenhouse gas emissions since 1850 have been attributed to land use change (Houghton 2003). Deforestation, largely in tropical countries such as Brazil and Indonesia, accounts for nearly 17% of total global carbon emissions annually. Forests, and more specifically changing the way forests are managed, have the potential to sequester atmospheric carbon, and have been touted as economical options for atmospheric carbon reductions when used in combination with other mitigation strategies (Sohngen 2010). Moulton and Richards (1990) evaluated the potential for afforestation on lower productivity agricultural land and environmentally sensitive land across the United States. More than 107 million ha of land were deemed suitable. Alternatively in Canada, van Kooten et al. (1999) found that 7 million ha of marginal agricultural land were suitable for afforestation.

With the advent of the Kyoto protocol, countries can choose to use terrestrial biological sinks as a means to sequester atmospheric carbon to meet their specific obligations (IPCC 2001). Verifiable carbon sequestration through afforestation activities that have taken place since 1990 can be counted against a countries greenhouse gas (GHG) emissions. Although carbon markets have not widely been adopted, there exist a few functional systems. Currently, the European Union, the state of California, a group of Eastern U.S., and the province of Alberta have either regulated or voluntary carbon cap and trade systems. The Chicago Climate Exchange is a voluntary carbon offset market developed for the United States. Other jurisdictions have carbon cap and trade programs under development. Under the European Union carbon trading system, the carbon sequestered through afforestation activities cannot be traded in the market. Alberta's afforestation protocol (under development) may allow landowners to sell credits, ex poste, following third party verification (Alberta Environment 2011). The details of Alberta's carbon legislation will be discussed later in this manuscript.

Other forest management alternatives, such as altering rotation lengths, pest management strategies, wildfire management initiatives, and varying silvicultural prescriptions, also have the potential to sequester atmospheric carbon (Boyland 2006, Malsheimer et al. 2008, Sonhgen and Brown 2008, Maness 2009). However, afforestation activities and changes in land use will be the primary focus of this review (see Van Kooten and Sohngen 2007 for review on management strategies for existing forests).

Forests may also be used as a vehicle to generate carbon credits if they are converted into bio-energy (White 2010). Depending on the regulatory framework and underlying assumptions, bio-energy/bio-fuels produced from forest biomass can replace traditional fossil fuel consumption and therefore be considered as reducing global atmospheric carbon emissions.

The costs of carbon sequestration have been examined using a variety of techniques in both the developed and developing world. Much of the variation in carbon sequestration estimates are derived from various modeling techniques employed and their underlying assumptions (Richards and Stokes 2004, van Kooten and Sohngen 2007). In this review, focus will be on land use change and carbon sequestration studies conducted in the developed world. For examples of the costs of carbon sequestration from avoided tropical deforestation in developing countries see Kindermann et al. (2008) and Murray et al. (2009).

The remainder of this chapter will be organized as follows. First, literature on the costs of land use change and carbon sequestration will be addressed. Specifically, attention will be paid to the ephemeral nature of carbon sinks, permanent vs. temporary crediting, and the challenges with carbon accounting. Sources of additionality and leakage will also be discussed. Next, the different land use change modeling techniques will be evaluated. These include bottom up/engineering, sectoral, and econometric models. Finally, a summary of the recent work studying the costs of afforestation using fast growing plantations in Canada will be presented.

2.1 Land Use Change and the Costs of Carbon Sequestration

Studies have assessed the costs of forest based carbon sequestration at various scales, including global, country, and regional analysis. For example, Sedjo and Solomon (1989), and Nordhaus (1991) conduct global analysis. McKenney et al. (2004) and Lubowski et al. (2006) estimate the cost of carbon sequestration at national levels for Canada and the United States respectively. At the regional level, Parks and Hardie (1995), Platinga et al. (1999), and Stavins (1999) estimate the costs of specific programs in the United States.

The economic study of land use decisions dates back to the seminal work of Von Thunen (1966) (original publication 1826). In his model, land has the ability to capture rent. Rent can be defined as the monetary surplus a firm receives from a resource in excess of the costs. These costs include labour, capital and entrepreneurship. Land is assumed to be allocated to the land use with the highest net present value (NPV). The major determinant of land use is thought to be the distance of the land from a central market. The rent-maximising land use will be the observed land use. Due to the assumptions of homogenous land and ownership in his model, the spatial land use pattern forms a set of concentric rings around centers of population (i.e the central market) (De Pinto and Nelson 2007, Angelson 2007). Von Thunen's key contribution was the linking of economic theory (rent maximization) with spatial data (distance from the market). Rent maximizing behaviour (or maximizing NPV) continues to be an integral element of most models evaluating land use decisions.

Many researchers continue to incorporate the basic principles of Von Thunen's work in modeling land use change. However, there remains much discussion about how the costs of land use change should be calculated. That is, what is foregone when land changes from one use (i.e. agriculture) to another (i.e. forestry). The inclusion of opportunity costs of land in land use change studies is imperative to successfully model rent maximization. In the simplest studies, land opportunity cost is derived from lost agricultural production (Parks and Hardie 1995, de Jong et al. 2000). Other studies use annualized rental prices for agricultural land (Moulton and Richards 1990, Mckenney et al. 2004, Mckenney et al. 2007). Contingent valuation methods have also been applied to capture the opportunity cost of land (van Kooten et al. 2002, Shaikh et al. 2007).

The opportunity cost of land is not, however, the only economic cost that determines the full cost of land use change or the costs of programs aimed at carbon sequestration through afforestation. van Kooten et al. (2004) identified three types of transaction costs that should also be addressed: search costs, bargaining costs, and monitoring and enforcement costs. Search costs potentially exist for both the landowner selling carbon credits and also for the firm/government organization looking to contract landowners to pursue afforestation projects. Once potential buyers and sellers have found each other, negotiation of contracts must occur, again adding to transactions costs (Kostritsky 1993). As few firms or landowners will have much expertise in carbon contracts, the expectations of both buyers and sellers will need to be firmly agreed upon before any transaction takes place. Finally, once buyers and sellers have agreed upon the form of contracting, there are monitoring and enforcement costs. The cost of ensuring that the services agreed upon in the contract are delivered could potentially prove to be substantial. Richards et al. (1993) speculated that as much as 15% of land rental costs are administrative costs. The carbon credit legislation and offset guidance protocols developed by the Alberta government attempt to lower these transactions costs by providing clear guidance for both buyers and sellers of their responsibilities. The verification of the offset, however, is the responsibility of the firm producing the offset, and therefore, could affect the viability of offset generating activities such as afforestation (Alberta Environment 2011).

Along with the transactions costs discussed above, there exist many economic costs associated with land use change. Recent studies have documented the existence of option values when facing irreversible land use decisions in the face of uncertainty (Pindyck, 1991, Isik et al. 2003, Schatzki 2003, Yemshanov et al. *under review*). Also, landowners may receive non-pecuniary benefits from keeping land in its current use (Platinga 1997). Moreover, landowners may face capital constraints when evaluating land use change decisions (Alig et al. 1999). Hall et al. (2004) note that nearly all afforestation activities in the prairie provinces have been undertaken by large forest companies. For example, AlPac has contracted numerous land owners in Alberta to establish hybrid poplar plantations on their land. Generally these firms are not likely to face the same capital constraints as individual landowners and can finance the high upfront costs of plantations. There may also exist "decision making inertia" that delays landowner's responses to economic stimuli (Lubowski et al. 2006). Finally there may be unobservable environmental externalities and/or cultural and social costs/benefits to land use change that are difficult to measure (Van Kooten et al. 2002, Shaikh et al. 2007). Researchers have developed a variety of methods in an effort to include these costs when determining the "true" cost of land use change. These techniques will be discussed in the following sections.

2.2 Time Dimensions of Carbon Sequestration

There are inherent risks associated with long term carbon sequestration projects due to the dynamic nature of biological carbon sinks. Growth rates of trees vary between region, species, silvicultural treatments, and site conditions. Some stands grow very quickly, but store relatively small amounts of carbon. Other stands have slower growth rates, but their cumulative carbon uptake can be very large through time (e.g. Yemshanov et al. 2007). In forests, there is always the risk of mortality. Large forest or stand replacing events, such as wildfires or insect outbreaks, can cause significant releases of carbon dioxide (Amiro et al. 2001, Kurz et al. 2008). Environmental factors, such as prolonged droughts, have been shown to cause very large carbon dioxide emission pulses (Lewis et al. 2010). Once a stand is harvested, much of the carbon stored in the system is released back into the atmosphere. Immediately following harvest, organic matter left on site begins to decay and release carbon dioxide. Also, the amount of soil organic carbon begins to decrease following harvest. Silvicultural prescriptions vary by region, site conditions, and desired forest composition, and the rate of decomposition varies greatly between different practices (Malsheimer et al. 2008). For example, if a site is burned following harvest, there would be a significant pulse of carbon emitted during the treatment whereas; if the site was left to regenerate naturally, coarse woody debris would remain at the site long after the harvest was complete (Gorte 2009).

When using the carbon accounting framework developed by the IPCC, all harvested biomass is treated as emissions. However, depending on the end use of the forest biomass, not all of the carbon is necessarily emitted to the atmosphere immediately. The half life of carbon in durable wood products (lumber) has been estimated at 80-100 years. Half life carbon estimates for fast decaying paper products range between 1 and 5 years (Skog and Nicholson 1998). Complicating carbon residence times even further, is the fact that not all non-durable products are simply discarded and left to decay in the environment. In a study conducted by McKenney et al. (2004), it was assumed that 66% of all fast decaying paper products ended up in landfills, resulting in a much slower decay rate of 0.005 (0.5%/annum).

Accounting for volumes of total carbon converted into products varies greatly in the literature. It has become clear that using one accounting system for every region is not appropriate. For the amount of carbon sequestered to be accurate, site specific conditions must be taken into consideration.

2.2.1 Temporary vs. Permanent Credits

One of the most contentious issues regarding the permanence of biological carbon sinks is how to package the sequestered carbon as credits. When choosing a carbon mitigation strategy that includes terrestrial sinks, policy makers must choose a crediting system that is both economically and politically attractive. The ideal system accounts for the non-permanence of terrestrial carbon sinks and minimizes transactions costs (discussed above). There are various ways of awarding carbon credits that have been proposed. The concept of the tonne-year accounting (TYA) proposed by Moura-Costa and Wilson (2000), is based on the idea that carbon sequestered for a specified period of time can be considered as permanent. This is due to the fact that carbon emitted from the combustion of fossil fuels will eventually be partially dissipated as it mixes with the ocean and biosphere. Using this concept, the temporary storage of carbon for the specified time period is equivalent to a permanent reduction (Marechal and Hecq 2006). Moura-Costa and Wilson (2000) estimated the time period to be 55 years. Alternative estimates range from 42 to 150 years (Marland et al. 2001, Artusio 2001). Based on the permanent equivalent storage time, a discount factor can be derived for shorter duration carbon storage. If the time period reported by Moura-Costa and Wilson (2000) is used, then the value of a tonne of carbon sequestered for one year can be valued by dividing the value of a permanent reduction by 55. The TYA approach, however, has not received much political support.

In 2000, the Columbian government proposed the expiring credit (EC) system. Under an EC system, a firm can purchase a carbon credit for a specified period of time. Following the expiry of the agreed upon time period, the firm must either purchase another EC, or alternatively purchase a permanent reduction or reduce their emissions below the allotted cap (Columbia 2000). According to Marechal and Hecq (2006), this system has many benefits for buyers, sellers, as well as the environment. For sellers, this system provides for fewer constraints and more flexibility in management. Short term projects can be undertaken. Additional revenue can be earned above business as usual conditions. For the buyers, purchasing of EC's allow for permanent reductions to coincide with the end of the economic life of their capital effectively allowing time for technical progress to provide less carbon intensive production systems. EC's will trade at a lower price than permanent offsets as long as the costs of permanent reductions grow slower than the discount rate.

Developed from the concept of EC's, temporary certified reduction certificates (tCERs) have been proposed by the European Union. This type of temporary credit has a fixed expiry date of 5 years. Following expiration, the purchaser of the credit is liable to purchase either a permanent reduction, or renew their expired tCERs (UNFCCC 2002). If policy makers follow the IPCC's current rules, tCERs can be used, however, they may not use tCERs for all of their carbon liabilities (i.e. some permanent reductions must be purchased). Similar to the concept of tCERs is the carbon rental system proposed by Marland et al. (2001). Under such a system, temporary carbon is simply rented in a fashion similar to any other form of capital. Functionally, there are not many differences between a carbon rental system and tCERs other than the imposition of a specified expiry date. For additional details on the theory of "renting" carbon, see Sedjo and Marland (2003).

The afforestation protocol currently under development by the Alberta government would assign a discount factor to the amount of sequestered carbon at the time of harvest that would vary depending on the durability of the end use product. This concept differs from the tCER system adopted by the IPCC. In this case, temporary carbon is assigned a permanent equivalent value. For bio-fuel production, lifecycle carbon assessments must be completed to determine the appropriate crediting level. The proposed Alberta protocol will be discussed in detail later in the manuscript.

2.2.2 Costs of Carbon Sequestration over Time

Because carbon sequestration rates vary between different forest systems, determining how to calculate the costs of carbon sequestration is not a trivial task. According to Richards and Stokes (2004), quality studies of the costs of carbon sequestration aim to answer three questions: how much carbon is sequestered, at what time, and at what cost? Three common methods have been used to calculate the cost of a tonne of sequestered carbon. The first technique is known as the flow summation method. Studies employing this technique effectively ignore at what time during the rotation carbon sequestration has occurred. All harvests are treated as direct emissions using this method. Marginal carbon sequestered in each time period is considered additive; any emissions are treated as debits. The second technique is to calculate the average carbon sequestration over a given time horizon. This method includes the time dimension (necessary for average calculations); however, when carbon sequestration occurs is ignored. Furthermore, the choice of rotation age, or time period of concern, greatly affects costs of carbon sequestration and must be exogenously determined by the researcher. If no rotation length is imposed, the results from this method are the same as the flow/summation results. Finally the discounting or carbon levelization method has been used to calculate the monetary value of sequestered carbon. This technique uses a discounting method similar to net present value calculations. The summary statistic generated using this method is known as present tonnes equivalent (PTE). The choice of discount rate directly affects the value of a carbon offset. Higher discount rates imply that future carbon sequestration and emissions have little effect on the present value of carbon. Increasing the discount rate has empirically been shown to increase the costs of carbon sequestration for afforestation projects (Newell and Stavins 2000).

In an illustrative example developed in their paper, Richards and Stokes (2004) were able to show the difficulty in comparing studies whose calculations vary by accounting method. Four offset projects were compared using the different techniques, three of which were generated through afforestation. Even though the projects sequestered the identical volume of carbon over the same time period, the cost per unit carbon varied depending on the accounting method employed. In a world where heterogeneity is the norm across forested landscapes, the issue is compounded.

Steps have been taken towards standardizing accounting practices. Generally, the flow summation and average storage methods have been replaced in more recent literature by the discounting/levelization method (Dempsey et al. 2010). As the discounting approach is the most widely accepted accounting technique, it is necessary to discuss the implications on the choice of discount rate. The decision should be based on how quickly the researcher believes the damages from increasing atmospheric carbon will increase (Richards 1997, Herzog et al. 2003, Stavins and Richards 2005). Often, a social discount rate is chosen in these calculations. If a discount rate of zero is used, it implies that it does not matter when, and therefore even if, carbon sequestration takes place (van Kooten and Sohngen 2007). Such an assumption would promote governments and firms to indefinitely delay any carbon sequestration projects.

2.3 Carbon Leakage and Additionality

When a carbon offset generated by forestry practices, either locally or internationally, there exists the potential for the benefits of the project to be countered elsewhere through unanticipated land use change (Alig 2010). The severity of leakage that could potentially exist has been debated in the literature. According to Murray et al. (2004) estimates range between 10% and 90%, depending on the activity and region. Leakage remains a serious concern for policy makers designing carbon mitigation strategies when a large percentage of the world continues to remain unregulated.

The concept of additionality must also be considered when evaluating a specific offset project. For a project to "pass" the additionality requirements, it must have sequestered carbon, or have prevented emissions, above and beyond what would have occurred under business as usual conditions. Additionality can be difficult to demonstrate for some forestry projects, especially avoided deforestation and forest management alternatives (Malsheimer et al. 2008). Afforestation projects, on the other hand, may be easier to evaluate as there are a number of methods to calculate their economic benefits and costs. For most afforestation/land use change models, a business as usual reference condition is presented, and different policy programs or carbon prices are used to estimate the magnitude of afforestation that would occur (e.g. Parks and Hardie 1995). Choosing the appropriate modeling technique, however, given the available data, computational requirements, and forest system, continues to provide significant challenges.

2.4 Land Use Change Models: Bottom-Up Engineering Models, Sectoral Price Endogenous Models, or Econometric Models

Over two decades ago, the work of Sedjo and Solomon (1989) spawned interest in how the costs of land use change dictate whether forests are economically viable as climate mitigation tools. The first studies measuring the costs of carbon sequestration applied bottom up engineering techniques (e.g. Moulton and Richards 1990). The principle behind these models is that all costs of land use change can be explicitly measured and accounted for. Using data on returns to agriculture, forest product prices, conversion costs, and forest yield information, the costs of carbon sequestration can be calculated in a relatively simple manner. By varying the amount of sequestered carbon, it is possible to construct marginal cost curves. Alternatively, the researcher can choose the desired quantity of carbon to be sequestered, and extract the resulting price per tonne of carbon. The decision rule in these models is, if the returns from forest products and carbon credits are larger (smaller) than the lost returns from agriculture and conversion costs, land should switch to (remain in) forestry (agriculture). The benefits of this modeling technique are that they are relatively simple and transparent, and do not require large data sets and complicated computer programming (Richards and Stokes 2004, van Kooten and Sohngen 2007).

Studies using these techniques, however, have been criticized for not being able to adequately describe the rich contextual framework in which landowners base their use decisions. Bottom up studies do not consider non-pecuniary returns to agriculture (Platinga 1997), unobservable landowner behaviour (Lubowski et al. 2006), option value in the face of uncertainty and irreversibility (Pindyck 1991, Isik 2003, Schatzki 2003, Yemshanov et al. *under review*), price endogeneity (Alig et al. 1997, Alig et al. 1998, Alig et al. 2010) or capital constraints faced by landowners (Alig et al. 1999). With these problems, bottom up engineering studies may fail to explain why many tracts of marginal farmland across the continental United States and Canada remain in agriculture despite higher net present values calculated for forestry. These studies may also fail to explain observed land use hysteresis in North America (e.g. Roberts and Lubowski 2007). Moreover, these models fail to account for possible leakages, as described above.

In order to address these concerns, researchers have developed two alternative modeling techniques. The first of these alternatives are sectoral optimization models which account for price endogeneity by linking the forestry and agricultural sectors. As agricultural land is increasingly recruited into forests, the price of agricultural products should rise in turn. Alternatively, as forests are increasingly protected from harvesting, the price of wood products should increase, recruiting further agricultural lands into plantations or causing unprotected forests previously uneconomically viable to harvest to become working forests (Alig et al. 1997). When captured in a general equilibrium model, these price effects temper land use transitions. The forest and agricultural sector optimization-green house gas model (FASOM-GHG), developed for the United States agricultural and forestry sectors is a model that represents over a decade of research (Alig 2010).

Adams et al. (1996) developed the first version of the FASOM model by linking the U.S. agricultural and forestry sectors commodity markets. Private land use decisions for grasslands, croplands, and forestlands are linked to the commodity markets. The model evaluates land use change using five year time steps. The latest version of the model FASOM-GHG has full carbon accounting for both the agricultural and forestry sectors. Carbon emissions from forest products are tracked in end-use products as well as disposal (Alig 2010). Alig et al. (1997) published the first in a series of papers that used the FASOM model to evaluate different carbon and environmental policies affecting the U.S. agricultural and forestry sectors. Leakage, at the national level, is accounted for in the FASOM model. The model has been used to evaluate land use change carbon sequestration strategies (Alig et al. 1997, Adams et al. 1999), the effects of urban development on land use change (Alig et al. 2010a/b), the effects of climate change on land use decisions (Alig et al. 2002), as well as market driven effects on land use change (Alig et al. 2002, 2004). For a complete description of the components of the FASOM-GHG model, see Adams et al. (2005). The cost estimates for carbon sequestration generated from these modeling exercises are generally higher than those from bottom up engineering studies (Richards and Stokes 2004). There exists, however, debate in the literature over whether endogenising price effects sufficiently models observed land use change decisions (Lubowski et al. 2006).

Econometric models represent another approach to evaluate land use change problems and the costs of carbon sequestration. Early work by Platinga et al. (1999) and Stavins (1999) developed the conceptual framework for later studies. The premise behind this modeling technique is to use observed landowner behaviour to ascertain the "true" costs of land use change. By using observable historical events and recorded landowner responses, it is possible to statistically estimate a response function (Lubowski et al. 2006). By relying on observed behaviour, the analyst is able to address many of the concerns with bottom up/engineering studies and sectoral models by implicitly including option values, non pecuniary returns to agriculture, and capital constraints (Dempsey et al. 2010). Returns to agricultural and forestry lands were, however, determined exogenously in earlier econometric models (e.g. Platinga 1999). Lubowski et al.

(2006) were the first, to this author's knowledge, to incorporate price endogeneity into an econometric model.

Lubowski et al. (2006) analyzed data spanning from 1982-1987. The area under analysis accounted for 91% of non-federal land in the contiguous U.S. (approximately 0.67 billion ha). Using a nested logistic formulation, they developed land use change elasticities and constructed marginal cost curves for carbon sequestration. Included in their analysis were six different land use alternatives: crops, pasture, forests, urban development, and land contracted under the conservation reserve program. Although their results suggested that the costs of climate change mitigation through afforestation were slightly higher than reported in many previous studies, they concluded that a national strategy aimed at afforesting marginal agricultural lands could play an important role in the United States climate change mitigation portfolio. This study represents the "gold standard" in land use change studies; however, as pointed out in Yemshanov et al. (*under review*) many areas simply do not have the required data to complete such analysis.

2.5 Canadian Research on the Land Use Change and the Costs of Carbon Sequestration

Numerous studies have emerged from Canadian researchers aimed at evaluating the potential of afforestation across Canada given different policy scenarios. van Kooten et al. (1999) identified 7 million ha of marginal agricultural land were suitable for afforestation using a bottom up/engineering model. This is the first article this author is aware of dealing with the potential of afforestation in Canada. Furthermore, van Kooten et al. (2002), and Shaikh et al. (2007) analyzed the results from a contingent valuation study to evaluate the viability of afforestation in the prairie provinces. Their results indicated that social concerns of landowners play significant roles in determining land use decisions. For example, farmers in the southern boreal and aspen parkland regions show more resistance to afforestation than do farmers farther south, even though their lands are, on average, better suited to growing trees. The resistance has been attributed to the large historic efforts made in clearing the land for agriculture. Reforesting these areas requires relatively large incentives.

The Canadian Forest Service Afforestation Feasibility Model (CFS AFM) and the Canadian Forest Service Forest Bio-economic Model (CFS FBM) have been widely used to evaluate the potential for afforestation given different policy scenarios (McKenney et al. 2004, McKenney et al. 2006, Yemshanov et al. 2007, Yemshanov and McKenney 2008, and Ramlal et al. 2009). These models are bottom-up engineering bio-economic land use change models. The CFS FBM model was developed out of the earlier CFS AFM model. Using spatial data from agricultural land values, forest product prices and location specific growth rates, the NPV of both agriculture and forestry can be compared for a given location. A detailed description of the CFS FBM model will be included in the methods section of this manuscript. McKenney et al. (2004) estimated the costs of carbon sequestration using hybrid poplar plantations, whereas, Mckenney et al. (2006) used a bio-economic model to address current research priorities for land use change across Canada. The potential for afforestation in southern Ontario using three different species was evaluated by Yemshanov et al. (2007). Yemshanov and McKenney (2008) analyzed the potential of hybrid poplar for bio-energy applications. More recently, Ramlal et al. (2009) investigated the potential for hybrid poplar plantations to reduce the costs of disposing municipal biosolids.

Overall, these studies showed that there exists the potential to practice afforestation on small areas of marginal farm land across the country. However, the results from CFS AFM and CFS FBM models suffer from the concerns mentioned in the previous section because of the bottom up engineering nature of the models. In an effort to address these concerns, Yemshanov et al. (*under review*) use a real options approach to adjust the costs of switching between land uses. The option value in the model accounts for the values associated with irreversible decisions facing future uncertainty. By adding this additional cost to land use change, they were able to temper some of the initial land use change earlier models had predicted.

The CFS FBM option value (CFS FBM OV) model (Yemshanov et al. *under review*) will be discussed in detail in the methods section, as it is the basis for this modeling exercise. The earlier version of the model did not include either carbon or bio-energy considerations. The reported land use change elasticities were similar to those in Lubowski et al. 2006 (an econometric model with relatively high costs of land use change). The subsequent chapter of this manuscript will focus on the effect of adding these considerations to the investment viability of afforestation in the province of Alberta.

Chapter 3: Methods

The model used in this manuscript follows from three previous models (CFS AFM, CFS FBM, and CFS FBM OV). The methods section will be organized as follows. First, a description of the CFS AFM model (McKenney et al. 2004 and McKenney et al. 2006) will be presented. Next, the CFS AFM model's successor, the CFS FBM (Yemshanov et al. 2007) will be outlined. Alterations to the CFS FBM model (i.e. the CFS FVM OV model) by Yemshanov et al. (*under review*) will subsequently be presented. Finally, changes made to the CFS FVM OV model for the purposes of this thesis will be discussed in detail.

3.1 CFS AFM

The CFS-AFM (hereafter referred to as the afforestation model), developed by researchers at the Canadian Forest Service (CFS), has been used to evaluate the viability of afforestation across Canada (McKenney et al. 2004 and McKenney et al. 2006). This model has also been used to study break-even prices for carbon that stimulate afforestation projects (i.e. the price of carbon that is needed to raise the NPV of afforestation equal to that of agriculture). The model has also been used to investigate the viability of electricity production through the combustion of woody biomass.

The afforestation model is a spatially-explicit, bioeconomic model that accounts for the opportunity cost of agriculture. Following the description of land use change models in the literature review chapter, the afforestation model is a bottom-up engineering model that links a spatially explicit growth and yield module and a cost-benefit NPV module. The model has an infinite planning horizon. Land use change is not constrained by capacity needed to process forest or agriculture products, and all price levels are assumed to be exogenous to the model. As such, returns to agriculture and forestry are not affected by the total area designated for each use.

A growth and yield module is used to track fiber production and carbon transfers in the modeling system. A cost-benefit module determines the land use decision for a given time period by comparing the NPV of agriculture and afforestation for each raster. Spatial output is in raster form and is compatible with geographical information systems (GIS). The spatial resolution (i.e. the size of individual raster) is determined by the resolution of the data used in the model.

The general framework for estimating each individual raster's land use is determined by the following equation:

$$NPV_{Afforestation} = NPV_{Timber} + NPV_{Carbon\ Seq.} + NPV_{Bioenergy} - NPV_{Ag\ Land\ Value} \quad (1)$$

Where $NPV_{Afforestation}$ is the net present value of afforestation, NPV_{Timber} is the net present value of merchantable timber, $NPV_{CarbonSeq.}$ is the net present value of carbon sequestration, $NPV_{Bio\text{-}energy}$ is the net present value of all bio-energy revenues, and $NPV_{AgLandValue}$ is the net present value of agricultural land value. If the $NPV_{Afforestation}$ is positive, the raster is assumed to convert to a hybrid poplar plantation. If the $NPV_{Afforestation}$ is less than or equal to zero, the raster remains in agricultural production. Determinants of each variable in equation (1) depend on the specific application of the model.

3.2 CFS FBM

Following the afforestation model, the CFS FBM (hereafter referred to as the land use change model) was developed (Yemshanov et al. 2007). A number of changes to the original model were implemented. First, the approach used to model transportation costs was altered. Second, unlike the afforestation model, the land use change model tracks outputs on a year to year basis, and also has a finite planning horizon. Third, forest carbon is tracked at a finer scale. Physical carbon flows and forest stocks are tracked for each individual raster in the model through time.

The carbon tracking algorithms were adapted from the Canadian Forest Service Carbon Budget Model 2 (CFS-CBM2) (See Kurz et al.1992 and Kurz and Apps 1999 for additional detail). Ten ecosystem carbon pools are tracked; five consisting of living biomass, and five consisting of dead organic matter (DOM). The living biomass carbon pools are made up of: merchantable biomass, non-merchantable biomass, roots, saplings, and other biomass. The DOM pools are categorized as: ultrafast, fast, medium, and slow decaying DOM and snags. All pools are tracked for each time period in the model. Tree growth (merchantable biomass) is calculated from growth and yield tables adjusted for site specific environmental conditions. Growth and yield of forest biomass is also tracked on a raster by raster basis for the entire modeling period.

3.3 CFS FBM OV

The CFS FBM OV presented in Yemshanov et al. (*under review*) (hereafter referred to as the option value model) was developed in response to criticisms of bottom up land use change models discussed in the literature review chapter. In an effort to incorporate more realistic landowner behavior into the CFS models, two main changes were made to the land use change model:

1. The calculation of an optimum economic rotation and
2. The inclusion of option values.

3.3.1 Optimal Economic Rotations

Previous versions of the model assumed a fixed rotation age for harvested stands. The option value model calculates the NPV of forest land for each raster based on the optimal economic rotation. The optimal economic rotation age is calculated using recursive numerical operations that search for the rotation that maximizes land value (treated as an exogenous variable after the first rotation). Future agriculture and forest land values in the model are considered to be stochastic, and are estimated through Monte Carlo simulation. The optimum economic rotation is calculated with the inclusion of values generated with a real-options approach that was adopted to capture the value associated with future uncertainty.

3.3.2 Option Value Calculations

A European spread option is used to quantify the value associated with the somewhat irreversible decision of afforestation vs. the somewhat flexible decision to grow an agricultural crop. This framework allows the model to assign value to postponing decisions until further information about uncertain future prices become available. A European style option, (an option that can only be exercised at the time of maturity) is used instead of an American style option (an option that can be exercised at any time) because of computational limitations associated with considering options at every time step. However the use of a European style option seems justified, as it is unlikely that once a site has been afforested, landowners will abandon the investment to return to agriculture before trees are harvested. Similarly, it is unlikely that a landowner would abandon an agricultural crop mid-season to plant trees. The following model discussion closely follows the notation found in Yemshanov et al. (*under review*).

The expected benefit of switching from the existing land use (agriculture) to the alternative land use (forestry) is captured by the following equation:

$$Expected\ benefit_{For} = \max[NPV_{Afforestation} - NPV_{Agriculture} - C_{Ag,For}; 0] \quad (2)$$

Where $NPV_{Afforestation}$ and $NPV_{Agriculture}$ are the annualized NPVs of afforestation and agriculture respectively, and $C_{Ag,For}$ is the annualized cost of switching to forestry from agriculture. In more specific terms, the expected benefit, or option value, from switching to agriculture from forestry and from forestry to agriculture is calculated as follows:

$$OV_{Ag,For} = \left[NPV_{Agriculture}\ e^{[b_{Ag}-r]T} + C_{Ag,For}\, e^{-rT}\right][S \cdot \theta[d_{For}]\theta \cdot [d_{Ag}] \quad (3)$$

$$OV_{For,Ag} = \left[NPV_{Afforestation}\ e^{[b_{For}-r]T} + C_{For,Ag}\, e^{-rT}\right][S \cdot \theta[d_{Ag}]\theta \cdot [d_{For}] \quad (4)$$

Where r is the risk free interest rate (i.e. Yemshanov et al. (*under review*) use 4%), b_{Ag} and b_{For} are the cost of carry for each land use, and T is the time to maturity of the asset. Agricultural land is assumed to pay a 3% dividend each model time step, and therefore the cost of carry differs from r (i.e. the cost of carry is reduced from 4% to 1%). Forestry is not expected to yield a dividend, so the cost of carry is the same as the discount rate at 4%. For forestry, the optimal economic rotation is used whereas for agriculture the rotation age is assumed to be one year. The remaining terms are defined below for $OV_{Ag,For}$:

$$S = \frac{NPV_{Afforestation} \quad e^{[b_{For} - r]T}}{NPV_{Agriculture} \quad e^{[b_{Ag} - r]T} + C_{Ag,For}\, e^{-rT}} \tag{5}$$

$\theta[]$ is the cumulative standard normal distribution.

$$d_{For} = \frac{lnS + (\frac{\sigma^2}{2})T}{\sigma\sqrt{T}} \tag{6}$$

$$d_{Ag} = d_{For} - \sigma\sqrt{T} \tag{7}$$

$$\sigma_{Ag,For} \approx \sqrt{{\sigma_{For}}^2 + (\sigma_{Ag} F)^2} - 2\rho\sigma_{For}\sigma_{Ag}F_{Ag} \tag{8}$$

σ_{Ag} is the volatility measure for $NPV_{Agriculture}$,

σ_{For} is the volatility measure of $NPV_{Afforestation}$

ρ is the correlation between returns to $NPV_{Agriculture}$ and $NPV_{Afforestation}$.

$$F_{Ag} = \frac{NPV_{Agriculture} \quad e^{[bAg - r]T}}{NPV_{Agriculture} \quad e^{[bAg - r]T} + C_{Ag,For}\, e^{-rT}} \tag{9}$$

Using the NPV and OV equations defined above, the landowner can optimize the land use by maximizing the expected land value (ELV_{Ag}, ELV_{For}), or the annualized value of allocating land to either agriculture or forestry (Equations 10 through 12):

$$Max[ELV_{Ag}; ELV_{For}] \tag{10}$$

Where:

$$ELV_{Ag} = NPV_{Ag} + OV_{AgFor} \text{ , and,} \tag{11}$$

$$ELV_{For} = NPV_{For} + OV_{ForAg} - C_{AgFor} \tag{12}$$

If a raster is currently in agriculture (forestry), for it to switch to forestry (agriculture), the ELV_{For} (ELV_{Ag}) must be greater than the ELV_{Ag} (ELV_{For}). There are no costs associated with switching from agriculture to forestry as agriculture leaves the ground prepared for forestry planting. However, a cost of $354/ha is associated with the land clearing prerequisite for switching back to agriculture from forestry (denoted in equation 12 as C_{agfor}).

3.3.3 Baseline Assumptions

The case study in this thesis uses many of the same assumptions as Yemshanov et al. (*under review*) that are described briefly below. The derivation of the option value (Equations 5-9) requires measures of correlation and volatility for agricultural and forest values. The volatility and correlation measures were calculated from the average county real estate transfers for the Province of Alberta (1994-2006) and from the raw materials price index (RMPI). County level data on past agricultural sales is categorized by municipality and agricultural productivity. Agricultural productivity is assumed to be correlated with the Canadian Land Inventory (CLI) classification. The CLI classification system ranks agricultural land on a productivity levels ranging from 1-7, with 1 being the most productive, and 7 being the least productive. Afforestation in the model was deemed possible on sites with a CLI rating of 5 or better. The specific productivity of each raster was determined by using the average CLI rating within the cell. Ideally, historical sales of private forest land would also have been used in the calculation of forest land values. However, little data are available on past private forest land sales in the province. The RMPI values serve as a proxy for private land values (i.e. pulp is most often the end use for hybrid poplar plantations). In the model, σ_{Ag} = 0.104, σ_{For} = 0.135, and ρ = 0.220.

For each time step in the model, future prices for forest and agricultural values are also required. An equation was first estimated using ordinary least squares (OLS) to determine the historic trends for each data set. Future values were predicted from this equation through Monte Carlo simulation and included as exogenous variables in the model. The drift ratio, or how the price expectations evolve relative to one another, has been estimated at $0.55_{for/ag}$ using the historical data.

Harvest and silvicultural costs follow those presented in Anderson and Luckert (2007). It is assumed that harvest and silvicultural costs for hybrid poplar plantations are \$15/m^3 and \$1231/ha respectively. Management costs (i.e. harvest and silvicultural costs) are assumed to evolve as do forest land values. Transportation costs are determined for each raster by using a distance weighting factor as described in Yemshanov et al. (2007). A millgate price of \$40/m^3 is used for pulpwood in the baseline scenario.

3.4 Additions to the Option Value Model

There have been two major changes made to the option value model for the purposes of this study; carbon and bio-energy considerations have been added. The motivation for adding carbon and bio-energy is that Alberta has a functioning carbon market. The carbon protocols have provisions for both bio-energy production and potentially for carbon sequestration through afforestation. There remains, however, much uncertainty regarding exactly how the Alberta carbon market will affect the profitability of hybrid poplar plantations. It is also unclear how new bio-energy/bio-technologies will change the price which landowners receive from their poplar crops.

The remainder of this section is organized as follows. First, an example of one of the promising new bio-technologies assumed to be adopted by the forest industry in this thesis will be described. Next, the Alberta carbon protocols for afforestation and bio-energy will be described. Finally, a description of how the carbon and bio-energy considerations will be incorporated into the model will follow.

3.4.1 Bio-energy Technology

Of the many bio-energy/bio-fuel technologies under development, syngas production will be examined in this analysis. For a review of other potential cellulosic bio-energy/bio-fuel technologies, see Carrol and Sommerville (2009). Syngas is an organic gas consisting of mainly carbon monoxide and hydrogen that can be produced through a number of processes. Black liquor gasification combined cycle (BLGCC) is a technology that could be well suited for adoption in the province for a number of reasons (Fornell et al. 2010). First, the technology is operating at the commercial scale. Second, there are many existing Kraft pulp mills within the province that could be retrofitted with BLGCC to produce syngas. Finally, syngas can be used for a variety of end uses, including electricity production, bio-synthetic fuel (e.g. Di-methyl ether, ethanol, methanol, Fischer-Tropsch Liquids), and industrial chemical production (Swedish Energy Association 2008).

For a pulp mill to be retrofitted to produce syngas as a byproduct, an existing Thomlinson recovery boiler needs to be replaced with a gasifier system. In traditional Kraft pulp mills, the cellulose (pulp) is extracted from wood chips through a process known as “cooking”. A mixture of caustic chemicals (white liquor) is applied with heat to the untreated wood chips to remove the lignin and hemi-cellulose components of the pulpwood. In the “cooking” process, the white liquor dissolves the lignin and hemi-cellulose, and becomes black liquor. In traditional Kraft pulping, this organic rich solution is burned in the Thomlinson recovery boiler to recover the pulping chemicals. By-products from the process include heat and high pressure steam. Existing pulp mills can use these by-products to produce electricity to power their operations.

If a firm were to adopt a BLGCC system, it is expected that electricity production could increase by 85 percent relative to a mill with a traditional Thomlinson recovery boiler (Swedish Energy Agency 2008). Electricity production may be considered a first step towards turning pulp mills into functioning bio-refineries, and will be the focus of this study. Electricity production data, reported for BLGCC systems under development, have been evaluated in a number of studies

(Ekbom et al. 2005, Swedish Energy Agency 2008, Fornell et al. 2010). We assume that the marginal increase in electricity production after a BLGCC system has been adopted to be 0.10MWh/m^3 pulpwood. Electricity production data and pulp usage data have been reported for various BLGCC systems (Swedish Energy Agency 2008). The derivation of the conversion factor for volume of pulpwood to electricity generation is:

$$\frac{494kWh}{ADT} * \frac{MWh}{1000kWh} * \frac{ADt}{4.93m^3} = \frac{0.10MWh}{m^3} \quad (13)$$

The electricity production estimate assumes that pulpwood production remains constant and that all syngas produced is used to generate electricity in a gas fired turbine. Also, the estimate is associated with implementing the BLGCC technology in a mill that currently has the most efficient Thomlinson recovery boilers available to date. As not all of the pulp mills in the province have new recovery boilers, the marginal improvement in efficiency may be considered to be a lower-bound estimate.

3.4.2 Alberta Carbon Protocols:

The Alberta Government introduced the *Climate Change and Emissions Management Act* in 2007. The primary role for this legislation is to develop a market for carbon emissions by setting emissions reduction targets. Large emitters (firms emitting over 100,000 tonnes CO_2/year) have three options for compliance. First, the emitter can take steps to reduce the carbon intensity of their operation. Second, the emitter can pay into a research fund managed by the Alberta government at a price of $15/tonnes $C0_2$. Finally, if an emitter does not meet their reduction targets, they have the option to purchase verified emissions reductions from offset projects within the province. In this context, an offset can be defined as "a reduction or removal in GHG emissions from a project that features a new management practice, technology and/or control system" (Alberta Environment 2011).

In order for a carbon offset project to be approved, a number of conditions must be met. First, the project must have occurred in Alberta. Second, the project must not be required by law. Third, the action/project must have taken place on or after January 1, 2002. Fourth, the offset project must have clearly established ownership. Finally, the offset project must be real, quantifiable and demonstrable (Alberta Environment 2011). To be considered real, quantifiable, and demonstrable, the project must show that GHG's were either sequestered or that GHG emissions were reduced. Various protocols have been developed that outline the steps that firms must undertake for an offset to be eligible. The relevant protocols for this study are the proposed Afforestation Protocol and the Bio-Energy Protocol and will be discussed below.

When a firm wishes to sell a carbon offset, they must prepare a project report for submission to Alberta Environment. The key component of the project report is the GHG Assertion; this is the total net reduction/removal of GHGs (measured in CO2 equivalent) achieved by the project. The third party reviewers ensure that the offset calculations are accurate and comply with the applicable protocols and legislation. Once an offset has been accepted, it is registered and can then be sold on the exchange to firms requiring emission reductions to meet their targeted emission intensities (Alberta Environment 2011).

3.4.2.1 Project vs. Baseline: How the GHG Assertion is calculated

The Alberta system is based on the concept of lifecycle carbon analysis. In order to be eligible, a project must show a net reduction in GHGs at the project site, as well as upstream and downstream of the facility/operation. Quantification of the GHG reduction in the Alberta Offset System is based on GHG emissions reductions/removal with the project compared to the baseline condition. The baseline condition emissions are those that would have been emitted had the project not occurred (i.e. business as usual). A key concept of the baseline/project comparisons is the concept of "equivalent function". The offset project must ensure that the same quality and function of services as the baseline are delivered (Alberta Environment 2011). A common metric must be used to compare the project and baseline output. For example, if electricity is generated, KWh would be considered the unit of measurement. If bio-fuel is produced, an energy equivalence factor would be used (e.g. energy content/liter of fuel).

3.4.2.2 Afforestation Protocol

The Afforestation Protocol is being developed by the Alberta government in conjunction with other stakeholders and is currently undergoing revisions. The final details have not yet been released; however, the general framework has been developed (Alberta Environment 2011). The crediting system will be based on a permanent conversion factor (PCF). As carbon sequestered through afforestation can be considered temporary (i.e $C0_2$ removed from the atmosphere is not permanently removed from the carbon cycle), the Alberta system will use a discounting factor to convert the temporary sequestered carbon into a permanent equivalent. Depending on the end use of the fiber, the size of the PCF may vary.

The total amount of carbon in the roots and shoots of plantation trees will be estimated at the age of harvest. This value is subject to the PCF depending on its end use. The concept of the PCF is applied in order to deal with the non-permanence issue of carbon sequestration in natural systems (discussed in the literature review). For example, a PCF of 0.1 may be applied to the total carbon stored in the roots and shoots if the merchantable biomass is destined for pulpwood. In effect, the owner of the carbon asset can sell 10% of the carbon in the living biomass at the time of harvest as a permanent offset. A PCF of this magnitude would be used for pulpwood because the end products (i.e. pulp and paper products) have a relatively short functional life. These products decay faster than more permanent forest products such as lumber and oriented strand board (OSB). If the merchantable biomass is destined for OSB, it is assumed that OSB has a longer product life than pulp. For example, a PCF of up to 0.5 may be applied to the total carbon stored in the roots and shoots at the time of harvest. To illustrate, if a one hectare poplar plantation destined for a pulp mill contains 100 tonnes of $C0_2$ (27.2 tonnes of C) in the roots and shoots at the time of rotation, the owner of the trees can sell a permanent offset of 10 tonnes CO_2 (i.e. 10% of the total CO_2). If the same stand is destined for OSB, the owner can sell a permanent offset of 50 tonnes of $C0_2$ (i.e. 50% of the total CO_2). It is important to note that these conversion factors have not yet been finalized and make up one of the key components of the protocol being negotiated at this time.

3.4.2.3 Bio-Energy Protocol

The crediting concept adopted by the Alberta government for green electricity production is based on the concept of marginal emissions displacement. It is assumed that when a new “green” electricity producer enters the market, a less profitable conventional producer will be eliminated and thus will not continue to emit. Marginal emissions displacement factors are used to determine how much GHG from conventional sources is prevented from being released by the new “green” or biogenic project. The marginal emissions displacement factor has been set at 0.65 tonnes CO_2 equivalent per megawatt hour (MWh) for the province of Alberta (Alberta Environment 2011). For example, if a pulp mill were to sell 100 MWh of electricity to the grid through the burning of biomass, it could claim a carbon credit of 65 tonnes CO_2 equivalent.

3.5 Changes to the Model

The calculation of the present value of carbon in this study will be based on an interpretation of the Alberta Afforestation Protocol. At the time of harvest, the carbon sequestered in the roots and shoots of the stand will be calculated on a per hectare basis. A PCF will then be applied to this value. In the new option value model, $NPV_{Afforestation}$ has been adjusted as follows:

$$RNPV_{Afforestation} = \frac{(P_{pulpwood_t} + V_{Carb_t} - C_{Silvi_t} - C_{Trans_t})}{(1+r)^t} \quad (14)$$

and

$$VCarb_t = PCF * P_{Carbon} * Total_{Carbon_t} \quad (15)$$

Where $RNPV_{Afforestation,}$ is the revised $NPV_{Afforestation}$ (first presented in equation (2)), P_{Carbon} is the market price for carbon (held constant over time), $Total_{Carbont}$ is the volume of carbon sequestered in the roots and shoots at the time of harvest, and PCF is the permanent conversion factor applied to pulpwood carbon as per the Afforestation Protocol (also assumed to be constant over time). The value of carbon will be adjusted by changing the initial carbon price and the PCF.

We assume that the effects of an emerging bio-economy and the bio-energy carbon crediting system will be to increase demand for pulpwood because of new opportunities in bio-energy and carbon credits. The increased demand may lead to higher prices for pulpwood. We therefore change both the initial pulpwood price as well as the pulpwood price trends in scenarios that follow. It is unclear how this potential increased demand will affect pulpwood prices as it depends on the elasticities of supply and demand, which have not been estimated for the emerging hybrid poplar market. We therefore develop scenarios based on plausible estimates.

The bio-energy carbon credit can be estimated using electricity production data associated with syngas production (Swedish Energy Association 2008), carbon prices (from the Alberta offset market), and the marginal emissions displacement factor described in the bio-energy protocol section. This value can be added to the model as an increased price/m^3 of pulpwood (hereafter referred to as the bio-energy premium). The bio-energy premium will be added to the initial pulpwood price at time t=0. In the model, landowners are assumed to receive 50% of the bio-energy premium while forest companies are assumed to receive the other

50%. A 50% split was chosen because it is unclear how the bio-energy premium will affect demand and supply of pulpwood. The resulting pulpwood prices depend on the elasticities of supply and demand, which have not been estimated for the emerging hybrid poplar market. To illustrate, the bio-energy premium can be calculated if we assume a carbon price of \$15/tonne CO_2, a marginal displacement factor of 0.65MWh/tonne CO_2 and an increase in electricity production of 0.10MWh/m^3, the bio-energy premium is estimated to be \$1.15/m^3 by the following equation:

$$\frac{tonne\ CO_2}{0.65MWh} * \frac{\$15}{tonne\ \ CO_2} * \frac{0.10MWh}{m^3} * 0.5 = \frac{\$1.15}{m^3} \qquad (16)$$

In addition to assuming that emerging bio-energy markets affect initial pulpwood prices, we also simulate increases in pulpwood prices over time. The growth rate of the pulpwood price predictions will be increased above the baseline assumptions provided in Yemshanov et al. (*under review*).

Chapter 4: Scenarios and Results

The modifications to the option value model discussed earlier will be applied in the context of six scenarios. Scenarios are used to perform a sensitivity analysis on a number of parameters in the model. The choice of parameters to be altered is based on the uncertainty surrounding the future of both carbon markets and bio-energy technologies. The changes made to the individual parameters reflect potential effects of carbon markets and structural changes in the pulpwood market derived from bio-energy technological improvements. It remains unclear what factors will have the greatest effect on the magnitude of land use change. Therefore, the model scenarios will attempt to explore the relative magnitudes that various parameters have on land use change. The model parameters adjusted in the scenarios are outlined in Table 4.1. Figure 4-1 outlines the pulpwood price predictions applied in the scenarios. Immediately following Figure 4-1, a complete description of the scenarios and their results are presented.

Table 4-1: Parameter values for the model scenarios used in the simulation.

	Carbon Price		**Pulpwood Price**		
Scenario	**Carbon Price (\$/Tonne CO_2)**	**Permanent Conversion Factor**	**Price Predictions**	**Initial Pulpwood Price (\$/m^3 millgate)**	**Carbon Revenue from Bio-energy (\$/m^3) to Landowner**
1. BASE	0	N/A	Baseline	40	N/A
2. BASE+CARB	15	0.1	Baseline	40	N/A
3. BASE+CARB+PCF 50	15	0.5	Baseline	40	N/A
4. BASE+CARB+BIO	15	0.1	Baseline	40	1.15
5. BASE+CARB+BIO15GR	15	0.1	Baseline rate +15%	40	1.15
6. FASOM 50	50	0.1	Taken from Alig et al. 2010 Higher than 15%	45.93	N/A

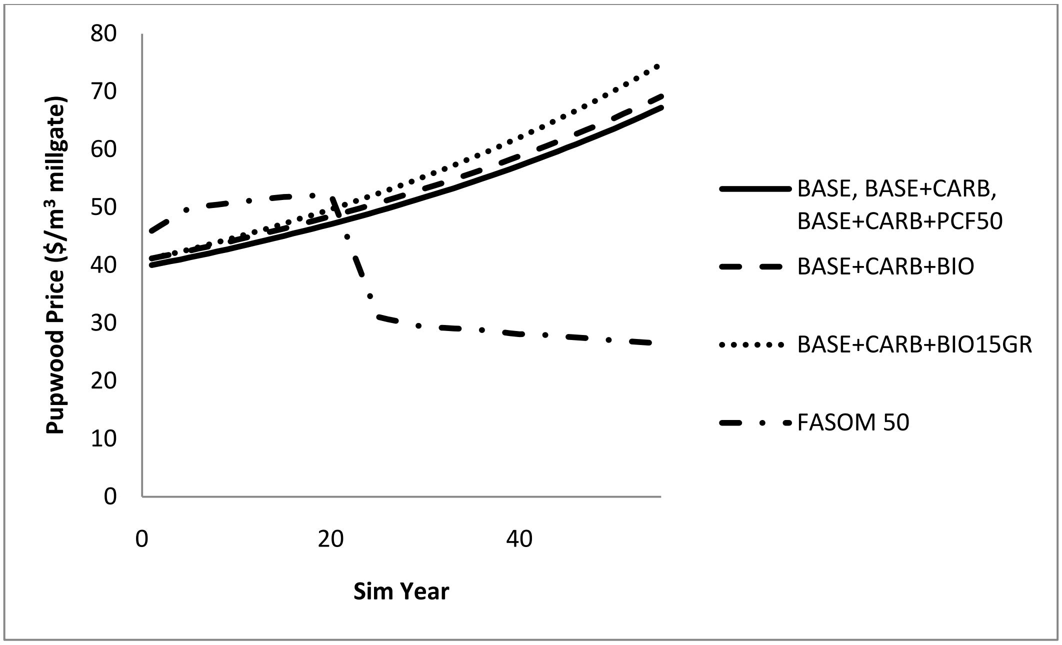

Figure 4-1: Pulpwood price predictions used in the six scenarios.

Prices are shown for the entire planning horizon. The BASE, BASE+CARB, and BASE+CARB+PCF50 share the same pulpwood price predictions. BASE+CARB+BIO has the initial pulpwood price increased, shifting the price projection curve upwards. The pulpwood price series for BASE+CARB+BIO+15GR shares the same intercept as the BASE+CARB+BIO case, however, the growth rate of the price series is increased by 15%. Finally, the FASOM 50 pulpwood price curve was adapted from the work of Alig et al. 2010. The FASOM pulpwood price projections are high in the short run because of reduced timber supplies predicted in the model. In the long run, prices trend downward towards the long run average.

Afforestation is presented spatially at simulation year 20 for the first five scenarios. Only cross sectional data can be presented to demonstrate the spatial extent of land use change. Simulation year 20 was chosen because the largest land use changes occur prior to year 20. Land use change in each of the first five scenarios slows after simulation year 20. The FASOM 50 scenario is very different from the first five scenarios. Land use change will be presented spatially at simulation years 10 and 50. Land use change over time will be presented graphically in the conclusion for each of the scenarios in the conclusion.

4.1 Scenario 1: BASE Case

The first scenario to be examined is the BASE case. The potential for afforestation will be evaluated for the province of Alberta using the option value model without carbon payments or bio-energy considerations. Baseline pulpwood price series and an initial pulpwood price of $40/m^3 is assumed. The BASE case will be used as a benchmark from which the marginal effects of adding carbon and bio-energy into the model will be estimated.

The BASE case shows the lowest level of land use change of all of the scenarios. The majority of rasters that switch from agriculture to forestry do so in the first year of the simulation. Sixty-four hundred ha convert to poplar plantations in the first year of the simulation. In the 27th year, another 400 ha convert from agriculture. The total area afforested during the simulation is estimated to be 6800 ha, representing less than 0.1% of the eligible agricultural land base (see Figure 4-2). Afforestation is predicted to take place in close proximity to mills in northern

Alberta. This is largely results from two factors. First, high transportation costs restrict the feasibility of afforestation to within close proximity of existing mills. Also, because agricultural productivity is, on average, lower in northern Alberta than elsewhere in the province, afforestation is more likely to be competitive in this region than in areas with greater agricultural productivity. All rasters that have been afforested remain as poplar plantations for the duration of the simulation.

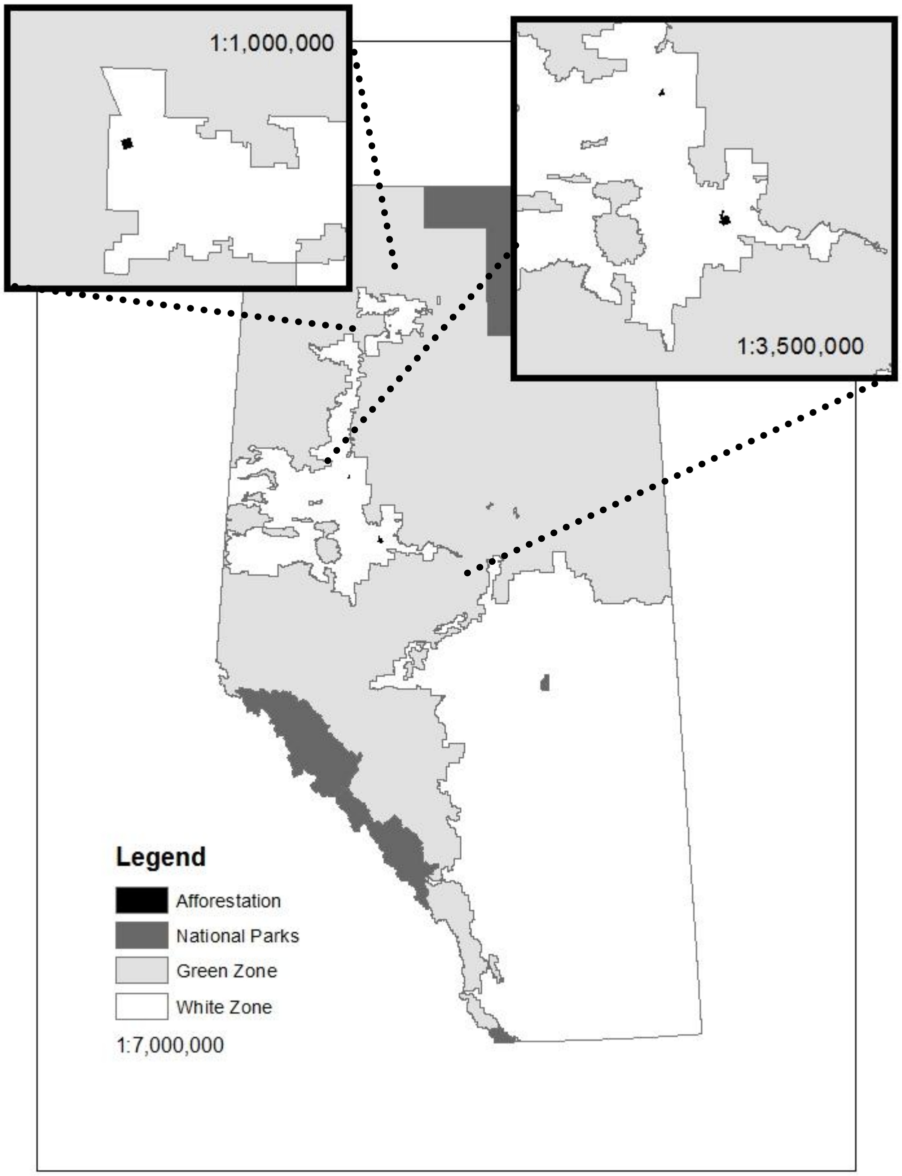

Figure 4-2: Afforestation for the BASE case at simulation year 20.

4.2 Scenario 2: BASE+CARB

The second scenario, BASE+CARB, is included to evaluate the effect that the Alberta Afforestation Protocol could have on the investment potential of afforestation in the Province. This scenario has a constant carbon price of \$15/tonne CO_2 and a PCF of 0.1. The \$15/tonne CO_2 price reflects the current cap on prices in the Alberta offsets system. The PCF of 0.1 reflects a likely permanent conversion factor for pulpwood. The pulpwood price series will be the same as the BASE case. A carbon price of \$15/tonne CO_2 and a PCF of 0.1 result in a price for carbon of \$5.50/tonne C in the model (illustrated by the following equation).[1]

$$\frac{\$15}{tonne\ \ CO_2} * \frac{3.667\ tonne\ \ CO_2}{tonne\ \ C} * 0.1 = \frac{\$5.50}{tonne\ \ C} \tag{17}$$

When the Alberta Carbon protocol is added there is a predicted increase in land use change compared to the BASE case predictions. The change results from the addition of carbon revenue. As with the BASE case, the majority of land use change occurs in the first time period. In the first simulation year, 8,800 ha convert to hybrid poplar plantations increasing to 10,400 ha in the 34th simulation year. Over the entire forecast horizon, 0.17% of the eligible land base is afforested (see Figure 4-3). This result equates to a 53% increase in the total area afforested relative to the BASE case. As with the BASE case, land use change is observed within close proximity to mills in Northern Alberta. In the final five simulation years, 800ha of hybrid poplar plantations revert back to agriculture.

[1] The model tracks carbon prices in \$/tonne C.

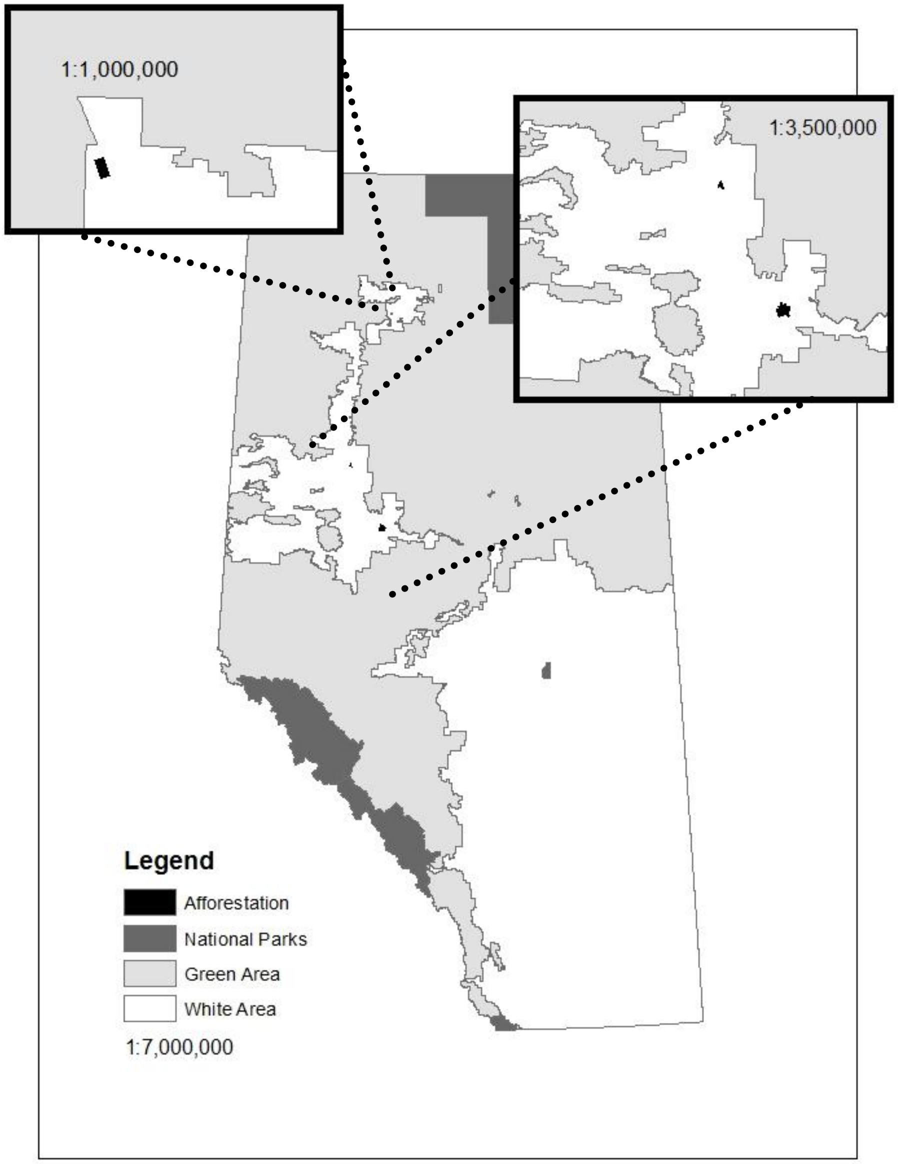

Figure 4-3: Afforestation for the BASE+CARB scenario at simulation year 20.

By adding carbon to the ELV equation, the returns to afforestation in the BASE+CARB scenario are unambiguously higher for each raster than in the BASE case. It is important to note, however, that changing the PCF will affect the returns to carbon sequestration. This scenario assumes a PCF of 0.1. As the PCF has not yet been determined in the afforestation protocol, it is important to understand the effect that changing this value will have on the investment potential of afforestation.

4.3 Scenario 3: BASE+CARB+PCF50

The third scenario, BASE+CARB+PCF50 has the same assumptions as the BASE+CARB scenario except that the PCF is increased to 0.5. Changing the PCF to 0.5 increases the price for carbon in the model to $27.5/tonne C. This effectively increases the carbon price in the model to five times higher than with a PCF of 0.1.

This change has a relatively large effect on land use change. Afforestation peaks in the middle of the simulation horizon at year 32. The maximum area converted to poplar plantations at any time is 84,000 ha. In the final three years of the simulation, there is a large conversion away from hybrid poplar back to agriculture resulting in 32,400 ha remaining in forestry. An important driver of land use change in this scenario is higher carbon prices. As carbon prices are static in the model, they become a smaller portion of the total pulp price further into the projection period, so some rasters revert to agriculture. During the peak of forestry activity, approximately 0.88% of the eligible land base is converted to hybrid poplar plantations (see Figure 4-4). Afforestation is largely concentrated around mills in Northern Alberta, however, unlike the BASE and BASE+CARB scenarios, some afforestation is also predicted to occur in close proximity to mills in Central Alberta

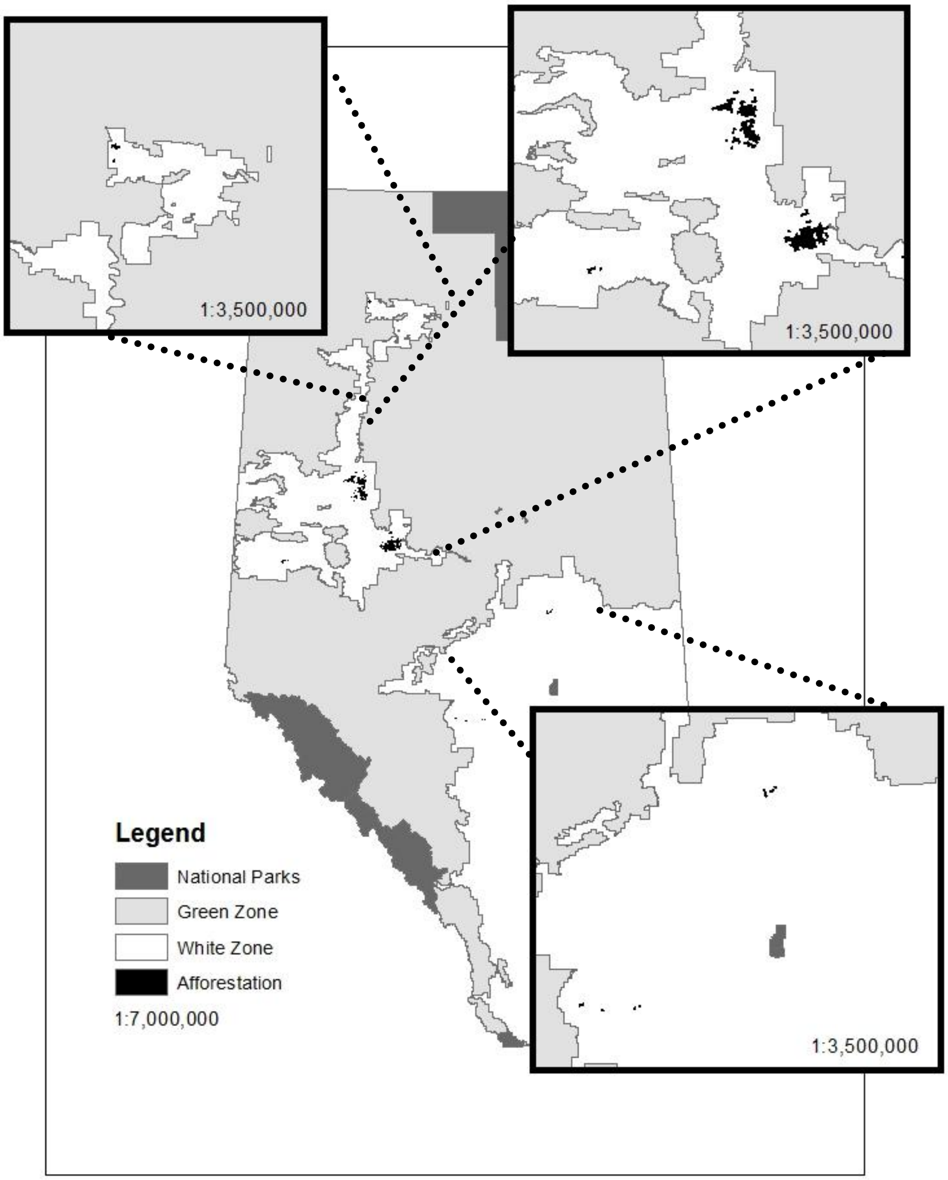

Figure 4-4: Afforestation for the BASE+CARB+PCF50 scenario at simulation year 20.

4.4 Scenario 4: BASE+CARB+BIO

The fourth scenario, BASE+CARB+BIO, shares many of the assumptions as the BASE+CARB scenario (carbon price =$15/tonne CO_2, baseline future pulpwood price growth rate, and PCF=0.1). For this scenario, a bio-energy premium of $1.15/$m^3$ to the landowner is included which increases the initial price of pulp from $40/$m^3$ to $41.15/$m^3$. The bio-energy premium is included in the BASE+CARB+BIO scenario in an effort to capture both the afforestation protocol and the bio-energy carbon protocol.

Afforestation in this scenario is higher than under the BASE+CARB scenario; however, not as high as the BASE+CARB+PCF 50 scenario. Again, the majority of the land use change takes place during the initial time period (Figure 4-5). The area afforested in the first year is estimated to be more than 1.3 times higher than the area afforested at the peak of the BASE+CARB scenario. During the 43rd simulation year, the area afforested is estimated to be 32,000 ha for this scenario. Of the eligible land base in the province, 0.17% switches to poplar plantations from traditional agriculture. The majority of land use change is predicted to occur in Northern Alberta in close proximity to mills. Some land use change is predicted to occur in Central Alberta.

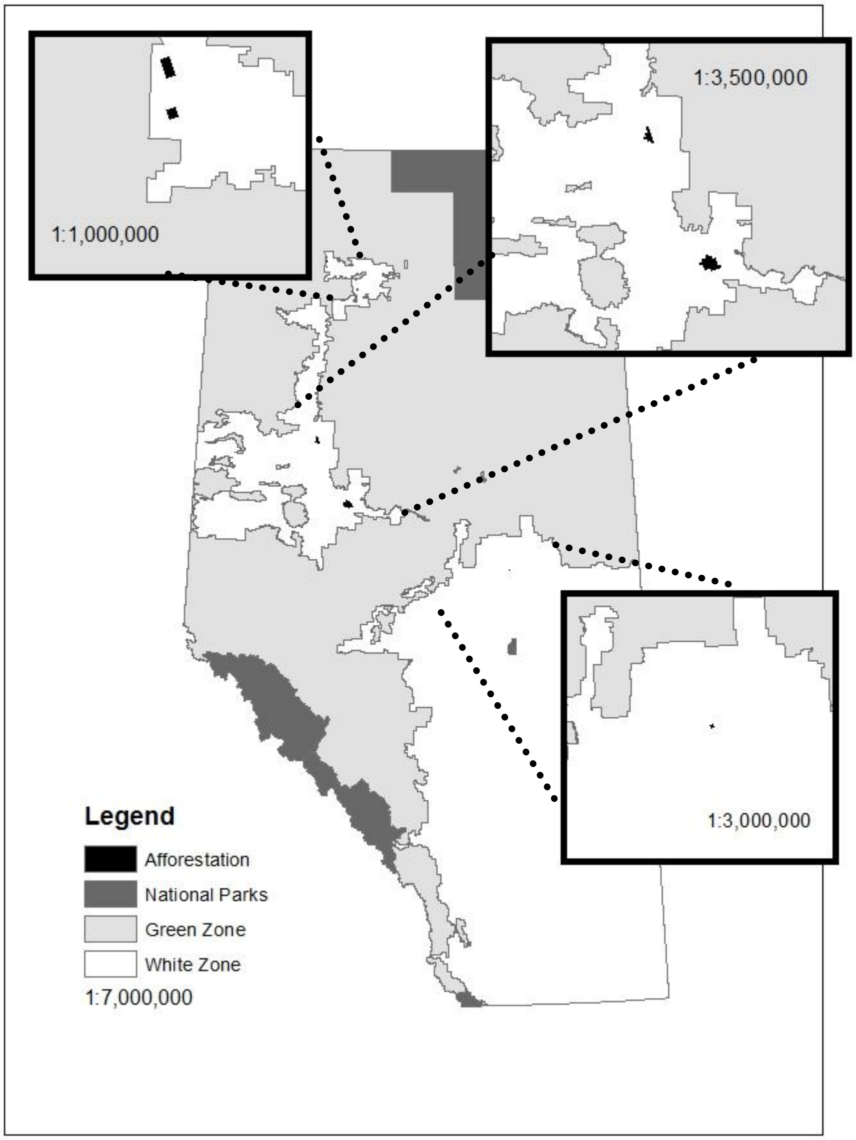

Figure 4-5: Afforestation for the BASE+CARB+BIO scenario at simulation year 20.

4.5 Scenario 5: BASE+CARB+BIO15GR

The fifth scenario BASE+CARB+BIO+15GR builds on the BASE+CARB+BIO scenario, increases the projected pulpwood price growth rates by 15% from the baseline assumption. The magnitude of the price increase was determined through sensitivity analysis conducted in initial research. At price increases below 15%, there was little change in predicted land use change compared to the BASE+CARB+BIO scenario. This scenario is included to model the general effects of a bio-economy (through increased future prices), as well as the afforestation protocol and bio-energy protocols.

There is a higher predicted level of afforestation in this scenario when compared to the BASE+CARB+BIO scenario. Afforestation increases throughout the simulation, and peaks in the second last time period. In the simulation year 53, the total area converted to poplar plantations is estimated to be 32,000 ha resulting in 0.34% of the eligible land base being converted from agriculture (see Figure 4-6). Consistent with the previous scenarios, the majority of land use change is predicted to occur in Northern Alberta in close proximity to mills. Some afforestation is predicted to occur in Central Alberta.

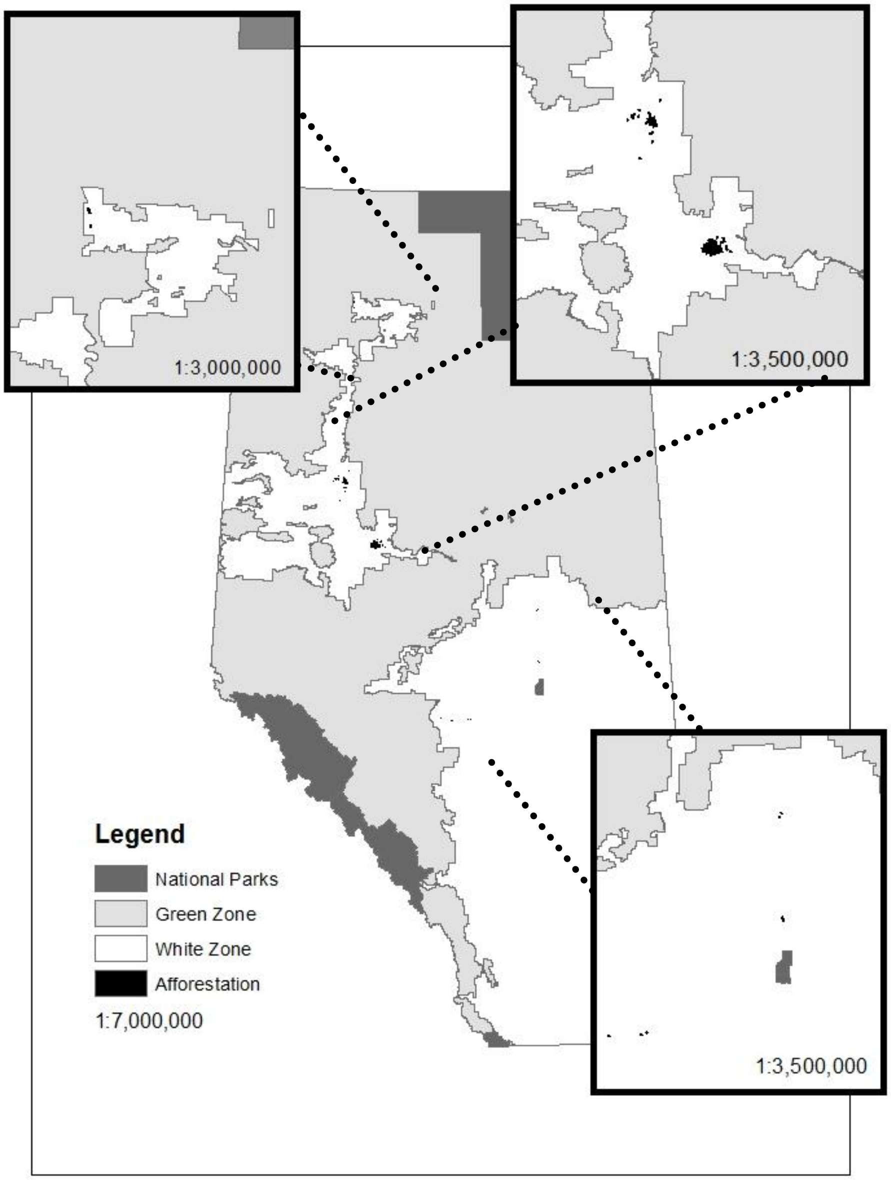

Figure 4-6: Afforestation for the BASE+CARB+BIO15 scenario at simulation year 20.

The combination of increased initial pulpwood prices and increased pulpwood price growth rates increase afforestation nearly five times above the BASE case.

Afforestation levels remain high at the end of the reporting period because pulpwood prices grow faster over time (relative to the BASE+CARB+BIO scenario) to compensate for the falling effect of a static carbon price.

4.6 Scenario 6: FASOM 50

The final scenario, FASOM 50, is included for comparison with pulpwood and carbon price projections presented in other recent work (eg. Murray 2005, Alig et al. 2010, Baker et al. 2010). The assumed carbon price is \$50/tonne CO_2 and the PCF is 0.1. Pulpwood price projections (initial and future) are taken from the FASOM modeling exercise presented in Alig et al. (2010). The initial pulpwood price is set at \$45.93/m^3. The projected pulpwood prices have been adjusted for the exchange rate and also for inflation. As the pulpwood price projections are not presented for the entire planning horizon of this model in the FASOM projections, pulpwood prices were extrapolated linearly past 2045 (the upper bound of the data provided by Alig et al. 2010).

In this scenario, there is a large initial spike in land use change for the first rotation of hybrid poplar (see Figure 4-7). In the initial forecast year, 226,800ha of agricultural land is converted to hybrid poplar plantations. The area converted increases to 250,000 ha in the 9th simulation year. In the 18th simulation year, however, most poplar plantations revert back to agriculture. Land continues to revert back to agriculture for the remainder of the simulation and in the final year, 2800 ha remain in forestry (see Figure 4-8). At the peak of afforestation, poplar plantations account for 2.62% of the eligible land base. Land use change is more widespread during the initial simulation years than for any other scenario, but is still concentrated in Northern Alberta in close proximity to mills.

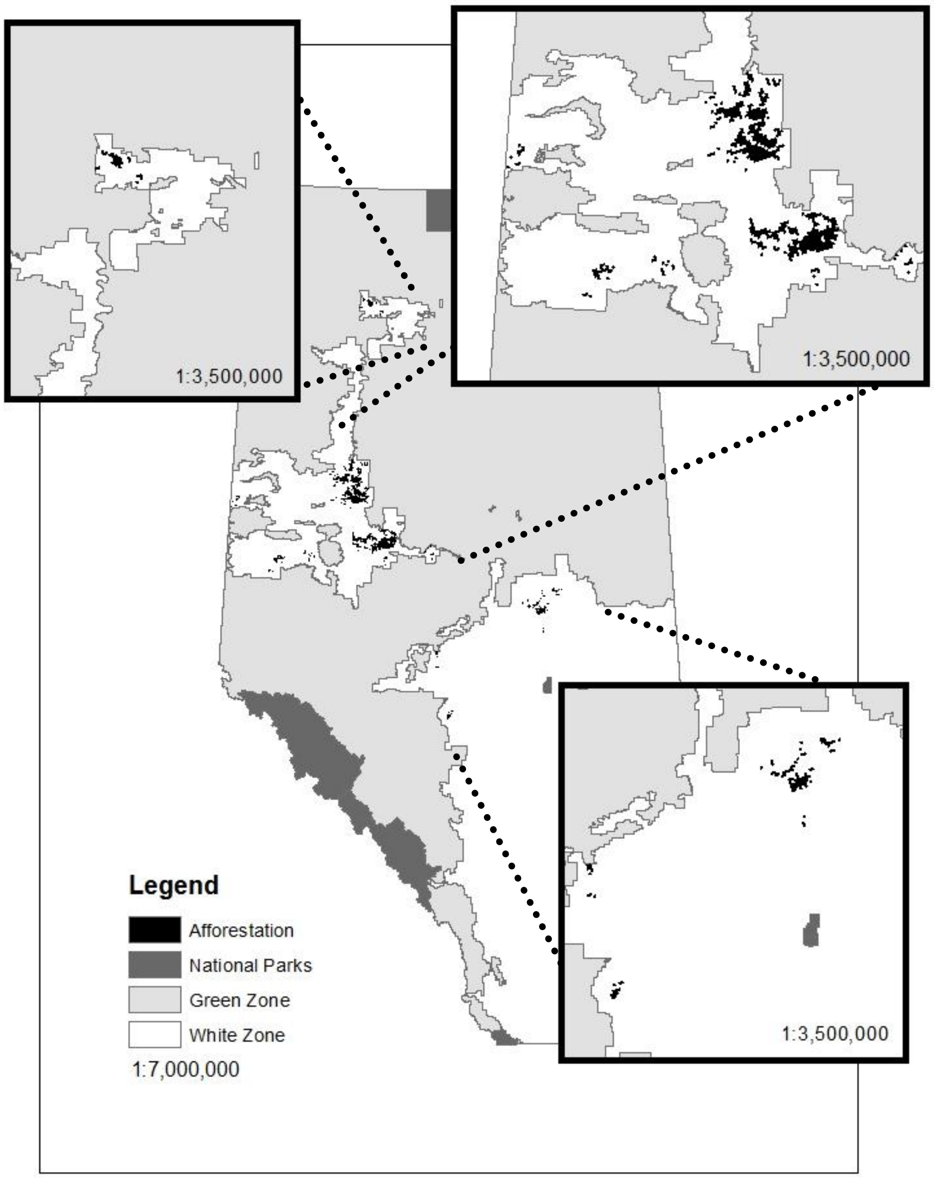

Figure 4-7: Afforestation for the FASOM 50 scenario at simulation year 10.

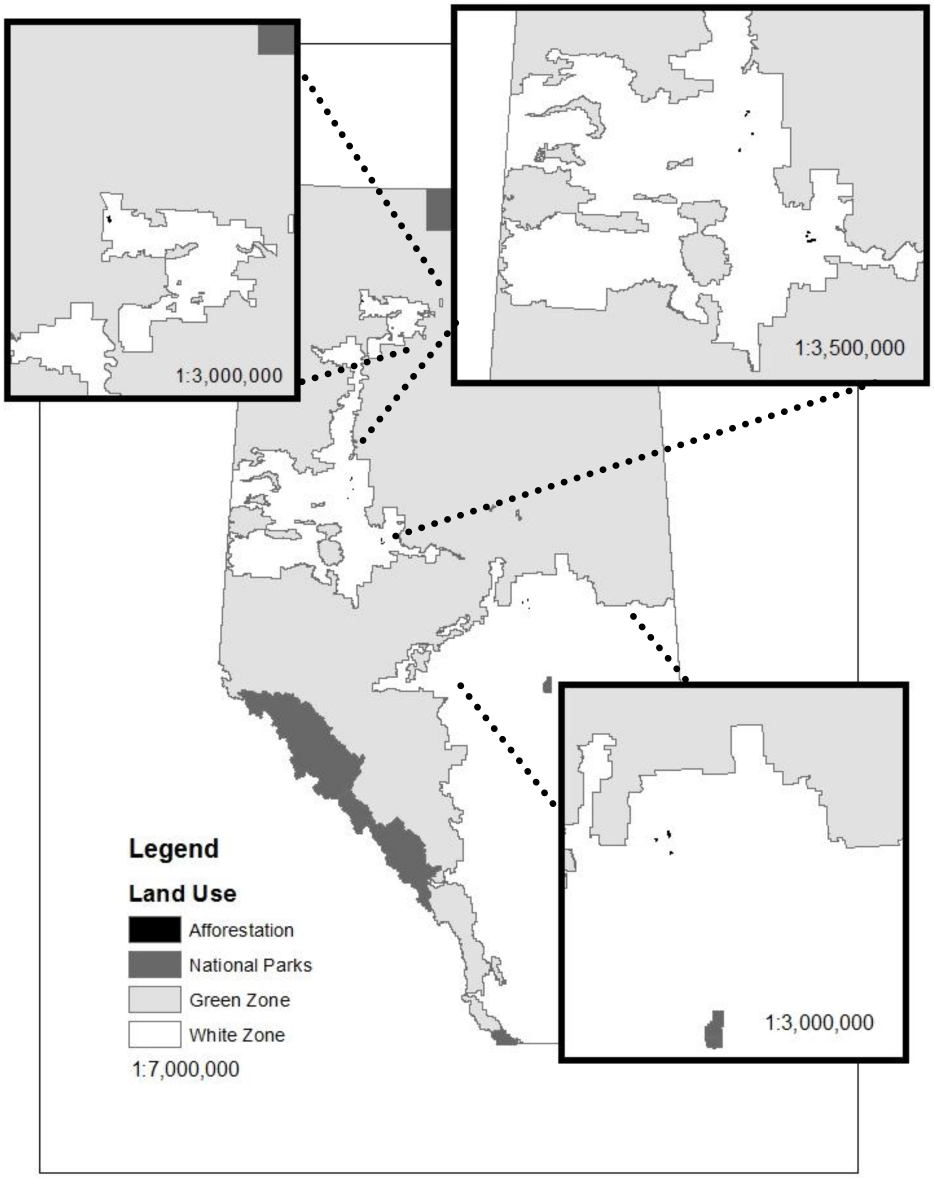

Figure 4-8: Afforestation for the FASOM 50 scenario at simulation year 50.

Chapter 5: Conclusions

Some general conclusions can be drawn from the modeling exercises presented above. Adding a carbon value to the model has an unambiguously positive effect on afforestation. Altering the PCF has been shown to have a relatively large effect on afforestation when compared to the other parameters. The bio-energy premium also increased afforestation. Finally, increasing the growth rate of pulpwood prices also increased the returns to afforestation resulting in higher predicted levels of land use change Figure 5-1 outlines afforestation levels over time for each of the scenarios.

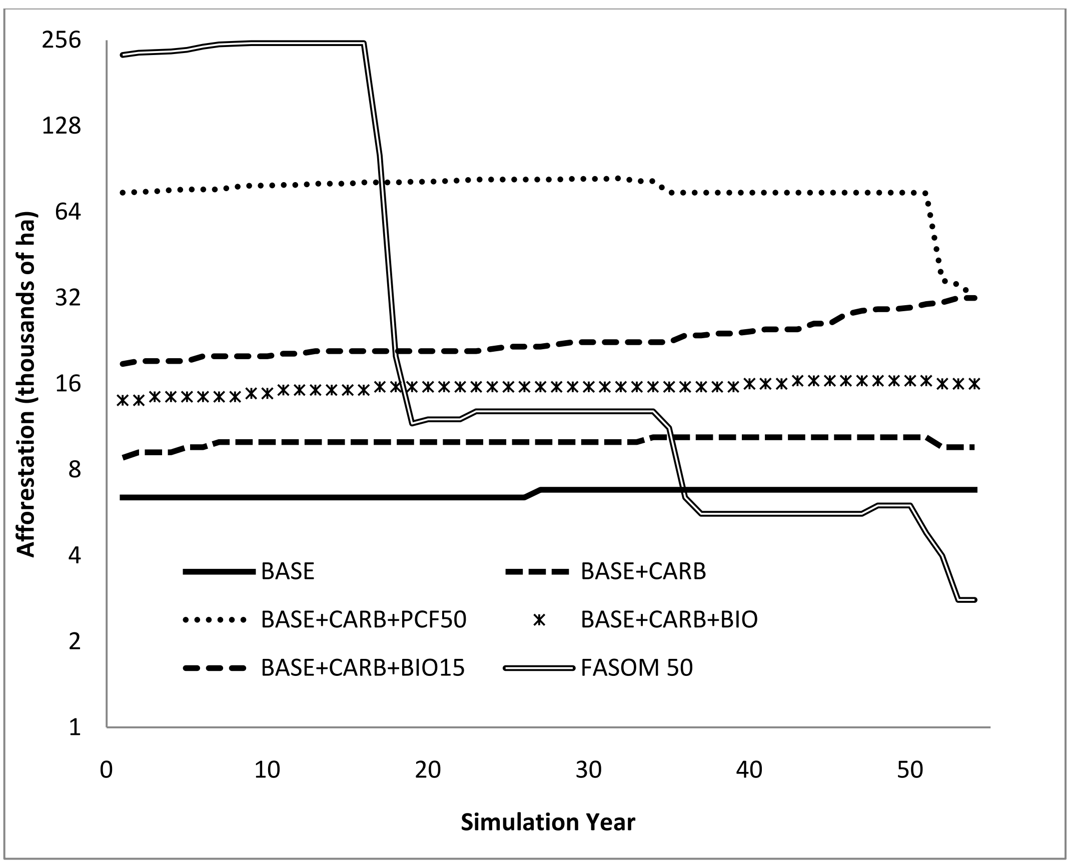

Figure 5-1: Afforestation levels for the six scenarios.

5.1: Effects of Changing the PCF

The PCF has a relatively profound effect on land use change. This is because changes to the PCF cause relatively larger changes in the price of carbon in the model. For example, if the price of CO_2 is $15, as in the BASE+CARB scenario, the model applies a price for C of $5.50/tonne with a PCF of 0.1 ($15/tonne CO_2 * 3.667 to C* 0.1). If a PCF of 0.5 is assumed, the price per tonne of C in the model is $27.50/tonne ($15/tonne CO_2 * 3.667 * 0.5). Therefore, changing the PCF in the model from 0.1 to 0.5 increases the price of carbon by 400%. With a PCF of 0.1, the price for $C0_2$ would need to be approximately $75/tonne to be equivalent to a carbon price of $15/tonne $C0_2$ with a PCF of 0.5.

The differences in afforestation between BASE+CARB and BASE+CARB+PCF50 illustrate the effect of changing the PCF. The BASE+CARB scenario predicted only slightly more afforestation (3600ha) than the BASE CASE. The BASE+CARB+PCF50 scenario predicted substantially more afforestation (77,200ha) than the BASE case. As the PCF is a measure of the "permanence of carbon" (see literature review), the more permanent the carbon from afforestation is believed to be (or more importantly legislated to be), the greater the returns to afforestation.

5.2: Spatial Extent of Afforestation

Afforestation in all of the scenarios is predicted to occur relatively closely to pulp and OSB mills in the northern part of the Province. Although many of the OSB plants in the province have curtailed production in recent years, they were included in the model. The future of the OSB market is uncertain, and the mills that have ceased operation still have forest tenure and invested capital. If OSB markets improve in the future, they may begin operation again. Land use change predictions for the six scenarios are therefore optimistic given the current state of Alberta's OSB mills. If OSB mills that are currently closed do no reopen in the future, the predicted afforestation in close proximity to these mills would not likely occur. The close proximity of afforestation to mills illustrates the substantial effect of increased haul costs on the viability of afforestation. Land that is relatively close to mills better suited for afforestation than for land that is further away. Furthermore, the returns to agriculture are lower in the northern part of the province, and are therefore better suited for afforestation.

5.3: Effects of Changing Price Series Growth Rates

The model demonstrates how small changes in current pulpwood prices have a relatively large effect on land use change. Moreover, a carbon sequestration protocol with a PCF of 0.5 is predicted to have a more profound effect on land use change than the bio-energy premium. An interesting area of future study could look at the land use change elasticities for each of the model parameters.

In the model, pulpwood and agricultural prices are assumed to grow over time in all scenarios (except in the FASOM 50 scenario). Carbon prices, however, are static over the planning horizon. The large conversion from hybrid poplar plantations back to agriculture predicted in the BASE+CARB+PCF50 scenario illustrate the effect of static carbon prices. The increasing returns to agriculture over time offset the static value for carbon. If the carbon price is not allowed to increase over time, the benefits from afforestation for the purposes of carbon offset generation will decrease over time. If the carbon price evolved as did pulpwood and agricultural prices, we would not expect to see a reversion to agriculture in the BASE+CARB+PCF50 scenario. The current price of carbon is capped at $15/tonne $C0_2$ equivalent in the Alberta market. The BASE+CARB+BIO15 scenario illustrates the long term effects of changing the growth rate of the pulpwood price series in the model. The returns to afforestation grow at a faster rate than the returns to agriculture in this scenario. Unlike the BASE+CARB+PCF50 scenario, afforestation continues throughout the planning horizon. In the final time period, the cumulative afforestation for both the BASE+CARB+BIO15 and the BASE+CARB+PCF50 scenarios are nearly identical (32,000ha and 32,400ha respectively).

5.4: Pulp Market Volatility

The results from the FASOM 50 scenario illustrate the effect of highly volatile pulp markets. High carbon prices would not be able to sustain afforestation levels if pulp prices decreases substantially in the long run. This scenario represents a pessimistic view of future pulpwood markets as pulpwood prices decrease substantially from simulation year 20 onward. Significant structural change to the world demand for pulp would need to take place for this scenario's predictions to be realistic.

5.5: Additional Model Assumptions

Electricity production was assumed to be the end goal of adopting syngas production. As future energy product prices change, and as advancements in syngas technology accrue, the relative investment viability of other end uses may also change. There is potential to use syngas to produce a wide array of other bio-products. The option value of producing various bio-products from syngas was not modeled in this exercise, but could be included in future work.

Furthermore, the growth rates of hybrid poplar were assumed to be constant over time. Increases in growth rates resulting from specialized breeding programs or from genetically modified poplars would also increase the relative investment viability of afforestation compared to traditional agricultural production on marginal lands. Future research should also be conducted to determine the effect of increased growth rates on land use change within the province.

5.6: Closing Statements

It is clear that the adoption of the bio-energy technologies and carbon markets could have a substantial impact on land use change in the province. This study illustrates how assumptions regarding carbon prices, carbon conversion factors, and future prices are important factors to consider when predicting future land use change. Factors increasing the demand for pulpwood will ultimately increase the investment viability of afforestation. Furthermore, revenue from carbon offsets also increase the investment viability of afforestation in the Province.

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Yemshanov et al. *under review.* A real options-net present value approach to assessing land use change: a case study of afforestation in Canada.