Production and Utilization of SRC Willow Biomass in Nova Scotia

by

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Dalhousie University is located in Mi'kma'ki, the
ancestral and unceded territory of the Mi'kmaq.
We are all Treaty people.

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ABSTRACT

Short rotation coppice (SRC) is a promising alternative to forestry. Within Nova Scotia and across Canada, the biomass industry is heavily focused on forestry products for biomass energy generation but is significantly underdeveloped with regards to agricultural biomass; specifically, SRC willow. Research has indicated that from a growing perspective, there are few barriers; with a suitable climate to support production in a number of provinces including Nova Scotia, however, uptake has been limited. This research investigates the policy and funding landscape that would support SRC willow production in Nova Scotia and develops a model; allowing potential producers to evaluate whether there is both potential production capacity and financial viability.

This research demonstrated that, while there is biomass policy across Canada, pushing forward biomass as an energy source, there is significant variation across the provinces and only minor mention is made of agricultural biomass (SRC willow) as a potential fuel source. This is reflected in the lack of funding opportunities available for agricultural biomass, translating into a significant lack of SRC willow production both at a commercial and at a research level. Spatial analysis was conducted to assess the production capacity of short rotation coppice willow in Nova Scotia, finding capacity in the Northern areas. To assess the economic viability of SRC willow, an economic model was developed and used on Dalhousie University's Agricultural Campus to determine the viability of them producing their own SRC willow for energy generation. The analysis found that production and use would only be viable where low land rental costs were available and high SRC willow yields could be achieved.

LIST OF ABBREVIATIONS

ALIP	Agricultural Land Inventory Project
CLI	Canadian land Inventory
COMFIT	Community Feed-in Tariff
DSS	Detailed Soil Survey
FIT	Feed-in Tariff
GHG	Greenhouse Gas
GWh	Gigawatt hours
Ha	Hectare
IRR	Internal Rate of Return
kWh	Kilowatt hours
MWh	Megawatt hours
NPV	Net present Value
ODT	Oven Dry Tonne
PJ	Petajoules
RHI	Renewable Heat Incentive
SRC	Short Rotation Coppice
TWh	Terawatt hours

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CHAPTER 1 INTRODUCTON

Canadians utilize a wide range of different energy sources for electrical generation, from traditional fossil fuels, to various renewable energy sources with a total installed capacity, of 145 Gigawatts (GW) as of 2017 [1], producing 639 Terawatt hours (TWh) in 2017 of which, 18.9% came from renewable energy sources [2]. Of the renewable energy sources, it is estimated that 1.4% come from biomass resources, with 2017 seeing seventy biomass power stations with a total installed capacity of 2.04 GW throughout the country, producing an estimated 8.7 GWh of electricity [2]. Projections from the National Energy Board estimate that by 2040, biomass energy generation will grow to 3.8 GW, representing 5% of energy generating capacity in Canada up from 3% in 2014 [3]. This increase is expected to occur in B.C., Ontario, Quebec and Alberta through the conversion of coal-fired power stations to biomass. Biomass feedstocks commonly used for electrical generation include forestry, forestry residue, landfill gas, spent pulping liquor and municipal solid waste. Across Canada 4.6% of households use wood as their primary or secondary energy source, with it being estimated that over 27 TWh of energy derived from wood is consumed by the residential sector per year. In the industrial sector it is estimated that from biomass, over 111 TWh of energy is consumed per year, being predominantly derived from industrial wood waste products, with the pulp and paper industry being the largest consumer with over a half of the biomass energy being used by this industry [2].

Energy from biomass, whether for heating, electrical generation or for use in combined heat and power (CHP) systems, is largely considered to be a ‘carbon neutral’ energy source that has the benefit of being a renewable and secure national energy resource. Traditionally biomass has been derived from forestry resources and is still widely used globally, however in the last 20 years, agricultural biomass, while it cannot compete on the scale of forestry biomass, does offer some benefits including using inactive land, development of new business, improved local economies, and the reduction of greenhouse gas (GHG) emissions [4].

According to the literature, predominantly European, there needs to be; 1) suitable growing conditions; characterized by the right soil type and quality on land that has low incidences of stoniness and on fields with a suitable gradient and adequate solar radiation, temperatures and rainfall, 2) available land that is acceptable for short rotation coppice (SRC) production; typically marginal land, 3) an available, easily accessible market, 4) access to appropriate harvesting and planting equipment, 5) economic viability which may involve the use of subsidies, and; 6) supporting policy and political will for SRC willow production and utilization.

Even within Europe despite SRC willow being evaluated from an economic perspective for the last 25-30 years, the market has still not fully developed due to the aforementioned issues. The production of SRC willow is relatively well known within Europe and there are a limited number of plantations in North America, however there is a distinct lack of knowledge of SRC willow production and supporting mechanisms for SRC willow production within the Canadian Maritime region and specifically Nova Scotia.

Whether for farmers, landowners, internal or external investors, considering involvement in developing or participating in a biomass industry, there is a clear need to de-risk the whole biomass supply chain process before interested parties may be willing to investing capital in the production or utilization of biomass feedstocks. One area that needs to be confronted is the lack of data within the province that will aid in identifying potential provincial crop yields and production locations and the need to provide a clear framework for investor decision making. Before investors are liable to invest in the province, there must be confidence in a return on investment, which can be indicated by running supply, logistic and economic models on the desired supply chain or using decision support models; defined as information systems that provide guidance in decision-making activities. An economic model should be able to compile and generate useful and meaningful information and offer viable options or outcomes through the analysis of raw data and via allowing the user interaction to evaluate different courses of action.

The primary focus of this research is to examine the potential of SRC willow as a biomass feed stock, classifying it as ‘agricultural biomass’ for use within Nova Scotia based upon current economic and production conditions. SRC willow is a fast-growing energy crop, suitable for direct combustion that is currently in production predominantly within the European Union, with some small-scale production in North America and a number of trials within Canada. SRC willow, under the right economic and production conditions has the potential to contribute towards a sustainable biomass economy, improve regional energy security, while contributing toward an overall renewable energy strategy and the reduction of GHG emissions.

CHAPTER 2 OBJECTIVES

SRC willow is a promising biomass feedstock, grown and utilized in parts of Europe as an energy feedstock for electricity generation. Within Europe, where there is significant unrealized potential for SRC, studies have shown from both an economic and spatial perspective that the adoption of SRC willow in a wider context needs to have multiple complex factors align for success to be realised.

To determine the potential for production, there needs to be a clear understanding of the current production landscape and what the potential challenges and drivers for production are. Seeing potential for production based upon the production landscape and the demand for a product, producers and users need to identify whether there is land capacity within their region for production and importantly whether it is economically viable to produce and/or use SRC willow for energy generation. This research aims to fill existing gaps and advance knowledge in the evaluation of SRC willow as a viable contribution to the biomass energy mix in Nova Scotia through:

1. A review of biomass policies and their influence on biomass production within Nova Scotia.
    a. Identification and review of biomass policy and support for developing agricultural biomass markets within Canada and internationally.
    b. Identification of funding opportunities used to promote biomass and SRC willow production.

    c. Identification of the production methodologies and technological components required for SRC willow production.

2. Evaluation of SRC willow production and utilization within Nova Scotia through:
    a. Evaluation of the land capacity for potential production and determining whether Nova Scotia can/should support the production and utilization of SRC willow based upon available land.
    b. An analysis of the economics of SRC willow production in Nova Scotia, based upon known production techniques and operating costs using a case study using Dalhousie University's Agricultural Campus biomass combined heat and power system.

CHAPTER 3 LITERATURE REVIEW

This literature review aims to provide background knowledge of the two major factors this research is focused on that influence SRC willow development: the economics and the availability of suitable land for production. This literature review provides a review of the different economic evaluation methodologies used and their conclusions and a review of the different spatial models used for evaluating SRC willow potential in a given region and their results. Chapter 5 contains a detailed review, incorporating literature of the different biomass policies used both internationally and within Canada and Chapter 6 focuses on reviewing the technological requirements for SRC willow production incorporating a literature review.

3.1 Biomass Definition

Biomass is defined as any organic matter present within an ecosystem, comprising of both living and dead animal and plant material. Biomass as considered in modern society references material that can be utilized as a feedstock for the production of products ranging from furniture to construction material, as a fibrous material for the manufacturing of pulp and paper, as a cellulosic material for the production of biofuels and as a modern direct fuel source [5].

As an energy/fuel source, biomass occupies both a traditional role for the purposes of cooking and the generation of heat in either open-flame or basic stove heating systems or as an increasingly important fuel source in the electrical energy-generating sector and in combined heat and power systems [5]. Current estimates state that approximately 2.5 billion people in predominantly developing nations are still utilizing solid biomass (wood, charcoal, agricultural residues) for the traditional purposes of cooking and for traditional heating methods in the home [6].

In contrast to developing countries, biomass in developed countries is considered a sustainable and alternative source of energy compared to that of fossil fuels [7]. As a fuel source it is utilized by the homeowner as a domestic heating system fuel source and as a feedstock that forms part of a sustainable energy mix system for either electrical generation, derived heat (heat generated from electrical generation), direct heat and transport fuel production [8]. The purpose of pursuing biomass as an energy source and the development of a bioeconomy is largely a part of pursuing three objectives; the reduction of GHG emissions, the pursuit of energy security within a given regions and to develop a sustainable system of energy generation and the sustainable growth of society [9].

3.2 Biomass Energy Generation

Total energy supply in 2014 was identified as 573 EJ (159,167 TWh), with a final energy consumption of 360 EJ (100,000 TWh) [10] [11], of this bioenergy accounted for 59.2 EJ of Supply and 50.5 EJ of consumption. Breaking total consumption down, 1.47 EJ is attributed to electrical consumption, 0.77 EJ for derived heat, 45.1 EJ from direct-heat and

3.09 EJ from transport, making bioenergy the third largest renewable source for total energy consumption.

Globally there is a continual increase in demand for biomass energy, with electrical generation from biomass provided directly from forestry, agricultural and charcoal having increased from 95.2 TWh in 1990 to 184.3 TWh in 2016, with this accounting for 7.1% of global renewable energy generation [12]. The World Bioenergy Association attributed all biofuels of generating 493 TWh of electrical generation, equating to 23% of global electrical energy generation.

Within the European Union the production of total energy from renewable sources for 2016 saw production reach 8.83 EJ with biomass in the forms of wood (both forestry and short rotation energy crops) and other solid biofuels account for 44.7% of renewable energy generation (heat, electricity, and transport). According to the International Energy Agency, the share of renewable energy for heat consumption in both space heating and water heating and for industrial processes was 9% in 2015 with it expected to rise to 11% by 2024 [13].

Data from 2015, identified 23.4% of wood fuel within Canada being utilized for electricity, 26.6% of wood fuel being used within the Residential sector and 50% of wood fuel being used within the industrial sector; the primary use of wood fuel in the residential and industrial sectors is for heat production [14]. Electrical energy from biomass facilities currently accounts for 3,198 MW of installed capacity (Table 3.1), generating 1.2% in 2005 to 2% in 2017 of Canada’s total electrical generation [14] and two hundred and eighty-two facilities using biomass for heat production [14]. British Columbia is the leader in terms of utilizing biomass for both electrical generation and heat production, with then dominant source of biomass being derived from forestry resources [15].

Table 0.1: 2017 Canadian biomass energy generation by province [9].

Province	**MW - Electric**	**MW - Thermal**
Alberta	460	1,454
British Columbia	1,423	55,677
Manitoba	23	276
New Brunswick	118	683
Newfoundland and Labrador	18	120
Nova Scotia	91	109
Ontario	625	1,727
Prince Edward Island	1	15
Quebec	379	1,242
Saskatchewan	63	174
Canada (Total)	3,198	12,872

Of biomass used in Canada for electrical generation, forestry accounts for the largest feedstock. The use of forestry biomass within Canada has expanded from the traditional uses; solid wood products (composites, logs, sawn-wood and squared timber) and pulp and paper to modern uses of electrical generation and the production of biomaterials (biocomposites and lignin and lignin-blended materials) and biochemicals (resins and thermoplastics) [16].

3.3 Canadian Biomass Fuel Sources

Evaluating biomass fuel sources used in Canada, the majority of systems utilize wood chips or pellets, with no indication that SRC or agricultural residues are being utilized, almost 75% of systems are using wood chips exclusively, with 13% utilizing wood chips and saw dust and sawmill by-products.

According to analysis by Stephen *et al.* [17], the choice of feedstock is highly variable and geographically specific within Canada. Biomass systems on PEI currently use woodchips exclusively, compared to New Brunswick using wood pellets, British Columbia utilizing secondary wood products, Quebec has been using chipped forestry harvest residues, thinnings, and pulpwood, when available and the Territories have been using imported wood pellet from Alberta and BC.

Reviewing the availability of forestry residues within Eastern Canada, there is estimated to be between 5 million and 49 million tonnes per year of forestry residues [18], with 1,145 tonnes per year of forestry residues available for utilization in the Maritime regions. Data from 2006 suggested 21,229,000 ODT of sawmill residues being available throughout Canada, however according to Krigstin, with Nova Scotia having potentially 340,427 ODT (2011) and New Brunswick having 233,497 ODT (2010) suggesting significant available biomass feedstocks [19]. However Krigstin *et al.* [18] highlight due to the recent turndown in the forestry sector there has been a number of sawmill closures throughout Canada and in particular the maritime region, with only twenty currently remaining. Despite the drop in sawmills, there is still available sawmill residues, however annual quantities are not available.

Figure 3.1 demonstrates the spread of heat producing biomass systems throughout Canada, with concentrations of systems focused in British Columbia, Alberta, Ontario, and Quebec.

Figure 3.1: Dispersal of biomass for heat production across Canada [15].

Regarding consumption of all biomass feedstocks, there are currently ninety-three projects within the Maritimes region utilizing wood pellets, eighty-one utilizing wood chips and forty-five utilizing a blend of wood chips and sawdust, of the other systems there are a mix of feedstocks including whole logs, construction wastes and hog fuel (Figure 3.2) [20]. The projects in question are systems producing heat, electricity or are combined heat and power systems.

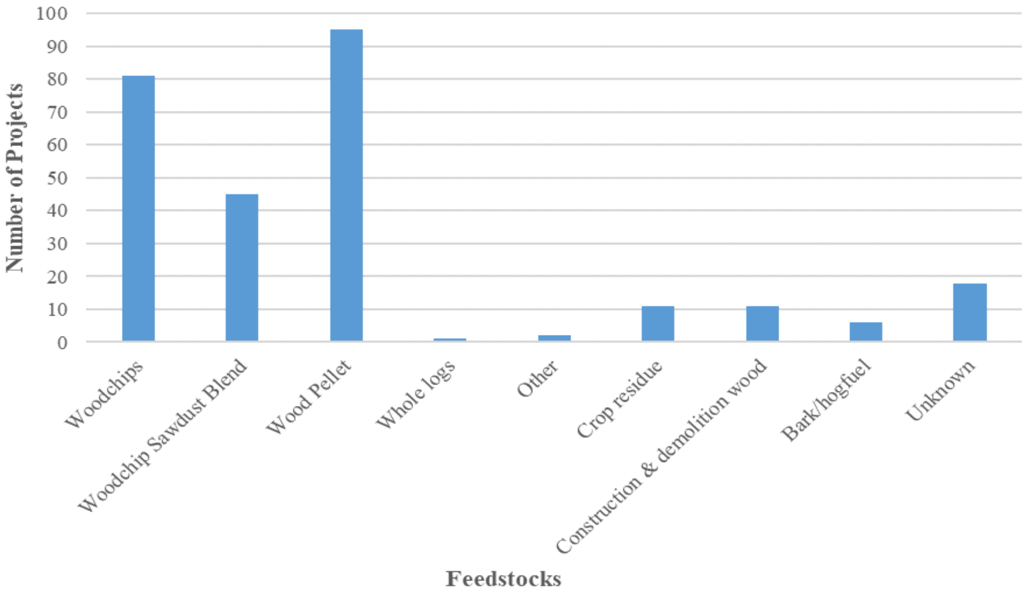


Figure 3.2: Biomass for heat generation projects within the maritime region - feedstock type.

Figure 3.3: Dispersal of bioenergy systems within the maritime region [20].

The proliferation of biomass systems within Canada and the maritime regions (Figure 3.3) is predicated on available feedstocks and there being a policy drive by the federal and provincial governments and available funding to push forward a biomass agenda [20].

3.4 Economic Viability of SRC Willow

The economic viability of SRC willow is determined through several factors: establishment and management, yield potential, market prices of SRC willow against alternative fuel sources and the availability of subsidies.

There have been a number of studies focused on evaluating the economics of SRC willow, predominantly within the European Union [16, 17, 18, 19, ,20, 21]. Faash and Patenaude (2012) evaluated the economic viability of SRC willow production in Germany, highlighting that despite SRC willow having significant potential of contributing woody biomass to Europe's energy mix there remains significant uncertainty [21]. They evaluated five key variables that influence SRC willow economic viability: SRC willow yields, woodchip market prices, available subsidies, cost level and opportunity costs (those being alternative annual crops) [21].

Based on novel approach to yield forecasting Faash and Patenaude (2012) assigned a 'cite suitability ranking index', based upon temperature, soil water table data, rainfall and soil quality and used that as a basis to determine how an average yield of a given SRC willow variety would perform; this was model was based upon known yields and site specific data from trial plots [21]. Woodchip market prices were used as a potential indicator for prospective SRC willow chip sale prices. Cost levels relate to plantation establishment and management costs and assume readily available and accessible planting and harvesting equipment, values were derived from fourteen literature sources, providing minimum and maximum thresholds. Subsidies focused 30% establishment costs and subsidies made per hectare of cultivated. Evaluation was made on three different subsidy scenarios. Finally, opportunity cost analysis costs were made against conventional crops [21].

In their evaluation, Faash and Patenaude (2012) found that under the existing conditions at the time, 1) it is still more profitable for producers to grow traditional agricultural crops,

2) that there are significant barriers to SRC willow development including limited practical experience, 3) a distinct lack of production and economic data, 4) uncertainty about economic variables, and; 5) the variable cash-flow of SRC willow production with high initial capital costs and late amortization results in SRC willow being seen as a high risk investment [21].

Conclusions on how to make SRC willow more viable focused on the need for more effective subsidies as their research demonstrated that even under the most favourable subsidies (30% establishment cost and a \$200/ha payment) it was insufficient economically compared to that of traditional crop production systems. The research also identified that the lack of alignment with regards to agricultural and forestry policy, regulations and legislation was providing a substantial barrier due to lack of administrative costs and supressing economies of scale [21].

Schweier and Becker (2013) evaluated the economic viability of SRC poplar of marginal land in Germany, using experimental plantations. The research focused on evaluating the economics of the establishment-management-harvesting-transportation supply chains and focused on specific planting and harvesting equipment [22]. The research concluded that the production of SRC poplar on marginal land is not profitable where the yield is less than 11 ODT/ha/year and the market price is less than \$103/ODT or less than \$132/ODT where the yield is 7 ODT/ha/year [22]. They further concluded that even accounting for subsidies under the Common Agricultural Program, subsidies of >\$400 would be needed to be financially comparable to growing other agricultural or horticultural products on marginal land [22].

To achieve this, the authors state that there needs to be a political will to push SRC production on marginal land unless the market price for woody biomass products significantly increases. The authors also state that economic viability can possibly be achieved where there are decentralized biomass energy systems and short transportation distances from field to end user, which would also as a side effect have a positive impact on local economies [22].

Pereira *et al.* (2016) evaluated the potential for SRC poplar production for bioenergy in Southern Portugal [25]. The research aimed to evaluate the financial viability of SRC poplar production from the perspective of farmers and two specific biomass power plants in the region of Alentejo, Portugal. The research aimed to evaluate the potential for SRC poplar to cover 10% of the two power plants needs giving a biomass requirement of 522,474 ODT/year [25]. The study found that based on different potential yield value scenarios (10, 15 and 20 ODT/ha/year), the scenarios were not financially viable with there being a need for subsidies to become economically viable. The research stated that establishment costs were one of the biggest barriers, however proposed that as well as establishment subsidies there could be potential for carbon allowances linked to the power plants and used to offset some production costs; tying these subsidies to the EU's GHG emission targets [25].

Kasmioui and Ceulemans (2013) undertook and financial analysis of SRC production in Belgium evaluating a number of different production parameters from an establishment-management-harvesting-transportation supply chain, having variability in equipment for planting and harvesting. The research found that at the specific time (2011 – 2012) SRC willow production was not financially viable in Belgium other than in very specific circumstances, finding that only under specific high yields, a high sale price (or the availability of reasonable financial subsidies), effective management and even then it may still be more financially advantageous to produce corn or other annual agricultural crops [26].

Inhibitors to adoption were found to be: 1) an established market, 2) evidence of potential profitability, and 3) availability of equipment for planting and harvesting being within reasonable distance. The researchers found that there was potential for markets but not fully established, the production of traditional agricultural crops was still more profitable, and the researchers found that the widespread availability of equipment within a reasonable distance was not currently achievable. Other risks to the financial viability of SRC willow production relate to; 1) disease and pest risks, where any infestation may tip the profitability margin due to the need for pesticide application, and; 2) increased distance to the end-user, where more than 50 km and delivery costs are absorbed by the farmer can impact profit margins [26].

Kasmioui and Ceulemans (2013) conclude that the key solutions to farmers investing in SRC willow production include incentivising power plant operators to offer long-term supply contract and the wider availability of appropriate, effective and accessible subsidies [26].

Buchholz and Volk (2013) evaluated the profitability of SRC willow grown in the state of New York, USA, in relation to the accessibility of various incentives programs. Within NY State, establishment grants of 75% were made available in addition to annual payments (for biomass production) and various low-cost start-up loans were available [27]. The research concluded that establishment grants were critical to the financial viability of production, and the use of loan interest loans were beneficial to production systems however annual payments had little impact on the probability of a plantation. A further incentive of match payment was evaluated which applied to production on marginal land, where \$50/ODT of delivered, material was made to the producer.

The research concluded that having incentives and subsidies available was the key driver in ensuring profitability of SRC willow plantations and their removal would inhibit further production to financial non-viability. Similar to other research, Buchholz and Volk (2013) highlight the challenges faced by the large investments required for establishment [27].

Similar research conducted by Feil and Musshoff (2018), evaluated investments in SRC under uncertain circumstances from a value chain perspective [28]. The researchers considered the main value chain to SRC production to be biomass heating systems, with the economics of production being positively influenced by understanding the capacity of nearby biomass heating systems. The researchers here are suggesting, like others that proximity to the end-user is key to success but to combat reluctance of production in relation to the uncertainties of production, supply contracts need to be in place [28]. Feil and Musshoff (2018) similarly reach similar conclusions to Spiegel *et al.* (2018) that pricing floor are liable to be ineffective and establishment and production subsidies are important in achieving a positive economic case [28].

A study by Stolarski *et al.* (2015) took a novel approach of evaluating the economics of seven different varieties of SRC willow grown in Poland without the use of subsidies. The study found that by utilizing naturally high yielding varieties with a high energy content on productive land can reduce the expenditure on fertilizers and being able to harvest on a three-year rotation. However, the research found that the main driver for a positive economic case is the impact of biomass price, with a higher market price resulting in higher income per hectare, especially for those high yielding variety. The study also concluded that transportation distance to the final end-user was critical, with distances of >25 km being preferable and anything over than 200 km being unviable for six out of the eight varieties evaluated [23].

A later study by Stolarski *et al.* (2017) evaluated the impact of different soil amendments on biomass yield for several different biomass species including SRC willow. The study found that the application of soil amendments can have a positive impact on biomass provided the correct biomass species and variety is selected; finding that SRC willow responds best to amendments (compared to black lotus and poplar) [24]. As with previous research by Stolarski *et al.*, they conclude that even with soil amendments (manures, composts, biosolids), the impact of sale price and transportation distance to the end user has the greatest impact on profitability [24]. However out of the eight amendments applied, the application of lignin or mineral fertilizers still resulted in revenue at a travel distance of 200 km, suggesting that the application of certain soil amendments can contribute towards revenue [24].

Hauk, Knobe and Wittkopf (2014) undertook an evaluation of available academic literature focused on the economic evaluation of SRC willow for biomass energy production finding thirty-seven different economic studies (combining willow, polar, black lotus, eucalyptus and daniella) going back to 1985 [29]. Of the studies, twenty-three were based on European studies, ten within the US and one each for Canada (a study on poplar), Chile, Benin and Belarus. Of the previous studies reviewed 43% drew conclusions of SRC willow being economically viable, 19% unviable and 38% provided mixed results, however in drawing these conclusions there is a wide variance in how these results and conclusions have been drawn [29].

Hauk, Knobe and Wittkopf (2014) concluded that there was significant variation due to a wide range of different underlying assumptions which has a direct impact on the financial conclusions drawn by the researchers. The research drew conclusions that the variability in underlying assumptions is as a result of there being a lack of real data on the costs and benefits associated with SRC willow production globally and there being a wide range of methodologies used to evaluate the economics and what production system is used. These wide variations in both economic and production system creates an issue of making it difficult to compare system to system and to provide an overall picture of the viability of SRC willow as a crop suitable for energy production. This study finally concluded with a proposal for future researchers to use standardized nomenclature and to use standardized or similar economic evaluation methods [29].

3.5 Modelling of SRC Willow Production

There are several research publications that have evaluated the economic potential of SRC willow production in various locations, predominantly Europe [25, 26, 27, 28, 29]. The key purpose behind these papers is to identify whether the production of SRC willow is economical from the perspective of a given region or country. The move towards assessing the viability of SRC in these research papers, is the need to contribute towards energy security and to contribute towards moving away from fossil fuels by using agricultural lands.

Ericsson *et al.* (2006) in evaluating Poland, where agricultural crop productivity was assessed to be lower due to traditional farming methods (reduced mechanisation) and had generally low soil quality, suggested that as Poland's needed to start moving away from coal based energy generation, SRC willow could potentially be a viable option [30].

To assess the value of SRC willow Ericsson *et al.* (2006) used a model that assessed the Annual Gross Margins of production using a discount rate of 6% over a twenty-two year life-span, the methodology used a cereal production model (although not detailed), switching out items, e.g. a thresher for a harvester, to allow for analysis. As an analysis, they compared SRC willow production against the production of wheat and barley and looked at the price of woodchips, finding that only a high price for woodchips leads to profitability [30]. Additionally, they found that there would be a negative impact to a farm currently growing cereal crops if they aimed to switch or partially switch to SRC willow production due to the high establishment costs associated with SRC willow and the loss of revenue associated with reduced cereal production [30]. Ericsson et al (2006) found that the for farmers to adopt SRC willow as a production crop, it has to be at least as profitable as cereal production, but that it is unlikely to be adopted by Polish farmers, unless suitable subsidies are provided to offset the loss in revenue before first harvest which would at the earliest occur in year four [30].

Styles *et al.* (2007) performed an economic analysis of energy crops in Ireland comparing miscanthus and SRC willow production taking a net present value (NPV), a method used to value all future cash flows over the life of an investment or a project discounted to the present, using a discount rate of 5% [26, 30]. The purpose of conducting the analysis was as a result of the introduction of the Irish Government implementing a planting and maintenance subsidies program, designed to boost the production of energy crops in Ireland, the study and aimed to determine the economic outlook of both SRC willow and miscanthus [31]. Styles *et al.* (2007) discuss the variable used and used a range of values based on literature from European plantations [31].

Styles *et al.* (2007) concluded that there were high establishment costs for both systems, finding that miscanthus production is more expensive than SRC willow productions, due to annual harvesting costs compared to every three years with SRC willow, and having a shorter lifespan. However, they state that on a dry matter basis, due to generally higher yields in miscanthus compared to SRC willow they are comparable. Further indicated that with SRC willow, chipping and drying incurs higher costs than chipping and using the chips wet, suggesting that the drying processes is a critical factor [31].

Stjepan *et al.* (2017) performed and economic analysis SRC production in in Croatia and used NPV and internal rate of return (IRR), the expected compound annual rate of return that will be earned on a project or investment [36], to assess the viability of SRC using a discount rate of 7% and varying between 5% and 10% for sensitivity an using the production values for a 5 ha plantation area, extrapolating to 1,000 ha with a potential yield of 42,000 tonnes per harvest cycle [32]. Stjepan *et al.* (2017) found that the with than increasing discount rate applied the NPV declined, however they determined that over the course of the plantation the NPV could be $4,328,000 CAD with a discount rate of 5%, dropping to $219,000 with a discount rate of 10%. Their conclusion was that for energy generators seeking to use SRC willow, there is potential, however there needs to a comprehensive financial analysis and there has to be sufficient up-front capital available to establish an SRC Plantation [32].

Schiberna, Borovics and Benke (2021) evaluated the economics of SRC plantation in Hungary, focusing on poplar, they similarly took a net present value approach but also included a mean annual net income (MANI) and looked at the variation between a high, medium and low yield, yields were based an experimental plantation in the northern region of Hungary and obtained through personal communication, the planting methods were based upon literature sources [33]. Schiberna *et al*. (2021) found that to achieve a break-even point, there had to be at least 7 ODT/ha/year, however with the inclusion of 75% establishment grants the break-even point can be 5 to 6 ODT/ha/year, however there were currently no subsidies available for SRC production, therefore their view was that SRC production will be limited in Hungary [33].

Fuertes *et al.* (2021) conducted an economic overview of SRC production in the Mediterranean region, with economic analysis based on the use of Net Present Value. Fuertes *et al.* (2021) found that the biggest impacts on profitability and thus viability related to land rental costs where it could range from $0 to $800/ha and the cost associated with irrigation due to the dry climate found in Mediterranean regions. The based their analysis on a cut and chip system, finding that the NPV after twelve years could range between $1,500 and $13,150/ha and will predominantly influenced the woodchip price and achieving acceptable yields [34].

A large proportion of the economic evaluation research papers reviewed either cite the need for improved subsidies for SRC production due to make SRC financially viable. In a study by Mola-Yudego and Pelkonen (2008), they evaluated data from eight hundred and ninety-one SRC willow plantations between the 1986 – 1996 period within Sweden. Their conclusion was that during this period where there were significant subsidies available, SRC production thrived; however from 1996, when the subsidies were reduced (in conjunction with new CAP regulations), the expansion of SRC willow plantations ended [37].

Research conducted by Spiegel *et al.* (2018) found that SRC adoption amongst farmers is limited due to the high establishment, harvest, and removal of SRC. The study aimed to evaluate different policy options for increasing the financial viability of SRC through, 1) the implementation a guaranteed price, 2) a price floor (minimum pricing), 3) establishment subsidies, and 4) ecological focus areas (This is an EU specific program similar to set-aside programs. In this instance, 5% of a farmer's land should be turned over for 're-wilding' which can include SRC). The research demonstrated that the use of guaranteed pricing and minimum pricing would be ineffective in increasing the uptake of SRC production, however the use of effective subsidies and ecological focus areas could act as drivers to increase production [38].

Review of available economic literature on the production of SRC willow clearly demonstrates that for successful production, notwithstanding a political will for SRC production, there needs to be, 1) effective selection of high yielding willow varieties, 2) production on suitable land or the application of effective soil amendments or use of fertilizers to achieve suitable yields, 3) short transportation distances from plantation to end-user, 4) biomass prices that are comparable or better than other agricultural or horticultural crops, and 5) available and effective subsidies for establishment costs and general subsidies for biomass production. Several studies also state that the financial success of SRC willow plantations is often site-specific and can be linked to the proximity of plantations to the end user.

The common theme through all these papers focuses on how to make SRC willow (or poplar) financially viable and is set in areas where there is, or was, limited to no production of SRC, with all of these economic evaluation studies are based on a single year establishment method followed by a twenty-two to twenty-four-year lifespan of the SRC willow plantation therefore do not take a staggered approach to SRC willow plantations. Basing production on a single year establishment, regardless of planting area, while providing a very useful analysis of how a plantation performs and the associated costs, does not account for the need to provide a biomass facility with year-on-year biomass feedstock. These other models have also taken the approach of basing their analysis on total combined area to be prepared (e.g. plowing) and planted without evaluating whether different fields require different levels of preparation. Using a total combined area is highly suitable when considering the planting process as there is a requirement to have the willow cuttings planted as quickly as possible, to minimise labour costs or refrigeration costs as the SRC willow cuttings are required to be chilled prior to planting to ensure viability. The other challenged faced by all studies is that there is still a lack of data to verify the results, this is an area where future work should be conducted and will be particularly important in the future for Nova Scotia.

3.6 Spatial Analysis of SRC Willow Production

Spatial analysis refers to the use of geographical data relating to factors affecting production of a given crop this often includes: soil type, soil quality, water table, slope and elevation and other factors including rainfall and temperature. Based upon sample data sets of known crop yields on known field parameters, spatial analysis aims to extrapolating this to a larger area, giving a theoretical overall yield for a region. Suitable and accurate spatial data is vital to achieving a good model as is having enough crop production data for the specific area being evaluated, where this is not available it is necessary to use good secondary data from the literature to approximate potential yields for a given area.

Typically, spatial analyses aim to determine, theoretically, how much of a given crop could be produced on selected land or under various scenarios, these exercises are not necessarily aimed at determining the economic viability of production or evaluating the logistical aspects of production but aim more to demonstrate what could be achieved. Spatial analysis is a useful tool for policy and decision makers as they provide useful insight into what may or may not be possible for any given item or system that requires land use or for planning purposes

Aylott *et al.* (2008) aimed to evaluate the spatial supply and potential for various SRC poplar and willow varieties within the UK. The study used data gathered from forty-nine trial sites throughout the UK and aimed to extrapolate the yield data to determine yield productivity and potential energy production potential across the UK. In the evaluation, the study undertook detailed soil samples of all forty-nine sites and compared these to various national soil datasets for the UK [39]. Temperature and rainfall were evaluated at each of the forty-nine sites and biomass yield was determined. Using these datasets in conjunction within soil, temperature and rainfall datasets, an empirical model was developed to create yield maps. The study considered all available land with some minor exceptions and aimed to identify the best areas for production using a hotspot analysis. Using all available land and not factoring in other crop production systems, based upon the three highest yielding cultivars of SRC willow grown at the time (cultivars including; Trichobel, Jorunn and Q83) it was estimated that the UK could produce 12.6 million ODT/year planted on 1.3M ha.

In a similar study to Aylott *et al.*, Bauen *et al.* (2010) utilized yield models for miscanthus and SRC poplar and willow and used GIS data including Agricultural land classification (ALC) datasets which categorise agricultural land into five grades of suitability for crop production: grade 1 relating to excellent agricultural land and grade 5 being poor for agricultural production. The ALC takes in to account the level of yield expected, the consistence of yields year-on-year, the cost associated with obtaining (harvesting the crop) and the flexibility of the land to produce a range of different crops. Bauen *et al.* (2010) utilized the datasets from Aylott *et al.* (2008) and Richter *et al.* (2008) and the ALC data to create unique parcels of land and to refine the model for identifying the production potential for bioenergy across England and Wales [40].

Bauen *et al.* (2010) focused on selecting the highest yielding crop for any given parcel of identified land, the results identified the potential of 15 million ODT/year in biomass production, with SRC willow as being suitable for 53.7% of land evaluated. With regards to the use of models success; it builds upon previous work conducted by other researchers, however the authors state that there are uncertainties within the model due to data gaps in areas including real drop production data and more up-to-date climate data to better reflect potential yields [40]. The authors conclude that while there could be significant land availability, for SRC willow, poplar or miscanthus to be widely adopted within the UK there needs to be a stronger economic case, political drive, financial incentives and significantly more research into production [40].

Kajba *et al.* (2010) aimed to evaluate the potential for short rotation coppice production in Croatia using a spatial model accounting for characteristics of soil type, soil quality, stoniness, slope length and elevation, to determine potential yields and land suitability, in addition the model further took in to account current agricultural land utilization [41]. The research identified the potential for 51,200 ha of forestry land that could be utilized for SRC production and 617,000 ha of agricultural land, producing a theoretical 470, 200 and 7,404,000 ODT/year, however by removing protected sites from the assessment and removing areas where production is not technically viable, theoretical production was reduce to a 430,000 ODT/year from forestry land and 2,827,800 ODT/year from agricultural land [41].

Kajba *et al.* (2010) conclude that while there is a considerable theoretical potential for producing energy crops, the small amount of SRC produced in Croatia is not likely to change without the availability of subsidies and incentives, effective and sustained political support and a change from current biomass policy, the lack of knowledge about SRC and production methods and a distinct lack of cooperation between different stakeholders [41].

Fiorese and Guariso (2010), based in the Emilia-Romagna region of Italy, developed a spatial model using spatial datasets focused on; 1) land suitability with the parameters of soil quality, slope, elevation and soil texture and excluding land that would be considered to be impractical for production (field size), 2) land availability; taking in to account current land use with the aim of not utilizing land that is currently used for arable cropping and pasture due to Italy's close link to agriculture and to reduce any negative socio-economic consequences [42].

The parameters set for land unsuitability for SRC production included altitude over 750 m, field slopes of 20% or greater, soil containing a high level of stoniness, limited upper soil layer and precipitation below 700 mm per year. Factoring in land suitability Fiorese and Guariso (2010) identified 970,100 ha suitable for production, however factoring in land availability, this is reduced to a potential area of 11,300 ha suitable for SRC production on marginal land (plus an additional 18,300 ha for sorghum on set-aside land) [42].

Fiorese and Guariso (2010) concluded that while it would be possible for farmers to produce SRC on marginal land within the region given the available market price (at the time this $102/tonne), the payback was approximately fourteen years, however this could be reduced to ten years [42]. Fiorese and Guariso (2010) further state that if incentives were available for both energy conversion technology (biomass to energy) and for biomass production, might be effective, however given the different administrative bodies for subsidies being different and the typical timeframe of five years for a typical national and regional government, this seems like an unlikely scenario. The authors cite this as one of the key reasons for a lack of SRC production within the region. In addition, within the region there is an lack of biomass-to-energy systems; reducing the market need for SRC biomass [42]. In reference to the model used, Fiorese and Guariso (2010), identify it as a useful model for policy makers and decision makers, citing the importance of incorporating land availability within the model to provide more likely and viable real-world results [42].

Taking a similar approach to Fiorese and Guariso (2010), Abolina, Volk and Lazdina (2014) evaluated SRC production in Latvia using a model based on land availability and land suitability [43]. Of the 2,352,159 ha of agricultural land in Latvia, the model identified 261,71 ha of agricultural land suitable for SRC production based on having available parcels of land that are greater than 2 ha, are within 1 km of a suitable road network and considering only marginal land. The model did not account for yields, however based upon SRC growth trials in Latvia, it is estimated that yields of between 7 and 10 ODT/ha/ year could be produced; giving a theoretical total yield of 1,584,856 to 2,264,080 ODT/year [43].

As with other studies, Abolina, Volk and Lazdina (2014) state that while this is a theoretical estimate, there are a number of factors that will impact the viability of SRC production in Latvia, 1) technical and infrastructure capacity, 2) market availability for SRC, 3) production knowledge, and; 4) the ability or willingness of potential producers to view SRC as a viable crop.

Other studies recognise that there is a need to evaluate SRC viability in relation to potential biomass end-user location, where an identified end-user, in the form of biomass-to-energy power generating facilities, would make SRC production more viable due the likelihood of long-term supply contracts. Voets *et al.* (2013) undertook a hotspot analysis focused on the Campine region of Belgium (focus on contaminated SRC willow) focused on determining optimum production areas abased on transportation distance to the end user.

Reviewing the research results for spatial analysis, there is a common approach to evaluation; the use of land suitability factors ranging from soil type and quality, elevation and field slope or gradient, stoniness, water availability (in ground and rainfall), minimum field sizing appropriate for production and in later studies [36, 35]; add in land availability; focusing on marginal land. By focusing on marginal land, this reduces the conflict of using highly productive agricultural land better used for crop production and incentivises the use of land that may otherwise remain un-used. As with the review of the economics of SRC willow, a number of authors put forward conclusions that while there is potentially available land in all of the countries reviewed there are significant barriers present; critically economic barriers through lack of effective subsidies or adequate market prices to make SRC viable for potential growers and there being a lack of strong political will for SRC production.

CHAPTER 4 METHODOLOGY

4.1 Policy Review Methodology

Part of the challenge facing the biomass industry is in ensuring adequate and sustained supply of biomass, which requires the uptake from farmers and/or ag-businesses. To understand potential production barriers, a review of barriers and challenges facing the production or agricultural energy crops, with a focus on (SRC) willow was undertaken.

Utilizing database search functions, key search terms were input based upon defined parameters: “energy crops”, “biomass energy”, “barriers”, “challenges”, “policy”. Each database provided a numerical value of results based on the search parameters. Based upon the number of results, additional filtering was applied to narrow the search results and remove articles with materials not deemed to be as relevant. Relevant articles are those that are specifically focused on barriers or challenges.

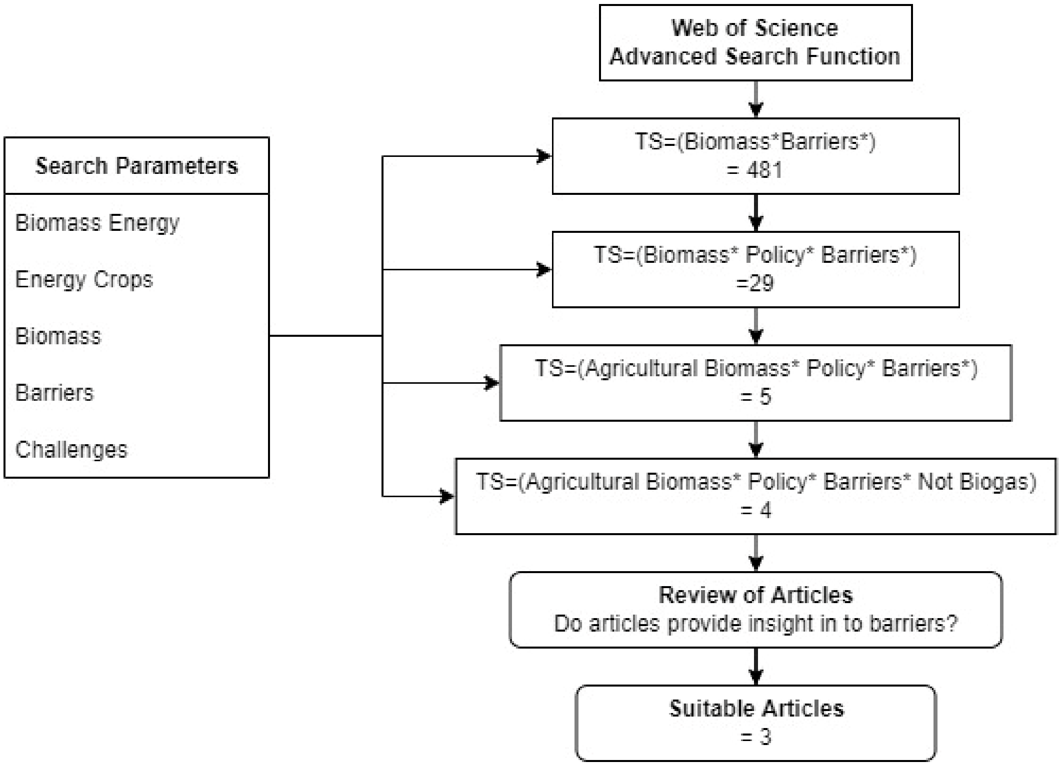


Figure 4.1: Policy barriers review methodology.

Articles were reviewed to identify production barriers to agricultural biomass with a focus on SRC willow. A second review was conducted to identify the activities and initiatives in each province within Canada to identify their status in relation to utilization of biomass, with a focus on agricultural biomass for energy generation. This stage assessed several criteria, including what levels if any of education, funding, research and development progress or opportunities were available in each province, with a focus towards SRC willow. The purpose of this was to provide an overview of best practices, particularly initiatives and activities, to identify where success is being achieved, determine relevance and how/if any of these practices or processes could be implemented in Nova Scotia.

4.2 Land Capacity and Economic Evaluation Methodology

In determining the economic viability of SRC production, there needs to be a clear understanding of the reasoning behind exploring SRC willow production and utilization, the most common reasons for production are for self-use or to sell to an existing or planned energy generating facility.

Regardless of the reasoning behind exploring SRC willow production there needs to be a clear understanding of the various production factors involved in SRC willow production and information must be available on whether there is available land for production. Spatial information forms a key part in the economic analysis through the requirement of identifying biomass production catchment zones, identification of facility or site locations, evaluation of field conditions and evaluation of financial costs in relation to field to facility transportation costs.

To determine the potential effective production capacity of SRC willow in Nova Scotia, there needs to be an understanding of the availability of agricultural land for production and potential yields based upon select field characteristics. Having identified these factors, production of SRC willow for biomass will be influence by the location of potential energy-generating facilities. Having determined whether there is sufficient land and whether there are sufficient yield estimates, an economic analysis must be conducted to determine the financial viability.

4.3 Biomass Decision Model

Biomass users can be defined as those who use, or intend to use, biomass, for the purposes of producing electricity, heat or combined heat and power (CHP). Users or potential users can range from dedicated energy producers to existing businesses with electrical and heat demands (processing facilities, farms, municipal buildings, colleges and universities, local businesses). Biomass users will have a number of clear objectives they will wish to meet, however, some objectives may be more important than the others, Table 4.1 provides the key objectives and decision variables for a biomass user.

Table 0.1: User objectives for SRC willow.

User Objectives and Decision Metrics	
Objective	**Decision Variables**
Obtain available biomass	• Can SRC biomass be produced within a specified range
Reduce Expenditure on Biomass Feedstock	• Is production economically viable • Is SRC willow production and utilization more/less economical than traditional biomass fuel sources

The decision pathways and considerations that need to be considered prior to evaluating the economic attractiveness is presented in Figure 4.2.

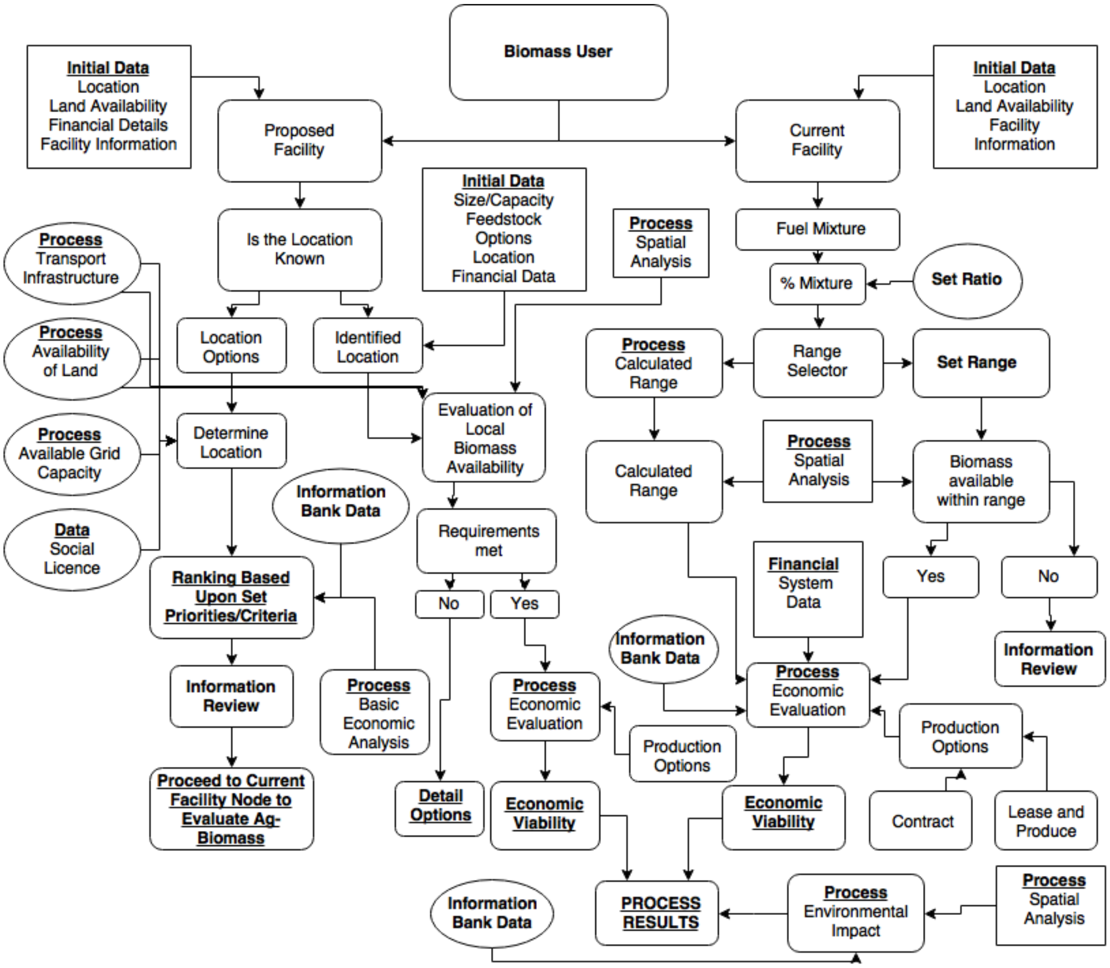


Figure 4.2: Decision pathways/considerations for a biomass user.

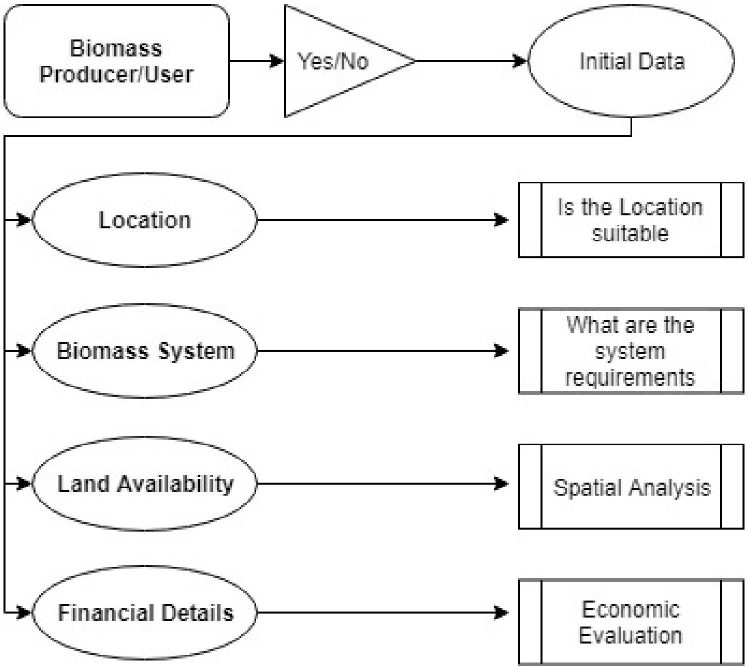


Figure 4.3: Biomass producer/user pathway model: step one

Step one of the pathway defines the key consideration in determining if SRC willow is viable based upon whether the location of the existing or proposed biomass system is suitable. Having a suitable biomass system, the system operating requirements need to be determined (Figure 4.3). Based upon system requirement and operational constraints (financial, maximum sourcing distance and land leasing options) and a financial analysis to determine whether SRC willow is economically viable for the biomass system. Alternatively, the location can be defined as a central location for production, followed by land availability analysis and financial analysis for production only.

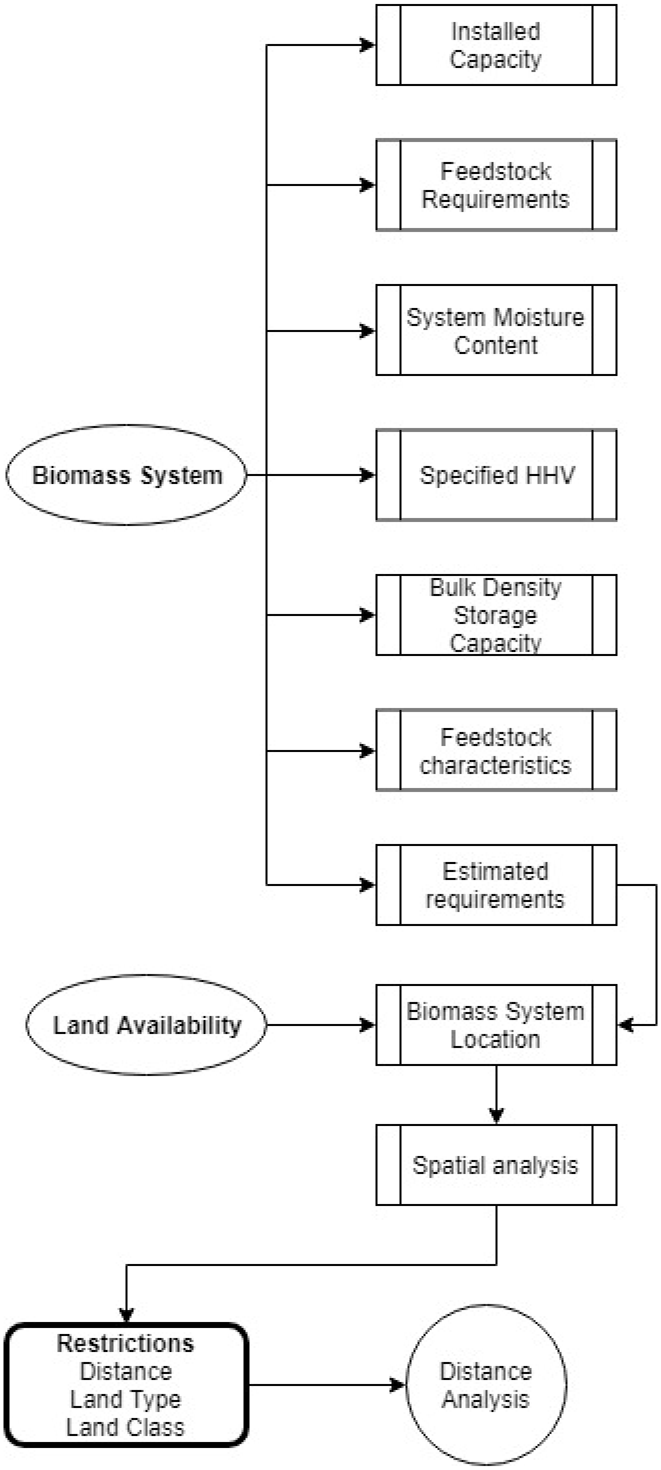


Figure 4.4: Biomass system and land availability analysis model.

Figure 4.4 displays the information needed to identify the requirements of the biomass system and identifies the estimated biomass consumption of the system. This is used in determining whether there is adequate land available based upon distance restrictions and estimated production based on land type and land class.

Table 0.2: Spatial information requirements.

Data Type	**Data Use**
Location	• Identifies location of user/producer
Land Availability	• Identifies hectares available
Land Types	• Rotational land and inactive land • Field-to-field proximity
Land Suitability	o Land class o Soil class o Stoniness o Water table o Slope
Provincial Map	• For placement of location • To find location
Road Networks	• For determining road transportation costs • Field to road proximity
Potential Yields	• Estimated yields based upon land suitability • Estimated yields based upon known varietal yields • To allow for land requirements
Grid Capacity and Locations	• Identify location for biomass system

Table 4.2 provides the key information required for to determine potential land capacity and potential yields at a given location.

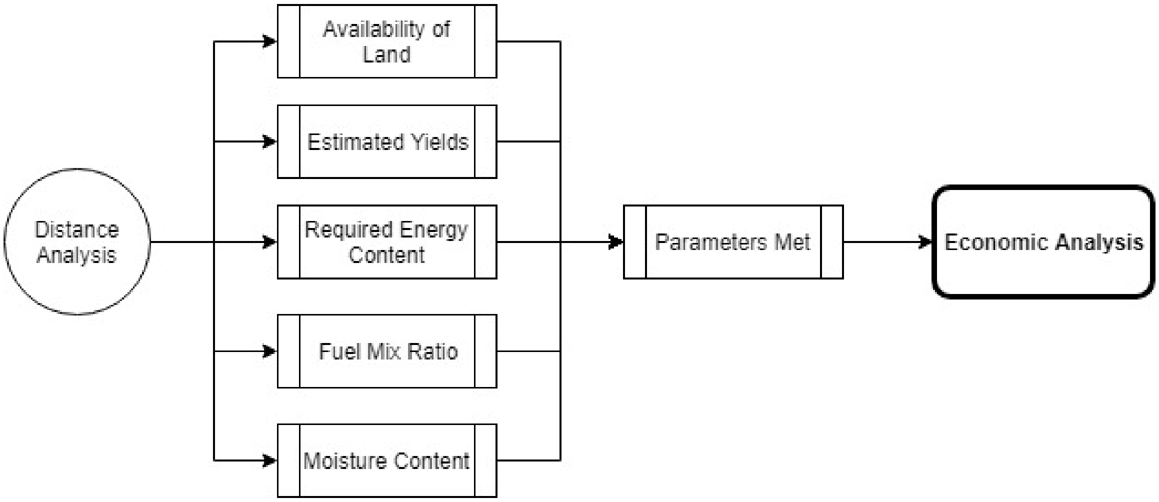


Figure 4.5: Distance analysis/spatial analysis.

Figure 4.5 provides a diagram of the steps taken after an analysis of distance has occurred and what parameter have to be met to ensure SRC willow production levels are acceptable before an economic analysis. Based upon the requirements of the biomass system and achieving a theoretical estimate of potential yields within the distance restrictions an economic analysis can be conducted. Figures 4.6 to 4.12 provides diagrams of each sub model of SRC willow production costs and considerations.

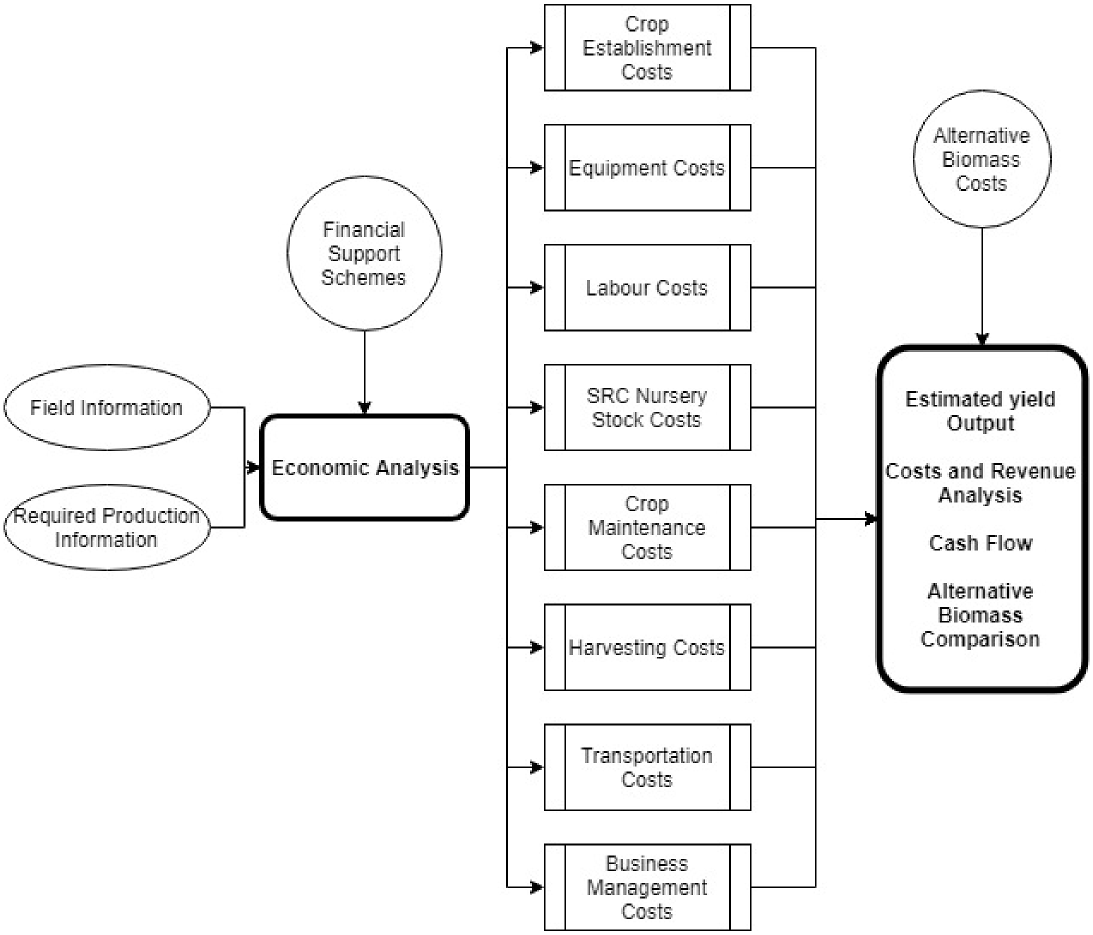


Figure 4.6: Economic analysis model.

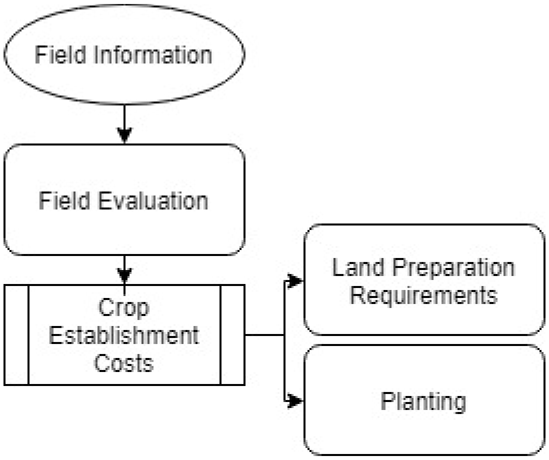


Figure 4.7: Crop establishment sub-model.

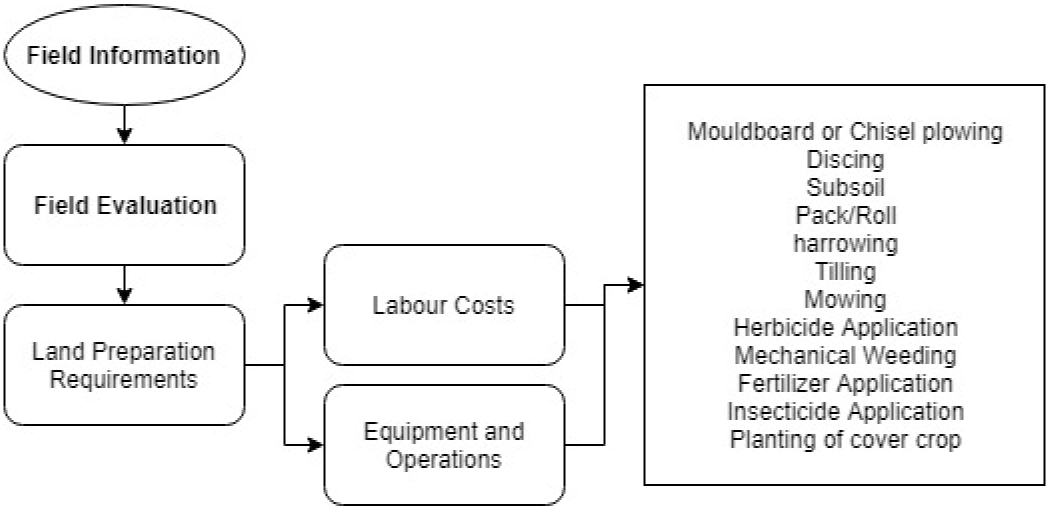


Figure 4.8: Land preparation sub-model.

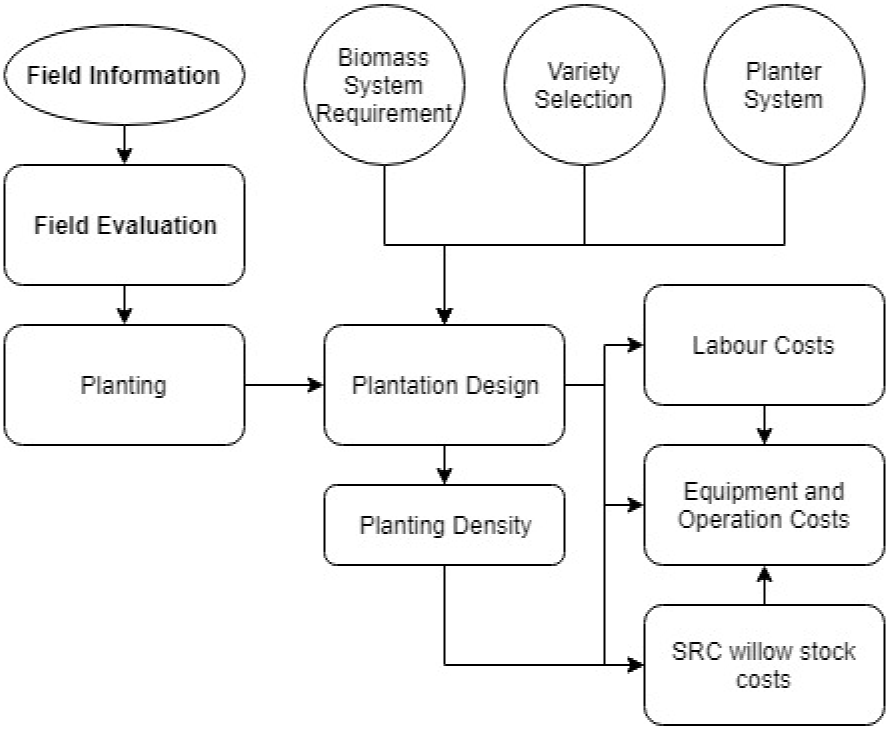


Figure 4.9: Planting sub-model.

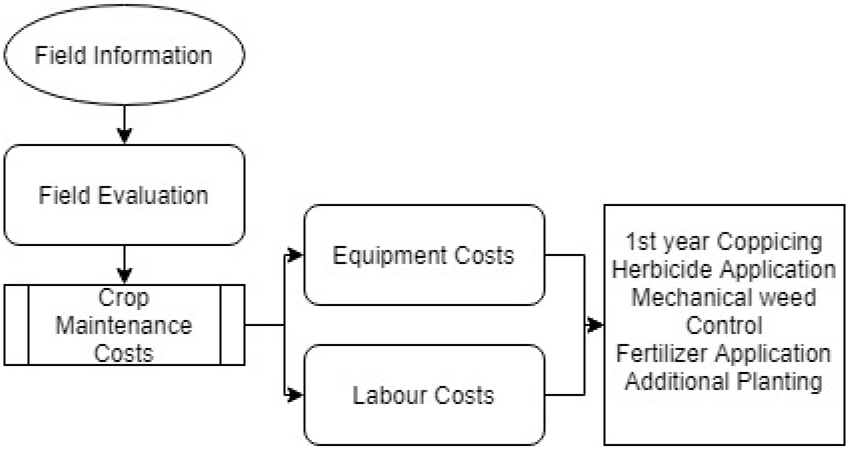


Figure 4.10: Crop maintenance sub-model.

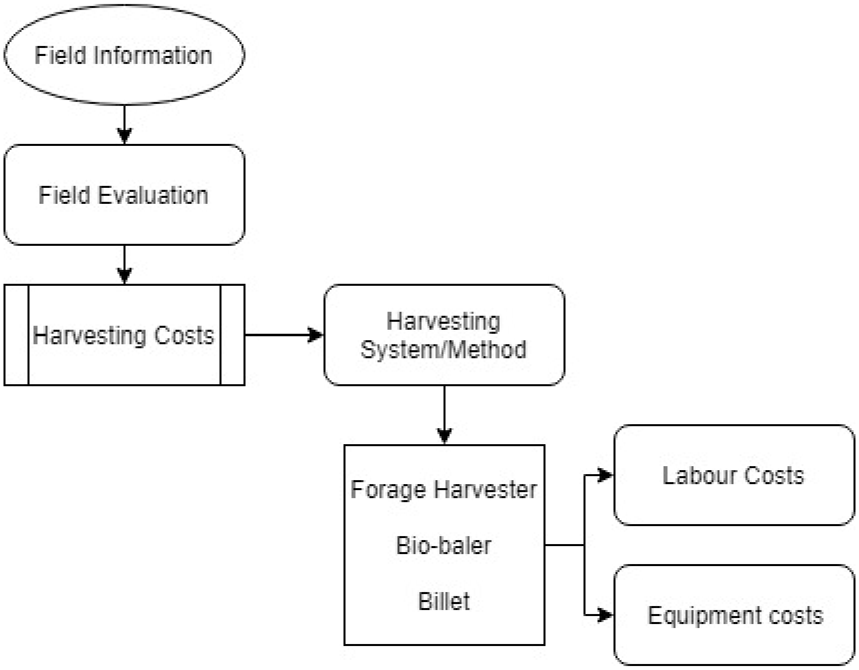


Figure 4.11: Harvesting sub-model.

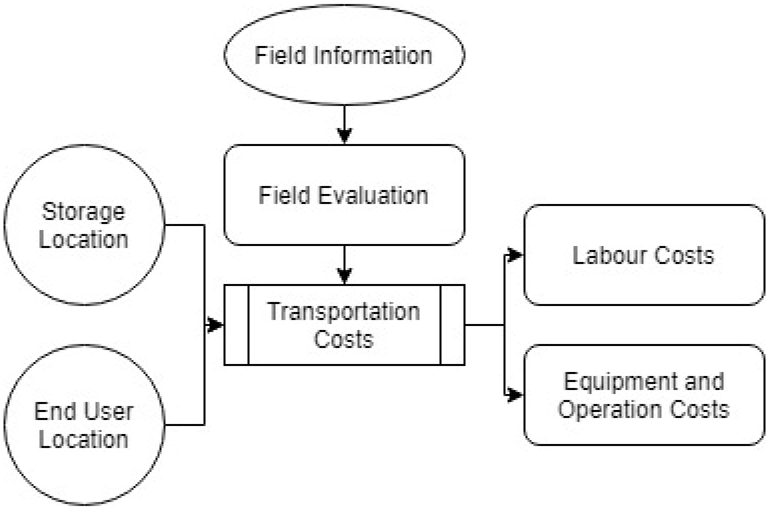


Figure 4.12: Transportation sub-model.

4.4 Model Variables for Site Specific Economic Analysis

The financial decision model comprises of several sub-models, reflecting the biomass supply chain, each of the sub-models is concerned with a differing aspect of the production supply chain. The section below provides examples of formula used to calculate costs.

Field area

This part of the model allows for the input of individual fields, and the application of a buffer zone area not to be planted), this can either be defined as set areas or it can be as a percentage of the field. Fields typically always have a buffer zone, the size of buffer zone will be different for each field, but will always be included, these can be areas where machinery needs to turn, it can be set-back from field boundaries, from water courses, or a particular part of a field may not be planted due to slopes or other land features that would prohibit planting.

$$T_{Plarea} = \sum_{k=1}^{k=n} TF_{Pra} + \cdots N$$

$$TF_{pra} = F_{Pra}/(1 - F_{Prbz})$$

$$F_{prbz} = F_{bzla1} + F_{bza2} + F_{bza1} + F_{bzwa2}$$

Or;

$$F_{prbz} = F_{bz}$$

Where:

T_{plarea} = total planted area (ha)

T_{Fpra} = Total individual field area less buffer zone (ha)

F_{pra} = Individual field area (ha)

F_{prbz} = Individual field buzzer zone (%)

Land preparation per field

This part of the model allows for the input of variable relating to the land preparation of SRC willow. Land preparation is broken down into each field, it is applied to each field and not to the overall 'planting' area to provide a more accurate costing. This allows for multi-year planting procedures, where associated costs or practices may vary. Not all fields will be required to have all the activities conducted. Bringing in inactive land or land that has not been used in a year or two will require more preparation, i.e. subsoiling, than land that has been in continuous production. There may be a need to apply a soil amendment during the land preparation phase, this could involve the application of composts or animal manures to increase the nutrient value of the soil or improve the soil condition. Each of the procedures (e.g. plowing) is calculated upon based upon field area, operating time, and costs associated with labour, fuel and rate of procedure.

$$LP_C = LP_r + LP_h + LP_s + LP_p + LP_d + LP_T + LP_{Pcc} + LP_{rcc}$$

Where:

LP_C = Land preparation cost ($)

LP_r = Crop removal if necessary

LP_h = Herbicide application

LP_s = Subsoiling

LP_p = Plowing

LP_d = Discing

LP_t = Tilling

N_{app} = Nutrient Application

LP_{pcc} = Planting cover crop

LP_{rcc} – Removal of cover crop

Example of plowing

$$LP_p = (TF_{pra} * \ FW_r * P_r) + (F_r * F_c * (P_r * TF_{pra})$$

Where:

LP_p = Land preparation plowing (\$)

TF_{pra} = Total individual field area less the buffer zone (ha)

FW_r = Farm worker hourly pay rate (\$)

P_r = Plow rate (ha/hr)

F_r = Fuel consumption rate (L/hr)

F_c = Fuel cost (\$/L)

Example of herbicide:

$$LP_h = TF_{pra} * Lp_{hr} * FW_r * H_q * H_c * F_r * F_c$$

Where:

LP_h = Land preparation herbicide application ($/field area)

TF_{pra} = Total individual field area less buffer zone (ha)

LP_{hr} = Land Preparation herbicide application rate (ha/hr)

FW_r = Farm worker hourly pay rate

H_q = Herbicide quantity (kg/ha)

H_c = Herbicide Cost ($)

F_r = Fuel consumption rate (L/hr)

F_c = Fuel cost ($/L)

Planting cost

The planting process is not on a per field basis but for the total planted area. This is to minimize time associated with refrigeration of SRC willow cuttings and the need to plant the cuttings as soon as possible. Planting will occur in years two, three and four. This is for one year of planting.

$$TP_c = (P_m + PL_c + P_{sc}) + P_{add}$$

Where:

TP_c = Total Planting Costs ($)

P_m = Planting material, SRC willow equipment cost ($)

P_{sc} = Tractor with planter cost ($)

PL_c = Planting labour cost ($)

P_{add} = Additional costs as a percentage of the total

Tractor planter costs

$$P_{sc} = (F_r * T_{ptime}) * F_c)$$

Where:

P_{sc} = Tractor with planter cost ($)

F_r = Planting Fuel consumption rate (L/hr)

F_c = Planting Fuel cost ($/L)

Planting labour

There will be a different rate applied to the farm worker who will be driving the tractor and directing the operation. Labourers will typically be paid a lower rate and will likely be on a short-term contract involving in the planting only process.

$$PL_c = (L_n * L_{hr} * T_{ptime}) * (FW_r * FW_n * T_{ptime})$$

Where:

PL_c = Planting labour costs

L_{nw} = Number of labourers for planters

L_{hr} = Labour Hourly Rate

FW_r = Farm worker hourly pay rate

FW_n = Farm Worker Number

Time Planting

$$T_{ptime} = T_{plarea} * P_{rate}$$

Where:

T_{ptime} = Total planting time

P_{rate} = Planting rate

T_{plarea} = Total planted area

Planting Material

The planting material encompasses the number of cuttings required per hectare and refrigeration storage of the cuttings.

Planting material and process

$$P_m = (P_c * P_d * T_{plarea}) + (P_{ref} * (\frac{T_{ptime}}{24})) + Pdt + (P_{ref} * (\left(\frac{T_{ptime}}{24} + P_{reft}\right) + (((\frac{T_{ptime}}{24}) + Pd) * P_{reffuel})$$

Where:

P_m = Planting material, processing and equipment cost

P_c = planting cuttings ($)

P_d = Planting density (number)

P_{ref} = Refrigeration truck cost

P_{reft} = Additional time for refrigeration trucks above planting time.

T_{ptime} = Total planting time

P_{dt} = Additional days to have the refrigeration truck

$P_{reffuel}$ = Refrigeration fuel cost (l/hr)

T_{plarea} = Total planted area

Harvesting Costs

Harvesting is a function of labour costs, time per hectare to harvest and time not harvesting.

Harvest time

$$H_{time} = \left(H_r * T_{plarea}\right) * H_{nh}$$

Where:

H_{time} = Harvest time

H_r = Harvest rate – known rate of the harvester (ha/hr)

H_{nh} = Percentage time not harvesting (maintenance, end of row turning)

T_{plarea} = Total planted area

Harvest Labour Costs

Harvest labour costs includes workers, machinery costs and fuel costs. At minimum there will be two farm workers, one driving the harvester and one driving a tractor with wagon (two to ensure continuous harvesting).

$$HL_c = (HFW_n * FW_r * H_{time}) + \left(H_{trac} * H_{time} * H_{tracfuel} * H_{tracfr}\right) + \left(H_{wag} * H_{time} * H_{wagfuel} * H_{wagfr}\right)$$

Where:

HL_c = Harvesting labour cost

H_{trac} = Harvester (number)

H_{wag} = Harvest wagon (number)

FW_r = Farm worker hourly pay rate (\$/hr)

HFW_n = Harvest Farm Worker Number (number)

$Htime$ - Harvest time

$H_{tracfuel}$ = Harvester fuel consumption rate (l/hr)

H_{tracfr} = Harvester fuel cost (\$/l)

$H_{wagfuel}$ = Harvester wagon fuel consumption rate (l/hr)

H_{wagfr} = Harvester wagon fuel cost (\$/l)

4.4.1 Model Outputs

The model output comprises of key financial information common with economic models and used in the methodologies used by those from the literature [16, 17, 19, 21, 24] as being the most useful for economic evaluation; IRR, NPV, and graphical representations of cash flows and cumulative cash flows. The analysis further provides a cost comparison against other biomass feedstocks.

The model provides five financial scenarios:

- Realistic case: this uses average costs and revenue projections.
- +5% case: Assumes a 5% reduction in costs and a 5% increase in revenues.
- +10% case: Assumes a 10% reduction in costs and a 10% increase in revenues.
- -5% case: Assumes a 5% increase in costs and a 5% decrease in revenues.
- -10% case: Assumes a 10% increase in costs and a 10% decrease in revenues.

Internal rate of return

Internal rate of return (IRR) is a forecast of what the predicted rate of growth is for a given project and what expected to generate. In this model it identifies the expected financial growth of SRC willow production over a twenty-four-year period.

$$IRR = NPV = \sum_{t=1}^{t} \frac{C_t}{(1+r)^t} - C_0 = 0\text{kn}$$

Where:

C_t = Net cash inflow during the period t (\$)

C_0 = Total initial investment costs (\$)

r = The discount rate (%)

t = The number of time periods (year)

Net present value

Net Present Value (NPV) is a method used to determine the current value of all future cash flows generated by a given project and includes the initial capital investment. It is used to determine which projects are liable to return the greatest profit, when comparing several options.

$$NPV = \frac{Cashflow}{(1+i)^t} - \text{Initial investment}$$

Where:

i = Discount rate or required return

t = Number of time periods.

4.5 Methodology for Land Capacity Analysis

The most common method of, as found in the literature [30, 31, 32, 33, 34, 35, 36], determining the potential for SRC production and estimating theoretical yields is through the use of land suitability and land availability data sets and ascribing potential crop yields to each parcel of land based on a defined rating system in relation to land suitability characteristics. One of the reasons that these models are used is due to the type of available data which is predominantly soil surveys (often historical) and land use data obtained through either dedicated surveys, regional or national agricultural programs that track land use or through land-holding data. Yield data, where it is used, is often derived from trial plots and in some cases commercial data; where commercial or trial plot data is not used, researchers are inclined to use data from literature that is most relevant to their locale.

4.5.1 Data Sources Used for Land Capacity Analysis

The following data sources were used to determine land capacity, availability and suitability of land and to determine the potential availability of biomass at a given location.

4.5.2 Agricultural Land Identification Program

The ALIP program was designed to categorize Nova Scotia's agricultural land into land use function: Long-term land use that would indicate crops such as blueberries or raspberries, vineyards, or apple orchards; rotational land that would indicate crops such as corn, wheat, vegetables; support land that would indicate processing facilities or farm equipment dealerships, and; inactive land that indicates that it is not currently being utilized. The ALIP project was first undertaken in 1997 and has been periodically updated since. Figure 4.13 provides the breakdown of agricultural land use within the province.

While the ALIP dataset is being used as a reference point for the development of a decision-making tool, this dataset is dated, therefore an up-to-date expansive dataset would show the potential risks and rewards in investing in either the production or utilization of agricultural biomass with greater certainty. The province needs to develop an updated land inventory as the previous 1997 agricultural land inventory project (ALIP) (Figure 4.13) may not reflect current land availability including location of land within the province, land parcel sizes and current agricultural land usage.

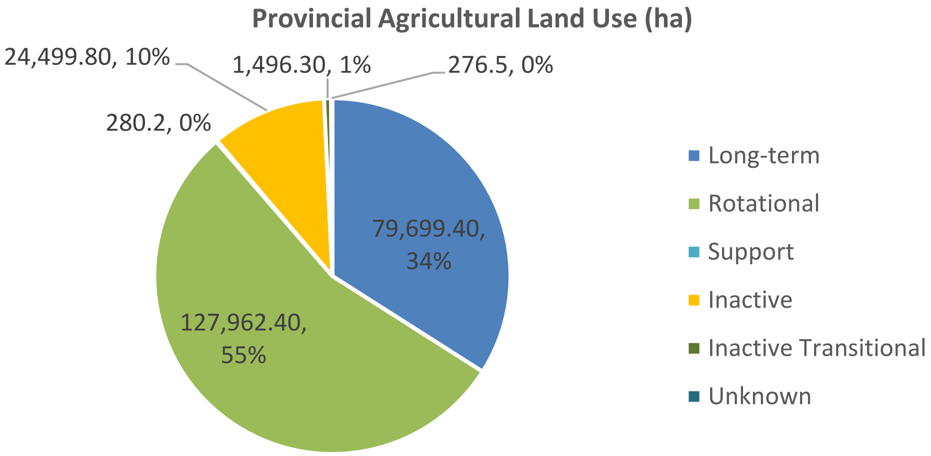


Figure 4.13: Agricultural land use in Nova Scotia.

4.5.3 Canadian Land Inventory

The Canadian land Inventory (CLI) dataset covers 2.5 million km^2 of Canada and provides an assessment of land quality (capability) of agricultural, forestry, wildlife, and recreational land. The data was collected between 1960 and early 1980s. While the data is old, according to the Canadian Soil Information Service [44] the data is still valid and is used in many Canadian jurisdictions for planning purposes.

The CLI has categorized the land into seven classes and thirteen subclasses, the Classes have been derived from several different factors including capability of mineral soil, type of soils management of land, improvements needed and limitations or hazards. Table 4.3 shows the seven different classes in the CLI dataset used in the project.

Table 0.3: Land capability classes

Land Capability Class	**Terminology**
1	No significant limitations for crops
2	Moderate limitations for crops
3	Moderately severe limitations for crops
4	Severe limitations for crops
5	Very severe limitations for crops
6	Perennial forage crops only
7	No capacity for crops

4.5.4 Detailed Soil Survey

Produced by Agriculture and Agri-Food Canada detailed soil surveys (DSS) for each province have been conducted since the 1970's, with the latest updated version (version 3) being in 2010 (minor updates from 1990's surveys) [45]. The detailed surveys look at a significant number of different soil factors including, slopes, stoniness, water tables soil types and drainage. Data used is presented in Tables 4.4 to 4.6.

Table 0.4: Detailed soil survey: slope classification

Slope (Degrees)	Terminology
0.3-3.0	Nearly level to very gentle slopes
3.0-5.0	Gentle slopes
5.0-8.5	Moderate slopes
8.5-16.5	Strong slopes
16.5-24.0	Very strong slopes
24.0>	Extreme to very steep slopes
-9	Unknown

Table 0.5: Detailed soil survey: water table classification.

Water Table	Terminology
YB	Water table always present
YG	Water table present during growing season
YN	Water table present during non-growing season
YU	Water table present during unspecified period
NO	Water table not present
-	Not applicable

Table 0.6: Detailed soil survey: drainage and stoniness classifications.

Drainage	Terminology	Stoniness	Terminology
VR	Very rapidly drained	0	Non stony (<0.01%)
R	Rapidly drained	1	Slightly stony (0.001 - 0.1%)
W	Well drained	2	Moderately stony (0.1 - 3%)
MW	Moderately well drained	3	Very stony (3 - 15%)
I	Imperfectly drained	4	Exceedingly stony (15 - 50%)
P	Poorly drained	5	Excessively stony (>50%)
VP	Very poorly drained	-	Not applicable
-	Not applicable		

4.5.5 Nova Scotia County Boundaries

The Nova Scotia County Boundaries data provides the shape of Nova Scotia and marks the boundaries for each County within the Province.

4.5.6 Biomass Facilities Location

The biomass facilities locations (Table 4.7) were determined based upon the proposed address for each facility, the coordinates for each location were identified and a new point layer was created displaying each site.

Basic information was obtained for each of the five biomass facilities: location and generating capacity. The quantity (tonnes/year) of SRC biomass required for each facility was determined based upon the total MWh of electricity produced per year at an assumed

Capacity Factor (80%) and the known energy content of SRC willow per tonne (13.2 GJ/tonne).

Table 0.7: Proposed Biomass Facilities.

Name	**Generating Capacity (MW)**	**Capacity Factor**	**Estimated MWh/Yr**	**GJ/Yr**	**Tonnes Required**
Bedford Development	11	0.8	77,088	27,5314	20,857
Bowater Development	3	0.8	21,024	75,086	5688
Kentville Development	6	0.8	42,048	15,0171	11,377
Minas Basin Development	10	0.8	70,080	25,0286	18,961
Sydney Development	6	0.8	42,048	15,0171	11,377

The following steps (Figure 4.14) were taken with the data sets to determine land capacity and to determine availability of biomass to a given location.

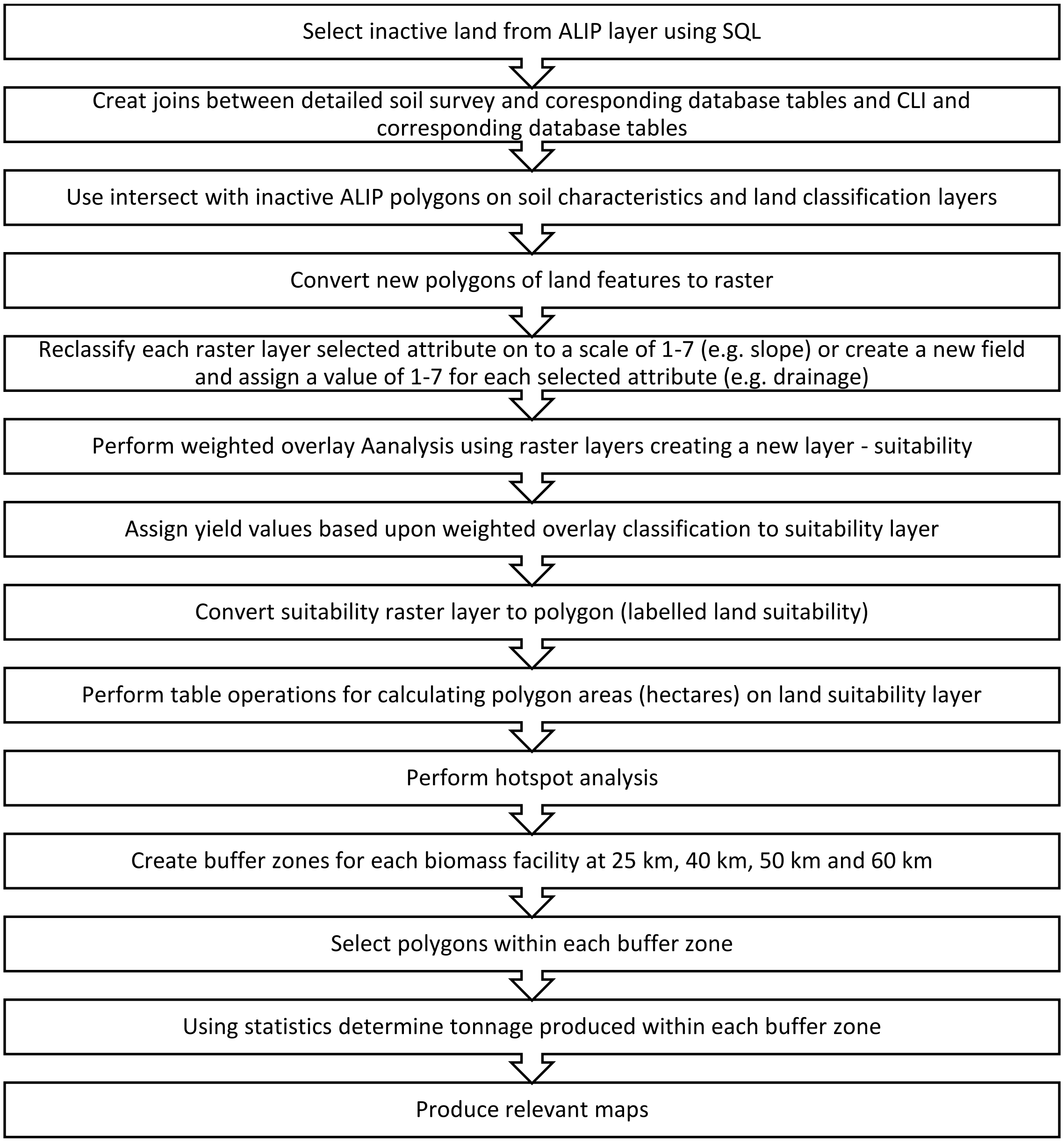


Figure 4.14: Geographical Information System process steps for determining land capacity.

4.5.7 Land Capacity Base Model

The model below (Figure 4.15) was produced/run with added fields for water table and drainage to allow for reclassification to occur.

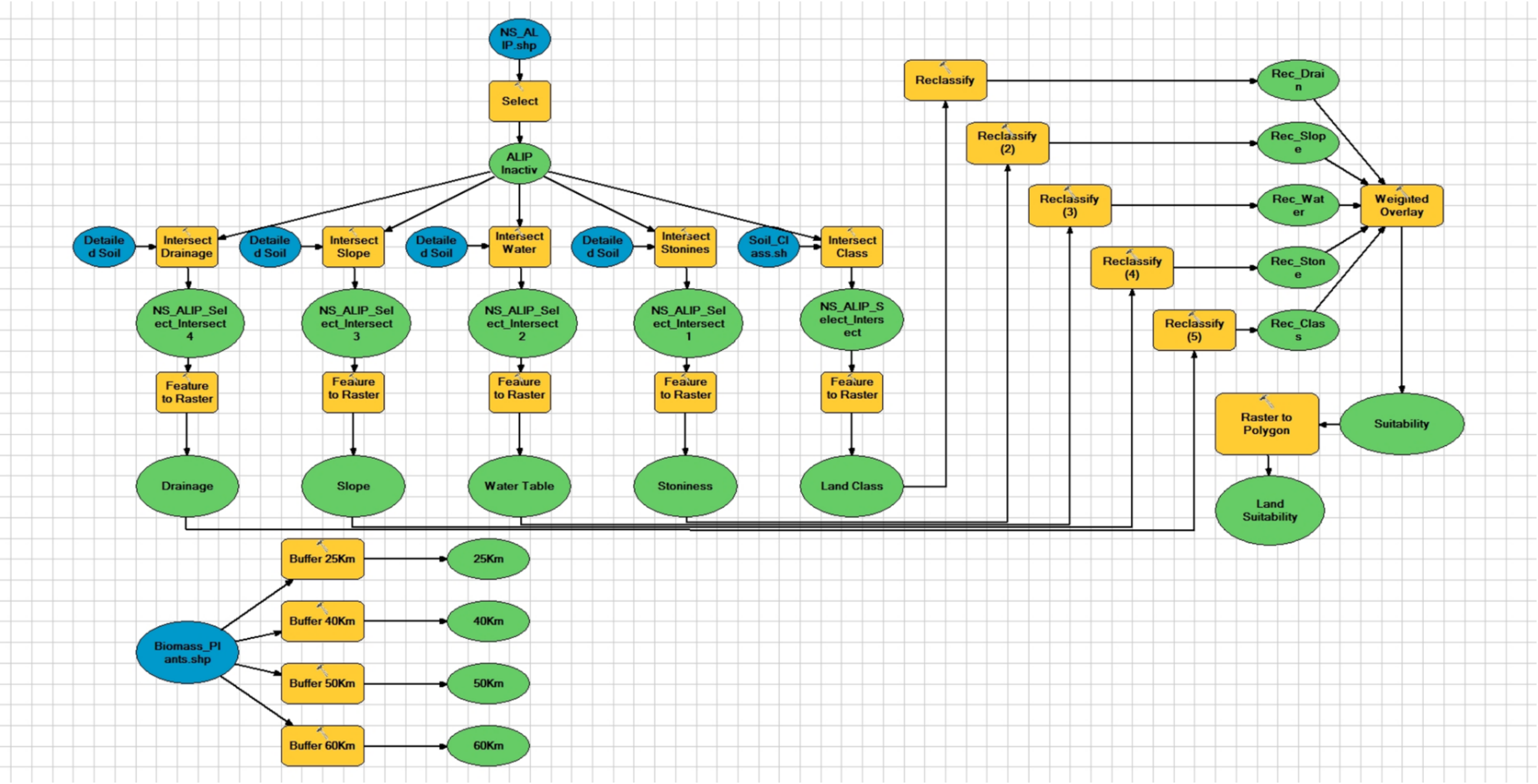


Figure 4.15: Spatial analysis for land capacity analysis model.

4.5.8 Weighted Analysis

To identify field suitability, weighted overly was performed. Weighted overlay is a useful tool to solve spatial multicriteria problems including site selection [39, 40]. Weighted overlay functions through assigning values to each of the different attributes in each layer using a common scale. This analysis used a 1-7 scale with 7 being the most preferable and 1 being the least. Table 4.8 shows the reclassification used.

Table 0.8: Reclassification of Land Capability Class.

Land Capability Class	Terminology	Reclassified Value
1	No Significant Limitations for Crops	7
2	Moderate Limitations for Crops	7
3	Moderately Severe Limitations for Crops	6
4	Severe Limitations for Crops	5
5	Very Severe Limitations for Crops	4
6	Perennial Forage Crops Only	3
7	No Capacity for Crops	1

Having assigned values to each attribute in each raster layer, each layer is assigned a weighted values (with the total weighting summing 100%). This then allows certain attributes to be considered to have a higher impact than another layer, with the output being the result of the weighted calculation. The output is similarly on a scale of 1-7, with 7 being the most preferable. Figure 4.16 shows the different layers and how each layer was weighted [38, 41].

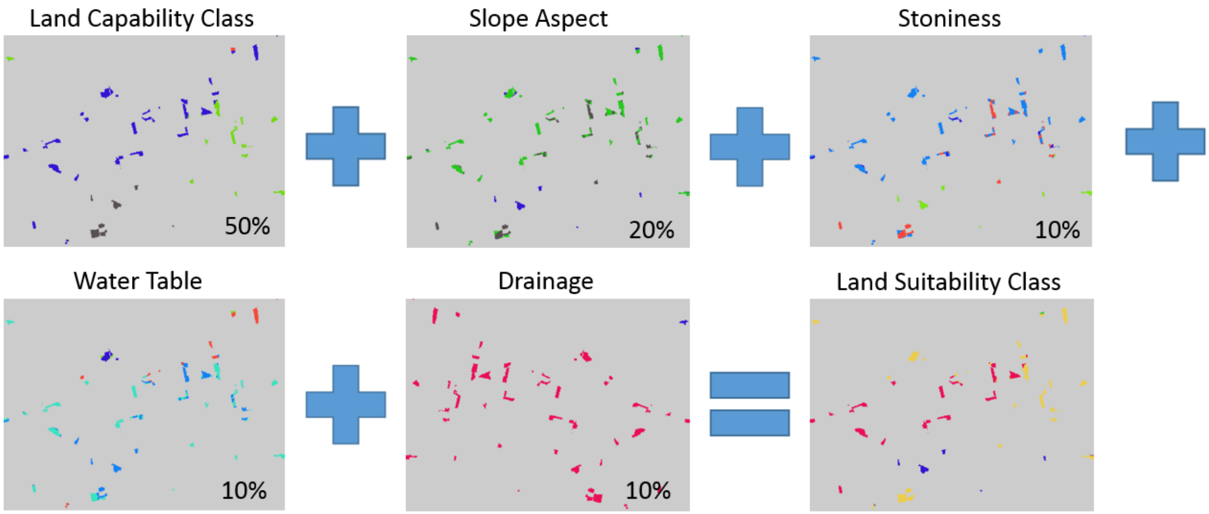


Figure 4.16: Land suitability analysis using weighted overlay methodology.

4.5.9 Hotspot Analysis

The purpose of the hotspot analysis (Figure 4.17) is to identify statistically significant areas where close proximity occurs between polygons with high values. In this case, the hotspot analysis identified fields with high suitability values (values 3 and 2) that are in close proximity to one another. Considering Figure 4.17 below, looking at the top left of the image a number of the polygons are red, and looking at the centre of the image the polygons are largely pale green or yellow. This indicates that the top left has fields with higher suitability rating and in close proximity to one another than those in the centre of the image that are more dispersed and have a lover suitability rating.

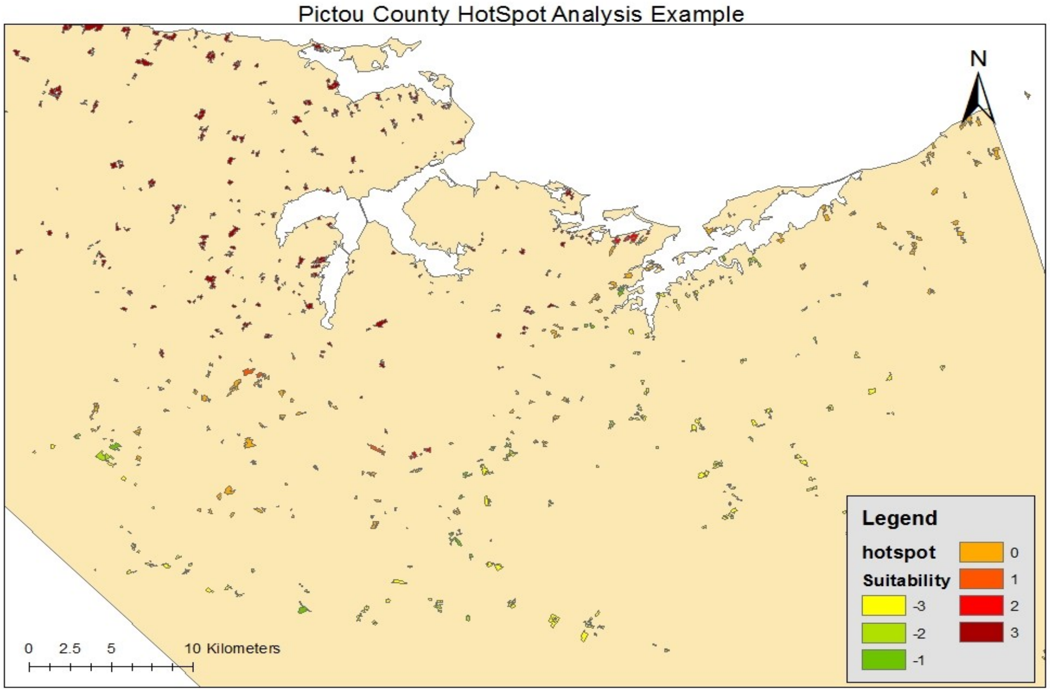


Figure 4.17: Hotspot Analysis of Pictou County.

This data and data from the other counties were taken and used to rank the different provinces in terms of highest number of suitable sites that are within distance to one another and the quantity of biomass available. This data is presented in Chapter 7.

Biomass Facility Catchment Zones

To determine biomass facility catchment zones, buffers were created at 25, 40, 50 and 60 km, each of the buffers and the total tonnes per catchment zone were identified using the layer attribute table field statistics function until the required amount of biomass for each facility was identified [38, 41, 42]. This data is presented in Chapter 7.

CHAPTER 5 POLICY REVIEW AND DEVELOPMENT

The use of biomass for energy generation is consistently considered to be an important part of formulating a well-rounded renewable energy mix, with the majority of developed countries having developed energy policies [38, 39, 40, 41]. Many international biomass policies state their intention of using biomass and in several instances setting out defined targets for biomass production for direct energy generation utilizing feedstocks from both the forestry and agricultural sectors. Globally, Europe has been consistently leading in the development of biomass policies and setting targets for production. The United States has a range of differing biomass policies at both the Federal and State levels. Similarly, Canada has some biomass policies that focus on energy generation from biomass, however, these policies are regarded as lagging behind other developed countries [46, 47, 48, 49].

5.1 The Purpose of Policy and its Applicability to Biomass and the Bioeconomy

SRC willow, an agricultural energy crop, and its production and utilization, is a small segment of the larger biomass industry or the bioeconomy. To understand how to push SRC willow as an energy crop for direct combustion, we need to understand what drivers influence the use of biomass, what limiting factors there are that influence biomass usage and what type of policies or mechanisms are being used to harness the potential of biomass energy and /or support a bioeconomy. The bioeconomy refers to the economic and sustainable use of biological resources, ranging from forestry products, agricultural and aquaculture products to organic waste streams, in a range of processes including energy generation, biofuel production, biochemicals or bioproducts, the traditional uses of the products, forestry for pulp and paper or lumber, agriculture and aquaculture for food production or the simple management of organic waste streams.

Policy drivers, defined as broad aims set out by governments and organisations and are the motivational factors that encourage change, develop new industries or develop new processes [58]. There are a range of different drivers that can, and do, push forward biomass production and utilization. The major drivers for the wider use of biomass can be attributed to:

GHG emissions and the environment: Greenhouse gas emissions reduction is a key driver in developing the bioeconomy and renewable energy. Both aim to reduce and/or eliminate the need for fossil fuels; with biochemical and bioproducts replacing fossil fuel derived chemical products and renewable energy replacing energy production from fossil fuels [51, 52, 53].

Stephen and Wood-Bohm (2016) argue that biomass is a low-GHG source of energy and can replace or can be co-combusted, in the interim, with coal fired power stations, highlighting ten of Canada's largest coal-fired power plants that could accommodate blended fuel (coal and wood pellets) [62]. They further highlight, while recognizing that biomass in not carbon neutral, provided biomass is continuously grown (trees replanted, SRC plantations maintained) that CO_2 will be sequestered, and hence partially offsetting emissions.

Pereira and Costa (2017) similarly highlight the role biomass, including SRC has in co-combustion systems as a way to reduce GHG emissions, however, highlight that due to the wide variability in biomass and environmental and climate conditions have on yield and combustion behaviour, it is difficult to accurately predict the scale of those reductions [51, 52, 53, 55].

The New Zealand Bioenergy Association (2018) assessed the use of wood fuel for process heat purposes, replacing coal as the fuel source [64]. Under a scenario, which included the Government setting specific GHG emission targets for their heat market including; food and meat processing plants, manufacturing, hospitals and correctional facilities, they estimate that a reduction of 1.3 Mt/year of CO2 eq emissions can be achieved [64], while Jåstad *et al.* (2021) assessed the role of woody biomass for the reduction of GHG emissions in the European Energy sector finding it an option to contribute towards reducing GHG emissions and reducing the costs for power and heat production [61]. hornley *et al.* (2015), conducted a life cycle analysis of several bioenergy systems, finding that overall, large-scale energy systems offer the best pathway to achieving GHG emission reductions per unit of energy generated [65].

Contributing towards energy security: biomass energy generation, where biomass is sourced in-country can contribute towards providing sustainable and renewable energy, all of which seek to reduce reliance on fossil fuels [5].

Thrän and Pfeiffer (2017) state that biomass has an important role in the transition of energy systems, from fossil fuel based to renewable, biomass energy systems, provide a local or regional source of energy, negating or reducing the need for fossil fuels, while maintaining the flexibility and controllability of consistent energy generation compared to wind and solar power [66].

Beilski *et al.* (2021) evaluated the importance of agriculture in creating energy security in Poland finding that within Poland agricultural crops (including dedicated energy crops) are significantly under-utilized, with approximately 180,000 ha of inactive land which could positively impact energy security, through supply of agricultural material for biogas production [67].

Developing a robust bioeconomy: biomass is a vital feedstock, as part of a bioeconomy, whether forestry products, agricultural and aquaculture products, or organic waste streams. Energy crops, such as SRC willow can be one of those feedstocks available for use by the bio-industry or for energy generation [19, 61, 62].

In reviewing biomass and biomass-based energy supply and demand for a growing bioeconomy, Popp *et al.* (2021) found that over 50 countries have developed bioeconomy policies. Within Europe, 59% of biomass is used for feed and food products, followed by bioenergy (21%) and biomaterials (20%) [70]. However, due to the still heavy reliance on fossil fuels, policy is now geared towards energy production, predominantly biofuels and bio-based chemicals (materials) [70]. Popp *et al.* (2021) project, that in the future, the demand for bio-based chemicals will increase, suggesting that biomass for energy production will decline in favour of this as more renewable technology systems are installed [70].

Szarka *et al.* (2021) reviewed the biomass flow in the German bioeconomy, finding similar results to Popp *et al.* (2021) in-terms of biomass use distribution, highlighting, that agricultural growth of SRC willow or miscanthus for energy generation is dwarfed by that of forestry and that when it comes to agricultural biomass production for energy generation, biogas and biofuels are dominant forms of bioenergy from agriculture and likely to remain so [71]. Musonda *et al.* (2021) conducted a resource analysis study for biomass allocation in Germany and its role in the bioeconomy, finding that on balance, while biomass should still be utilized for energy generation, the use of biomass for biochemicals is likely to provide a greater saving in GHG emissions compared to its use in bioenergy production, however highlight its short term importance in the bioeconomy and for GHG emission reduction [72].

Regional development: The production of localized biomass, including SRC willow can contribute towards regional development, allowing farms or ag-businesses to produce it (or other suitable biomass crops) for local consumption or to stimulate bioeconomy businesses to the area [73] .

Willmer (2018), identified that due to the EU's target of creating one million new green jobs by 2030 [74], that there will be significant development growth in local and rural areas, especially through agricultural biomass for biofuels and bioproducts and biochemicals [75]. Lange *et al.* (2021), in reviewing circular bio-based economies determined that biomass and bioenergy, products and biochemicals will have a positive effect on not just local but regional economies as production and business develop and growth but that there is a need for extensive knowledge sharing to facilitate it [76].

Employment creation – With regional development opportunities, employment creation should follow. The Energy Technology institute (2018), highlight employment creation including off-farm specialists, labourers, logistic experts and tractor-trailer drivers, but note the seasonality of the work, with more employment in the spring and fall seasons [77]. With SRC willow this may be through farm businesses employing local agricultural workers, ag-businesses investing in supply chains, or new bio-economy start-up or existing businesses moving in-to local areas [77].

Hondo and Moriizumi (2017) evaluated the employment creation potential of several renewable energy systems, finding that wood biomass and biogas systems had higher rates for direct employment, especially around operations and maintenance, averaging four and a half jobs per GWh of energy produced compared to solar, wind, geothermal and small-scale hydro, which are all less than three jobs per GWh produced. They further found that there will be a higher percentage of indirect jobs in biomass based systems in operation and management areas compared other renewable technologies [78]. Similar results were also found by Tourkolias and Mirasgedis (2011), and Flomos *et al.* (2011), who both found that biomass based energy systems had a higher potential for job creation through operation and maintenance and the supply chain logistics systems [79] [80].

5.2 Policy Mechanisms

There are a variety of different policies and tools that can be implemented when seeking to promote change or encourage the development of an industry. Within the biomass industry or bioeconomy, these policies often are used to develop a particular part of the biomass industry or economy and as such are currently the limiting factor or the bottleneck to development. This could start with:

1) Market development by building desire in the end user or finding end users, promoting the values and benefits of using a particular biomass, or building awareness of a particular biomass and its potential end use [74, 75].

2) A focus on trying to determine the viability of a biomass product or promote the production of a particular biomass product; in essence trying to limit production barriers. For example, focusing on SRC willow in the UK, Glithero *et al.* (2013) [83] surveyed two hundred and forty-four farmers to determine their willingness to grow SRC willow and miscanthus, with 81.6% stating that they would not consider growing miscanthus and 87.7% stating that they would not consider growing SRC willow. The reasons cited in the study determined that there were perceived negative land impacts, the lack of access and affordability of appropriate planting and harvesting machinery, the commitment of land long-term for production, the length of time until a financial return is achieved and the uncertainty of profitability [83].

A similar study conducted by Warren *et al.* (2016) [84] found that 33% of respondents believed that SRC willow was not suitable for their farming practices or their land, 18% were concerned about the long-term commitment of growing SRC willow and the subsequent difficulty in harvesting and stump removal. In addition, 13% respondent were concerned about the economics of production and price uncertainty in selling SRC willow and respondents were further concerned about a lack of available land to dedicate towards production, the risk of field or drainage damage and finally that there was no developed or competitive market for SRC willow products. Warren *et al.* (2016) [84], found however that if financial incentives were available for planting and establishment or if there were pre-payments for a future crop, half of the respondents believed that it would make the prospect of growing SRC willow more favourable.

3) Assessing and/or developing supply chains from the harvesting to the transportation of the product to the end-user, and; 4) developing or encouraging the uptake of the technologies or conversion processes that would use the biomass processes.

Mechanisms that are commonly used include: 1) Financial incentives such as subsidies, tax credits, tax breaks, rebates, and grants are designed to encourage behaviours or actions that may not otherwise occur [85], 2) Loan programs, providing repayable loans; allowing businesses, groups or organizations, the ability to cover start-up costs associated with a new enterprise [86], 3) research programs, while financially sourced, are designed to build knowledge of a particular industry [87], 4) educational programs for promoting the development of an industry or providing knowledge on processes, values, and systems and benefits [88], and,5) establishment of working groups or networks, used to create links and partnerships between businesses, enterprises, government and other relevant stakeholders with the aim of developing an industry. The review here aims to identify and evaluate different barriers and policies other countries have used related to the use of biomass for energy generation with a focus on SRC willow and energy crops.

5.3 Barriers to Energy Crops and SRC Willow Development

A review of published papers assessing the barriers or challenges of utilizing agricultural biomass for direct combustion or biofuel production (Table 5.1) found thirty-four papers that focus on reluctance to produce biomass energy crops. The review focused primarily on European countries, the United Kingdom, the United States of America and one in China. Of the thirty-four papers reviewed, seventeen included SRC willow when assessing energy crop production barriers or hesitancy of production.

Table 5.1: Studies focused on the barriers to agricultural energy crop production.

Publications	***EC***	***S&I***	***FR***	***K***	***R***	***M & ROI***	***Inc. SRC***	***Ref***
Roszkowska & Szubska-Włodarczyk (2022)	X					X	X	[81]
Bielski et al (2021)	X	X					X	[67]
Sherrington and Moran (2021)		X	X	X			X	[89]
Weger et al (2021)		X	X	X		X		[90]
Welfle and Alawadhi (2021)				X			X	[91]
Yang et al (2021)				X			X	[92]
Zhou et al (2021)				X				[93]
Zyadin et al (2021)			X			X		[94]
Beer and Theuuvsen (2019)			X	X		X		[95]
Embaye et al (2018)				X				[96]
Helliwell (2018)			X				X	[97]
Petrenko and Searle (2018)	X	X						[98]
Secchi and Varble (2018)			X	X		X		[99]
Spinelli, Pari and Magagnotti (2018)			X			X		[100]
Usla, Detz and Mozaffarian (2018)		X	X	X		X	X	[101]
Perrin Fulginiti and Alhassan (2017)								[102]
Lindegaard et al (2016)		X		X	X	X	X	[103]
Lynes et al (2016)		X						[104]
Wang and Watanabe (2016)		X	X	X				[105]

Publications	***EC***	***S&I***	***FR***	***K***	***R***	***M & ROI***	***Inc. SRC***	***Ref***
Warren et al (2016)	X	X	X	X			X	[84]
Zyadin et al (2016)		X	X				X	[106]
Gedikoglu (2015)			X					[107]
Caldas et al (2014)			X					[108]
Wilson, Gilthro and Ramsden (2014)	X		X	X				[109]
Alexander et AL (2013)			X				X	[110]
Baum et al (2013)		X				X	X	[111]
Ostwald et al (2013)		X		X			X	[112]
Convery, Robson and Long (2012)			X				X	[113]
Villamil et al (2012)		X	X				X	[114]
Jonsson et al (2011)		X		X				[115]
Cocchi et al (2010)		X	X				X	[116]
Styles, THORNE, and Jones (2008)		X	X			X	X	[117]
Jensen et al (2007)				X		X		[118]
Nilsson et al (2007)		X	X		X		X	[119]

EC: Establishment Costs, S&I: Subsidies and Incentives, FR: Farmer Resistance (Land Commitment and Cultural), K: Knowledge, R: Research, M & ROI: Market Access and Return on Investment. Inc SRC: Includes SRC willow in research.

Reasons identified for the hesitancy or resistance to growing energy crops include issues around the establishment costs (four papers), lack of direct subsidies or incentives to encourage production (seventeen papers), lack of knowledge about energy crops including processes and establishment (sixteen papers), lack of market or Return on Investment uncertainty (ten papers) and farmer resistance which included issues related to the long-term commitment to producing an energy crop, i.e. length of time SRC willow would be in the ground or issues around the culture of growing energy crops, i.e. “it is not traditional” or it is “not in keeping with the area” (nineteen papers).

Nilsson et al (2007), assessed why there was little uptake of SRC willow in Poland, and on the region of Grudziądz where there was an energy producer looking to source SRC willow for energy generation. The results were that there were significant barriers including high establishment costs, perceived low Return on Investment, lack of subsidies, a clear lack of knowledge around energy crops in general and limited market for SRC despite suggestions that it could be utilized in energy generation [39].

Jensen *et al.* (2007) surveyed Tennessee farmers in the US to ascertain their willingness to grow switchgrass for energy production, finding that only 30% of farmers would be willing to grow switchgrass, finding that the lack of a market and potential income, lack of knowledge and the need for technical assistance. [38].

Styles *et al.* (2008) assessed the viability of SRC willow in the Republic of Ireland, finding that SRC willow has a better economic case than miscanthus production, however there was significant concern from farmers around the long-term commitment, establishment cost the lack of a market and the Return on Investment, they go on to suggest that subsidies and/or incentives as well as a concerted education campaign may be the answer to stimulate production [117].

Wang *et al.* (2016) evaluated the socio-demographic characteristics of farmers of different income levels, finding that those with low and middle incomes were resistant to growing biomass for energy generation due to lack of knowledge and a high perception of risk, finding that subsidies or incentives, in conjunction with education would be the mechanism most likely to help develop the supply of agricultural biomass [24].

Warren *et al.* (2016) assessed the limited adoption of SRC in the United Kingdom found that while farmers in general are not opposed to SRC willow production themselves, the majority of those surveyed would not grow it as it is either; incompatible with their current farming practices or desires and the risk of a long-term commitment is too great [25]. Warren provided several examples of where there is a market outlet from nearby biomass energy generating systems, farmer apathy towards SRC willow production is high, suggesting that the two key policy needs to address farmers uncertainty about financial risk, either through subsidies or the ability for favourable long-term purchase contracts and that there is still a lack of education.

Lynes *et al.* (2016) evaluated the willingness of Kansas farmers to produce alternative cellulosic biofuel feedstock found that only 44% of survey farmers were willing to plant a perennial energy crop (grasses or SRC) finding that adoption is seen favourable if there are favourable contracts to do so or long-term purchase commitment to their grown energy crop [23].

Yang *et al.* (2021) evaluated the likelihood of perennial energy crop production in the US Midwest, surveying farmers attitudes towards energy crop production finding that 41.85 of farmers surveyed believed that energy crops, including SRC willow, have potential environmental benefits, yet do not believe that there are economic benefits, and this is what hampers wider adoption. They further found that there is a definite need for education programs, the development of local markets for any grown biomass and a guaranteed reasonable Return on Investment and without these the production of perennial energy crops would stall [11].

Roszkowska and Zubska-Włodarczyk (2022) evaluated the barriers to biomass market development in Poland finding lack of knowledge of biomass and information on the possible uses of biomass, the high cost linked with establishment and production and concern about profitability.

The common thread here throughout these literature examples, from 2007, 2016 and 2021, is that the issues around the widespread production of energy crops, including SRC willow, by farmers is that there is still a knowledge gaps where farmers (or agricultural landowners) are concerned that inhibits their desire to grow energy crops, including SRC willow and that there is still a concern around financial viability, whether through subsidies or not.

A second common thread throughout these literature examples and from the review of publications (Figure 5.1), is that most of the studies have been conducted in countries/regions where there is a presence of energy crop production, the issue is how to increase productions [40] [41] [42].

Focusing specifically on SRC willow production, the UK saw a drop in production area and number of growers in 2019, with 2,233 ha producing SRC willow across 271 growers, down from a peak of 2,962 ha across 437 growers, the drop has been attributed to the closing of government subsidies [42]. It should be noted that solid fuel biomass production is significantly lower than crops grown for biofuel production in the UK with approximately 11,000 ha of wheat and 8,000 ha of sugar beets grown for biofuel production and 67,000 ha of maize/corn used in anaerobic digestion [42]. Within Europe, data from 2019, 63,907 ha of SRC willow and poplar and 54,494 ha of grassy energy crops is in production for direct combustion compared to 7.7 million ha which have been utilized for biofuel or biogas production [43].

This indicates that the production of agricultural biomass is focused predominantly on biofuel production followed by biogas production with a small portion of agricultural land being utilized for direct combustion crops such as SRC willow. Reasons for this discrepancy may include: traditional crops being readily and easily produced, known production methods, known market value and a ready market [44] for the products, as well as significant push for biofuel production at government levels [45, 40].

A larger study on SRC willow production and SRC policy by Lindegraard *et al.* (2016), the EU instigated a six-country study regional study, called Rokwood, to evaluate the production of SRC willow from an economic, technical and sustainability perspective. Despite significant regional difference between the countries in relation to climate and landscape and difference is management and implementation partnerships, similar challenges were identified in developing and SRC market [103].

In a comprehensive review of the barriers faced within the EU (focusing upon the six Rokwood participants), there are significant challenges relating to the lack of development of local supply chains and markets [96, 113]. A lack of available cash-flow for farmers, a distinct lack of skill or resources, lack of infrastructure, lack of incentives, the requirement for a long-term financial commitment from farmers and uncertainty with regards to supply and demand. In addition, there are barriers caused by political decision, the competition for land, market competition, technical issues, and lack of education and information [103].

The Rokwood study identified a lack of education as being a key barrier to the adoption of agricultural biomass [96, 113, 114]. Finding not only that there is a lack of information relating to the production, processing, and use of SRC willow, but in how SRC (and other energy crops) could make a positive contribution towards reducing fuel poverty by creating jobs and providing alternative fuel sources.

All regions in the study state the need for developing and furthering research into SRC willow production including the identification of appropriate SRC willow varieties, and appropriate planting, harvesting and management practices as well as a need for understanding the long-term ecological benefits of producing SRC. Lindegraard *et al.* [103] puts forth that without more research to develop the knowledge and disseminate information to governments, biomass using industries and potential producers, the likelihood of prioritizing and developing new funding streams for SRC willow within Europe is unlikely.

All the regions involved in the Rokwood program identified the need for greater financial support to develop an SRC market, with there being a need to lower the initial risk investment of planting SRC and the risks inherent with having a long-term established crop where there is uncertainty around end-user markets [96, 113, 114]. It was identified for individual growers, whether for on-farm consumption or selling on the open market, that there will be negative cash-flow due to the heavy up-front costs. In addition, producers will not see revenue until delivery which, if delivering dried, will be in the fifth year of the establishment, pushing the risk of zero profits until year twenty of production, due to the need for establishing plantations in three consecutive years to ensure continued supply.

All the regions stated the need for financial support from government to help stimulate the market, like those seen for the production of biofuels, or support to offset the differential between the cost of fossil fuels and the cost of SRC production [96, 113, 114].

Unique to Spain, they identified an over installed capacity within their region, with significant investment in wind farms and gas power generating systems, and the relatively small market for SRC as a heating fuel source, making SRC willow production and biomass generally unfavourable due to the continued on-going infrastructure and logistic costs with using biomass as an electricity generating feedstock. Further, due to the over installed generating capacity, there is a competitive electricity market, further reducing the potential incentives for SRC producers.

The Spanish portion of the study identified potential heat markets within rural communities, where access to gas for heating and cooking is typically not available, stating that this would lead to an increase in energy security in the rural setting. However, Spain states that there is a distinct lack of knowledge around SRC and heat production in general in across the board. This lack of general awareness around SRC production and the wider benefits of SRC was found to be similar in all six of the Rokwood regions.

With regards to policy Lindegraard *et al.* (2016) found in evaluating the Rokwood program that all regions identified a significant lack of lobbying groups to promote the interest of SRC, further reducing the likelihood of SRC willow in Europe, further within government policy there is a distinct lack of policy that focuses on SRC willow, while there is significant policy on forestry for biomass and the production of biofuels. Ultimately within Europe there is still a lack of financial support for SRC willow and agricultural biomass for combustion or direct energy generation despite the widely available funding for agriculture through the Common Agricultural Policy [103].

5.4 Financial Mechanisms Supporting Biomass Production

There have been several policy options available to boost the production of biomass use, however, there have been a limited amount directly related to the production of agricultural energy crops. Policy for biomass use largely falls in to two categories; the production of energy from biomass, regardless of the biomass source and financial incentives focused on the establishment of agricultural biomass plantations.

Financial incentives do offer the best course towards developing an SRC willow market, as can be seen with the general market development of renewable energy technologies, demonstrated clearly in Europe, where the strong policy objectives of reducing GHG emissions and developing renewable energy targets resulted in financial incentives to stimulating market development and clean energy.

Research conducted by Moiseyev *et al*. (2014) into the impact of subsidies, to power producers, for wood (forestry) biomass in Europe, found that subsidies and carbon taxes increased the uptake of bioenergy generation or co-generation and predict that both mechanisms are needed to drive down energy produced from fossil fuels between now and 2050 [122].

Direct subsidies are defined as payments made to supplement the income of farmers, landowners, and agribusinesses, but should help to manage the supply of an agricultural commodity and have an impact upon the cost and supply of an agricultural commodity [123]. One of the most famous subside programs is through the European Common Agricultural Policy (CAP), designed to support farmers and improve agricultural productivity, protect rural areas, and help tackle climate change and promote sustainable. which saw 57 billion spent on agricultural development with 39 billion being on direct farm subsidies [123].

There are a range of reasons for subsidies, including as a protectionist method to ensure that production of agricultural products stays within a given region, improving food (or energy) security while maintaining internal quality and health and safety standards, maintaining internal markets, and ensuring employment within the industry. For some farmers, it is a necessary means of supplemental income, where a livelihood may not be viable due to external market forces [117, 118].

Direct payments may be made in relation to policy decisions either for environmental reason or to keep a specific area or region economically viable, in that without subsidies, agribusinesses and farms may go out of production or business resulting in a knock-on effect to the wider community. An example of this would be Pillar 2 of the CAP, designed to stimulate and maintain rural communities with a simultaneous aim of maintain, protecting and improving the environment [126]. Pillar 2 of the CAP, focuses on ensuring effective rural development, ensuring competitive agriculture, sustainable resource management and climate action.

Subsidies may be made to achieve specific environmental goals, for example the Scottish Agri-environment Climate Scheme, which aims to promote land management to improve natural heritage, improve water quality, develop good flood management, and help Scotland adapt to climate change. Examples under this program include the Completion of a valid "Farm Environmental Assessment" that incorporates a land management plan and capital funding for the development of habitats to improve biodiversity, reduce flooding risk and prevent soil erosion [127].

In relation to energy crop production, however, payments can be made directly for the establishment of a particular crop, examples include the European Energy Crop Scheme which subsidised 50% of establishment costs for SRC willow and polar, oilseed rape and miscanthus [128].

Within the UK there have been several policy mechanisms to support direct production of agricultural biomass, through dedicated schemes or through indirect mechanisms that were applicable to land management or the production of energy, both heat and electricity via biomass feedstocks. Evaluating the UK experience to date, the majority of policies that have been successful relate not to the production of agricultural biomass like SRC willow and poplar and miscanthus, but for the installation of biomass heating systems or the use of biomass in large scale co-firing or fully biomass-based systems. While there was some success with both phases of the Energy Crop Scheme (ECS) the majority of success was focussed on oilseed rape and not wood biomass.

The United Kingdom operate the renewable heat incentive scheme (RHI), designed to provide financial support for the generation of renewable heat through biomass boilers, solar thermal and heat pumps with payments based upon every kWh of heat produced, payable over a 20-year period. Under the RHI scheme, two streams are available; domestic and non-domestic, the non-domestic scheme opened in 2011 followed by the domestic scheme in 2014 [13]. The non-domestic scheme has resulted in over 1GW of installed capacity, comprising of over 6,000 installations, by 2014, 155 installations were using energy crops as their biomass feedstock. For large-scale energy generation, the United Kingdom offered a range of different subsidy levels depending upon the installed capacity (Table 5.2)

Table 0.2: UK Subsidies in relation to generating capacity.

Technology	**Installed Capacity (kWh_t)**	**$/kWh**
Biomass	< 200 (Tier 1)	2.85
Biomass	< 200 (Tier 2)	0.75
Biomass	200 – 1M (Tier 1)	5.32
Biomass	200 – 1M (Tier 2)	2.31
Biomass	>1 M	2.08
Combined Heat and Power	All	4.29

One of the requirements of utilizing biomass under the RHI scheme states that for eligibility all biomass must follow the RHI biomass sustainability criteria, which stipulates that all biomass must be sourced from sustainable sources. The scheme classifies sustainability as being produced in a carbon neutral or lean source [129].

The UK ECS operated between 2007 and 2013 (allowing establishment to 2015) and was part of the Rural Development Program for England, funded through the European Union and the UK Government. The objective of the program was to increase the amount and availability of home-grown energy crops to promote energy generation from biomass production and reduce reliance on energy generation from fossil fuels. The ECS provided an establishment grant for farmers and landowners for the production of a range of woody biomass crops including SRC willow, poplar and miscanthus. Under the scheme, the ECS offered 40% of establishment costs for miscanthus and 60% for SRC willow and poplar plantations, with three hectares being the minimum requirement per crop type planted. The 60% equated to £1000 per hectare, suggesting an establishment cost of £1,666 per hectare. One of the additional financial benefits to potential SRC producers was the availability of other grants and payments awarded under the EU Common Agricultural Policy including set-aside payments under the Single Payment Scheme. Where the set-aside payment were not available to applicants, applicants were also eligible to apply for the EU' Energy aid payment.

Within the UK, by 2016, 132,000 ha of agricultural land was utilized for bioenergy production, accounting for 2% of UK arable land. The majority, 53% was utilized for the production of biofuels predominantly from oil seed rape and sugar beet. As of 2016, the UK has 437 individual growers of SRC, utilizing 2,962 ha with production being attributed to the direct application of the Energy for Crops Scheme (while the ECS closed in 2013, it allowed establishment up to the end of 2015). This has resulted in an estimate of between 18,000 – 35,000 ODT of being produced in 2016, the large range of potential yields is as a result of no collated government data, therefore is based upon known productions areas and an estimated range of 6 – 12 ODT/ha/year and assumes a three-year harvesting cycle. The wide range is informed through varying estimates being provided to government with the National Non-food Crop Centres estimating an average annual production of 9.4 ODT/ha/year, the UK Forestry Commission suggesting yields of 8 ODT/ha/year and some industry bodies estimating 6 ODT/ha/year.

The majority of SRC willow within the UK has been utilized in large scale power plants in either a chipped medium or in pelletized format, largely driven through the United Kingdom Renewable Obligation requirements for biomass to use sustainable biomass of which SRC willow is considered to be. 2016 saw approximately 9,000 tonnes of SRC willow used for electricity generation, a decrease from previous years (2012 - 2013) which was attributed toward the Renewable Obligation Program being amended which removed the financial incentives for power stations to utilize energy crops in energy generation [130].

The remainder of yearly harvests from SRC willow in the UK have been used within the internal biomass market including district heating schemes, residential heating schemes and a limited home market. Adams and Lindegaard (2016) state that one of the predominant failures of the ECS, largely focusing on SRC willow, poplar and miscanthus establishment was the result of policies promoting biofuels over direct energy generation [131].

Mawhood, Slade and Shah (2015), found that the UK Energy crop Scheme had little impact on the production of energy crops, despite the UK aiming for between 300,000 and 900,000 ha of energy crops [132], concluding that subsidies do not necessarily combat uncertainty around profitability, long-term-land commitments or producing non-traditional crops [132].

Payments for set-aside is a form of direct payment made to landowners to suspend annual production of crops or in some instances removing land from use as pasture-land. The purpose of land set-aside is often to improve local environmental conditions or to control production within a given area; typically to reduce production of a various crop commodities [133].

The set-aside program available, through the EU Common Agricultural Policy and paid through the Single Farm Payment Program was designed to remove land from annual cropping production to control the production (originally designed to deal with over-production in the 1980s – 1990s) and was available to farmers who were currently producing crops [134]. Under the scheme, farmers could rotate set-aside land on a yearly basis or remove a proportion of land out of food crop production. While the set-aside program removed land from food production, there was a provision, were farmers able to utilize the set-aside land for energy crop production, however the majority of take-up was dedicated to annual oilseed rape production with over 90,000 ha used for energy crop production. Despite the initial success of the program, an increase in grain prices in 2008 resulted in the program closing down [135] [136].

As a replacement for the EU set-aside program, the EU developed the ecological focus area, requiring arable farmers with more than 15 ha removing 5% of land from traditional production. With the 5% being converted to buffer strips, the planting of hedges or trees on the land, field margins or leaving land fallow, all of which directly impact biodiversity. However it is also possible for farmers to plant crops where there is a significant reduction in agricultural inputs or there is a positive contribution to the soil; i.e. the production of nitrogen fixing crops [137]. As land set-aside programs are currently not in use in any region, the use of set-aside programs to provide in-direct financial incentives for SRC production unlikely to become viable in the future, nor, within the EU, is the planting of SRC under the current Ecological Focus Area program as an eligible option.

Where producers of biomass were not eligible for the set-aside scheme, those producing SRC willow, poplar and miscanthus were eligible for a per hectare payment of $45 /ha for carbon credits, with 2,544 ha of SRC and 6,016 ha of miscanthus being supported over the course of the scheme (2003 – 2009). However, the bulk of payments were made for oilseed rape production for the biodiesel market [138]. Eligibility in the Scheme was conditional on producers having a contract with a processor and cross-compliance with all CAP policies, however there was provision for farmers to process and utilize the feedstocks on agricultural holdings for heating purposes or for power production. By 2006, Europe saw 1.2 million hectares of land cultivated for energy crop production [138], but as with the United Kingdom, the predominant crop was oilseed rape, due to it being an annual crop, ease of processing into biodiesel and European policy pushing biofuel production.

The UK instigated a bioenergy Infrastructure Scheme (BIS) between 2005 and 2008, designed to develop the internal supply chain markets by providing grants of up to 100% for the harvesting, processing (wood chipping), storage and supply logistics. According to Adams and Lindegaard [131], the scheme was largely successful and benefited those seeking to get in to the SRC willow market as harvesting equipment was eligible under the program. Under the scheme, several harvesters were purchased and utilized amongst groups of growers in various regions of the England, expanding the production area of SRC willow.

Adams and Lindegaard (2016) highlight, while the BIS scheme was successful, a change in government policy relating to what equipment could be purchased under the scheme resulted in the rejection of applications for harvesting equipment and the stalling of SRC willow in certain regions of England, due to the lack of availability of harvesting machinery which was being used. They estimate that 38% of SRC willow in the South of England was removed as a direct result of a lack of access to harvesting machinery and a lack of available local markets for the SRC willow [131].

Across Europe, through the common agricultural policy’s rural development program there are several routes for farmers and landowners to capitalize on funding opportunities, either through subsidies or grants to allow to produce agricultural biomass and in general and some that specifically target SRC willow, poplar and miscanthus production. It has been estimated, that by 2020, 20.3 million ha of predominantly fallow and marginal land could be utilized for the production of energy crops (Figure 5.1) [139].

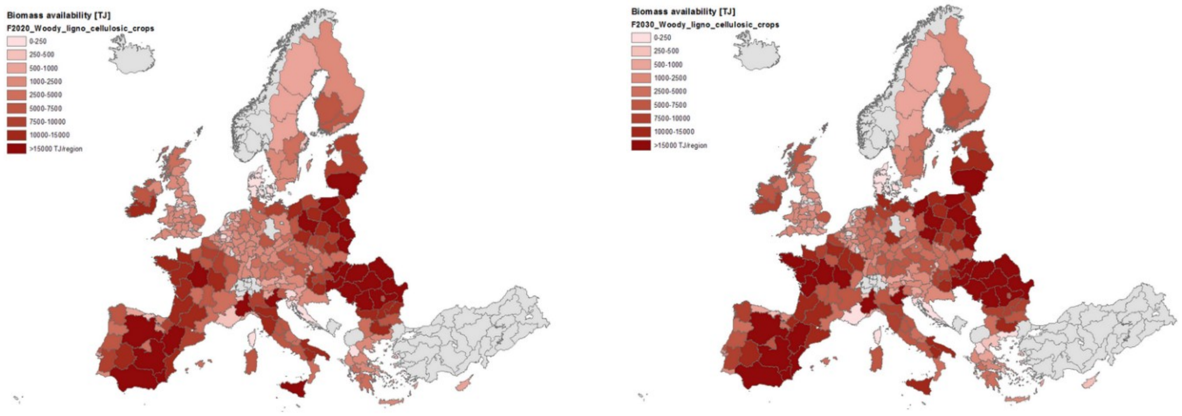


Figure 5.1: European biomass availability – 2020 to 2030 scenario [132].

From researching the different options for the production of SRC willow and agricultural biomass crops in general, access to funding for biomass infrastructure, access to grants and subsidies for land management, access to dedicated funding or research funds for the establishment and production of agricultural biomass and access to payment schemes for the generation of renewable energy is the main driver in whether SRC willow and agricultural energy crops are established. However, it is clear that funding for the direct production is not enough, there needs to be clear policy to develop agricultural biomass and funding for the development of supply chains.

From reviewing the literature and available data, one of the key barriers to the development of sustainable SRC willow productions is the lack of financial incentives, which, as highlighted, is likely because of a lack of information for government, potential producers, and industrial, commercial, and residential end-users, which in turn leads to a lack of policy in SRC willow development, suggesting a circular issue. It was highlighted that to counteract the lack of policy, there needs to be a larger push towards research and development, but without dedicated funding this becomes a circular problem.

5.5 Biomass Policy and Development: The Canadian Perspective (Excluding Nova Scotia)

A 2012 evaluation of Canada’s Energy Sector Sustainability Bioenergy Strategic Priorities [140] found that a well-developed bioeconomy is vital to Canada and that Canada could have the potential to become a bioenergy leader and recognised the need for extensive public and private investment in to research and development to stimulate the economy. With regards to agriculture, the strategic review mentions the role agriculture can play in biomass production, estimating that it has the potential to contribute up 102 TWh/year in energy generation (referring to agricultural residuals) and further mentions that energy crops should play a role [140].

The Federal Government is invested in the bioeconomy, in making sure it succeeds and how it applies to bioenergy and bioproduct production; but the focus is still heavily dominated by the forestry sector [141] (with the exclusion of biofuel production). Up until 2016, there had been criticisms that Canada was lagging behind most other developed countries with regards to a coherent and broad reaching bioeconomy strategy [112, 113, 114, 115] and groups have recommended approaches to developing the Canadian Bioeconomy [146]. The Canadian Federal Government's "Forest Bioeconomy Framework for Canada" [15] which states the importance of forestry in the renewable energy generation and the importance of biomass, especially within Indigenous and Northern communities is a good first step at pushing forward a Canadian bioeconomy but there is no core policy that focuses on agricultural biomass.

Despite the positive move by the federal government to promote biomass on some level through recent policy and funding opportunities, there is still currently no Federal funding available for developing agricultural biomass supply chains. Nor is there any dedicated policy to promote the use of agricultural biomass or seek to develop supply chains, with the exception of the 'Bioenergy Systems for Viable Stationary Applications Program'[147], however this program, while mentioning supply chain development, there is no indication that research has taken place in this area.

This focus on the forestry industry as Canada's bioeconomy and the lateness of biomass policy in relation to other developed countries, it could be argued, is having a detrimental effect on the potential for agricultural biomass development. It could further be argued that the lack of Federal policy on this matter is reducing the development of biomass policy and agricultural biomass policy and supply chain development at the Provincial level. This is not to say that neither the federal nor provincial governments are not invested in Canada developing a robust agricultural biomass economy, but that it is currently not a priority.

As highlighted the majority of the Canadian provinces do not have any coherent biomass policies, however, the majority of the provinces have dedicated renewable energy plans, climate adaptation plans and clean energy plans as well as forestry resource management plans. Not all the provinces refer to the utilization of forestry biomass as a means for energy generation, nor surrounding the development of provincial bioeconomies.

Recent work by the Solid Fuels Sub-working Group from the Canadian Government's Clean Fuel Steering Committee (CFSC), a government-industry collaboration, evaluated several scenarios for increasing the supply of biomass, concluding that biomass could supply up to 277 GWh of energy by 2030 for both heat and electricity [148] utilizing 67% or 87 million tonnes of available yearly new sustainable biomass supplies. The biomass in reference relates primarily to new primary forestry products, forestry residues and a small amount of crop residues. A brief mention of energy crops in mentioned (switchgrass and SRC willow) however no assessment has been made to the potential of these crops.

Based on the analysis by the CFSC, while forestry biomass has the potential to be a vital resource in Canada's energy mix for both electricity and fuel, there are multiple roadblocks to this happening, but of the ten recommendations made and of relevance to the development of SRC willow the Canadian Federal Government and Provincial governments need to:

> *"Use public procurement to kick-start solid fuel supply chains" and "Support initiatives to reduce investor related feedstock risk perception and develop supply chains".*
>
> CFSC (2019)

The focus is largely put on the need for improving and further developing solid-fuel supply chains and reducing the risk, however given the well-established forestry biomass industry, it is difficult to identify when a focus will be put on to agricultural crops as a source for solid fuels, whether for heat production or energy generation. The following sections (5.5.1 – 5.5.10) outline the steps each province has taken to develop the bioenergy industry.

5.5.1 Alberta

In 2006 Alberta instigated a nine-point bioenergy plan in 2006, with the program coming to an end in 2016, with the stated aim of promoting bioenergy within the province [149]. To promote bioenergy production, the province provided funding to develop and commercialize biofuels and biogas within the province, providing $24 million (2008-2009) and $6 million was dedicated towards the development of bioenergy infrastructure (2008-2009). Similarly aimed at the production of biofuels, a renewable energy producer credit program between 2007 and 2011 with the aim of providing credit towards the production of biofuels. Alberta's Climate Leadership Plan [150], which sets out the province of Alberta's GHG emission target, renewable energy targets and sustainability objectives, currently makes no major commitment to the development of biomass, nor agricultural energy crops, with the main focus being on wind, solar and hydro power generation. As of 2016, biomass/biogas electricity accounts for 2.62% of electrical generation, down from 2.79% in 2011, suggesting that of the renewable technologies, biomass energy generation is not currently a key priority, or it is not being widely adopted.

However Alberta, in 2016 instigated a Bioenergy Producer Program, for the generation of electricity and liquid biofuels, with the scheme originally running from 2016-2017, however this program has been extended to 2020 [151], this program was the successor to the Alberta Bioenergy Producer Credit Program and has the similar goal of GHG emissions reduction. Under the program, those producing bioenergy are eligible for funding if they have produced energy for a minimum of three consecutive months, prior to the application for funding being submitted. Depending upon the program period, those facilities producing bioenergy from the gasification of biomass are eligible for up to $2 million in the first period and for those applying in periods two and three, $3.7 million, derived from a total funding budget of $63 million [151], as of 2017, thirty individual agreements have been made for generation through bioenergy [152]. Installed systems for direct combustion must have a minimum installed capacity of 5MW and must be a system whose sole purpose is energy generation and not part of a commercial enterprise (e.g. pulp and paper mill or sawmill), producer credits are offered at a rate of between $25 - $70 depending upon current energy rates [151].

Despite the Bioenergy Producer Program and the obvious success of the program due to it being a successor program, the Province of Alberta are predominantly focussed on other renewable technologies. Given the relatively small funding pool available to biomass and given that it is directed at energy generation (incorporating biogas and biofuel production), it is currently unlikely to see the development of agricultural biomass and SRC willow supply chains being developed within the province, with the current program only focusing on the use of biomass and not its sourcing.

Focusing on resource development, Alberta Innovates and Silvacom developed the Bioresource Information Management System (BRIMS), designed to be a centralized data system provides an assessment of biomass from forestry, agriculture and municipal waste systems to help inform bio-resource and investment decisions in Alberta and acts as a tool for policy makers [153].

Alberta currently has one of the largest SRC willow plantation located in Keoma, covering 350 hectares and expanding by another 180 hectares operated by Sylvis, to evaluate the potential of using biosolids in conjunction with SRC willow to improve conditions on solonetzic soils [154]. A second project, at Forestburg, Alberta, an old strip-coal mine, so the purpose is land restoration, covering about 500 hectares and will be using biosolids from Edmonton, bringing up the land quality from a 4-5 class to a class 2 in terms of soil quality and productivity value. This has been funded through a number of partners including Alberta Innovates, National Resource Canada's Clean Growth Program and from Emissions Reduction Canada [155]

5.5.2 British Columbia

British Columbia are one of the few Canadian provinces with a dedicated Biomass strategy, out-with a general renewable or climate change action plan. Published in 2008, the BC bioenergy strategy set out clear goal to achieve by 2020 and reviewed potential biomass availability, identifying 10% of their biomass resource potentially being derived from sustainable agriculture [156], with the predominant focus on crop residues as an untapped source but recognising the role energy crops could potentially play.

Promoting biomass within the region is the BC Bioenergy Network, which has helped partly fund a number of capital funding projects, investing $16m into eighteen projects, ranging from biogas systems, CHP projects and biofuel projects. The BC bioenergy Network have also focused on capacity building, within funding having been directed towards developing agricultural bioenergy. In reference to SRC willow and poplar production, both are recognised as primary agricultural products

5.5.3 Manitoba

As part of a clean energy strategy [157], the Government of Manitoba instigated a biomass energy support program, as one of their commitments to reducing GHG emissions, with the funding tranche available between 2014 and September 2017 [158], operating on a first-come-first serve basis. The funding was a Provincial/Federal partnership, funded in part through the 'Growing Forward 2" program. The province further offered a support scheme to encourage coal users to switch to biomass, offering funding up to $12,000 to offset the price differential between coal and biomass over a 14 month period [159]. It is estimated that Manitoba has between 3 and 5 million tonnes of biomass available on an annual basis, with the program stating that through utilizing a proportion of available provincial biomass, there would be a reduction in fossil fuel imports, improvement in local economies and stimulate renewable development in rural areas within the province.

The program offered two components; capital incentives for producers and processors for use in infrastructure development and equipment upgrades and research and development funding to support innovation that would advance the biomass sector in Manitoba. Through the capital funding stream, provided on a cost-sharing basis, eligible applicants, were able to apply for up to $50,000 or a maximum of 50% of the total costs. Under the scheme, there were a wide range of eligible biomass sources available including purpose grown agricultural energy crops including SRC willow and poplar and energy grasses.

In part, due to the success of the scheme, the Government of Manitoba has signed a five-year agreement with the Canadian Federal Government to focus on agricultural priorities. Under the partnership Manitoba will receive $176 million to invest in sustainability and competitiveness in the agricultural sector, however there is no indication on whether SRC willow will be a priority focus.

5.5.4 New Brunswick

New Brunswick, currently has no dedicated biomass policy in place, however produced, in collaboration with the University of Moncton a report entitled “Forest Biomass to Energy Atlas of New Brunswick” [160]. The report identified that New Brunswick has the potential to support up to 463 MW installed capacity for electricity generation and 1,111 MW of installed capacity for heat generation, stating that CHP systems (or using co-generation) are viable within the province, being supported by a potential 15.5 M green tonnes of biomass per annum.

The New Brunswick Energy Blueprint [161] stated that they will seek to develop wood based biomass resources within the province, with a specific focus on pellet production and prioritizing energy generation. The province in the follow-up “New Brunswick Value-added Wood Sector Strategy” [162] aims to develop specific policy to support biomass heat technology and to develop a wood pellet supply chain.

5.5.5 Newfoundland and Labrador

Newfoundland and Labrador, in their Innovation Roadmap [163] (an analysis of Newfoundland and Labrador Resources), make specific reference to biomass for energy generation and reference to agricultural biomass however, drew conclusions that biomass is only feasible at local markets under specific market conditions where there is a system in place and the need for biomass. The 2007 Newfoundland and Energy Plan makes reference to biomass energy generation, but it is low on the list considering the potential for wind power and hydro [164]. There are currently no policies pertaining to agricultural biomass nor funding opportunities available for agricultural biomass production or utilization.

5.5.6 Ontario

Ontario currently offered a feed-in-tariff program, of which biomass systems were able to apply, with four systems being commissioned. With regards to agricultural biomass, Ontario instigated a Farm Innovation Program along with several other farm programs that incentivised farm biogas systems, by offering funding and tax incentives.

Focusing specifically on agriculture, Ontario ran a successful policy promoting the use of biogas production on-farm through the Farm Innovation Program, the Canadian Agricultural Adaptation Program and via the feed-in-tariff program, providing a wide range of funding opportunities and tax breaks for farm-based projects.

Currently there are no dedicated polices that focus on agricultural biomass or biomass for energy generation specifically, however Ontario's "2017 Long-term Energy Plan: Delivering Fairness an Choice" [165], mentions biomass use for energy generation, with biomass only accounting for 0.4% of Ontario's energy mix, with nuclear and hydro being the predominant source of energy.

5.5.7 Prince Edward Island

Prince Edward Island in their 2016-2017 provincial energy strategy [166] are one of the few provinces to go into some depth with regards to biomass for energy generation and set forth some specific policy objectives.

With regards to agricultural biomass, the strategy, in reference to using biomass for large-scale energy generation, currently regard it as an expensive option due to production, harvesting and supply logistic concerns, but recognise that there may be potential in the future but not for residential heating systems. The energy strategy further breaks down biomass use into different categories (Industrial, commercial, and residential) and feedstock options as a heating source. Stating that wood chips for large heating systems at institutional and municipal levels are limited, with some biomass based heating systems having to be de-commissioned due to lack of wood chip availability, however the province is committed to utilize some biomass provided it is in a sustainable manner [166].

At a residential level, PEI has, through Efficiency PEI incentivized the use of pellet stoves through rebates [167] and state that there has been significant uptake in wood pellets. However these are imported from other Provinces and that they are considering the adoption of policy to further promote biomass heating which would make the use of pellets more attractive as they would anticipate larger bulk deliveries on a more frequent basis to the island, making the economics more attractive to the residential and possibly commercial sector [166].

The Prince Edward Island Government produced a recommendation document [168] in 2009 dedicated to biomass heat and the future outlook of the industry, that state that the province should adopt biomass extensively as a means to reduce reliance on fossil fuels. The document makes specific reference to agricultural biomass and reference to SRC willow and poplar, making recommendations for a pilot project (see SRC willow production in Prince Edward Island) and ran a Bioeconomy Initiative to trial SRC willow and poplar [169].

5.5.8 Quebec

Quebec has taken several approaches to promote biomass, including funding towards the conversion from oil-based heating systems to biomass systems, with funding available to municipalities and institutions. Regional authorities, as opposed to the Provincial government are able to operate biomass policies and deliver funding on a local level at a case-by-case basis.

5.5.9 Saskatchewan

Currently Saskatchewan has no dedicated biomass policy however Saskatchewan Power aims to add in some form of biomass energy by 2030, somewhere between 1-5% [170].

5.5.10 Northwest Territories

The Northwest Territories currently have a dedicated Biomass energy strategy with the sole focus on promoting the use of local and imported forestry biomass to reduce the province's reliance on fossil fuels and reduce GHG emissions. The strategy has a major focus on promoting biomass as a heating source option for both residential and commercial purposes and promoting CHP technology [171]. While the Territory is keen to promote the use of biomass between now and 2030, they recognise that expanding the supply of biomass will be challenging due to the absence of a large forestry industry in the Territory and limited transportation infrastructure. Currently the majority of biomass (in pellet and chip form) being imported from Alberta and British Columbia, however despite the challenges the Territory is committed to developing biomass for heating [172]. The Territory has no provision for agricultural biomass; however, it is widely accepted that the production of SRC willow and poplar and miscanthus would not be viable products due to climactic considerations.

5.6 Canadian landscape of agricultural biomass support

There are a number of large-scale funding programs within Canada, BioMass Canada is a new cluster from 2019, with a vision for the Canadian agriculture to become competitive in the production of biomass for bioenergy and bioproducts [173] with funding of $10.1 million from Agriculture and Agri-Food Canada. The focus is on; 1) developing feedstock and processing and utilization systems in the Northern Zone of Canada to work towards energy security in the region;

2) the optimization of biomass production in different regions of Canada, which includes yield studies of SRC willow, and; 3) biomass pre-processing, supply chain logistics and economics [174].

The value of this program is the breadth of partners from government, industry and university that are seeking to develop the biomass industry backed up with funding. It should be noted that BioMass Canada is an offshoot of the successful BiofuelNET Canada, an expansive network organisation and partnerships seeking to mobilize Canada's biofuel industry through extensive partnership development, funding and offering of education. They further offer policy positions including areas on biojet fuels, biorefineries, and the use of low quality forestry products for biofuel production [174].

While Canadian biomass policy and funding is behind, that is not to say that there is no innovation and lobbying for the Canadian bioeconomy and biomass production. A review of bio-energy organizations across Canada demonstrates a wide range of different organisations that have been set up to support, lobby and promote the use of biomass as a means for energy generation; both biofuels and biomass for combustion (Table 5.3).

Table 0.3: Canadian industry commitment to biomass.

Organisation	Role	Provision of Funding	SRC Development Funding	Ref
BC Bioenergy Network	BC bioenergy technology development	Yes – Funding available for capacity building and Capital projects. Capacity building funding is available for forestry and agricultural residues and municipal wastes. A large focus on Anaerobic Digestion	No	[175]
BC Green Heat Initiative	Supports the development of renewable heat projects	No – Offers assistance and support in accessing funding, developing networks to build up green capacity and building technical knowledge.	No	[176]
BioFuelNet Canada	Network of Excellence, research, and Lobbying Organisation	No – While no funding is directly available from BioFuelNet, however there is an Investment Network that offers capital investment, advisory services, and venture capital funding.	Previously available research grants available for supply chain development but not dedicated to SRC willow Production	[177]
Biomass Energy Resource Center	Resource and industry Collaboration Organisation offering services including resource and supply chain feasibility studies	No – Offers assistance to parties in evaluating biomass potentials including supply chains and regional biomass availability studies.	No	[178]
Biomass Thermal Energy Council	Lobbying Organisation for biomass heat	No – However, BTEC lobbies and supports various biomass policies and funding mechanisms	No	[179]
Canadian Biomass Innovation Network	Networking Organisation	No – has links with industry funding, and helps to shape biomass policy	No	[180]
Canadian Bioenergy Association	Bioenergy Lobbying Organisation		No	
Canadian Renewable Fuels Association	Renewable Energy Lobbying Organisation	No – supports and promotes the development of biofuels	No	

Organisation	Role	Provision of Funding	SRC Development Funding	Ref
Canmet Energy	Renewable Energy research and Technology development Organisation	No -	No	[181]
Forest Bioenergy	Forestry Information Organisation			[182]
FPInnovations	Forestry Supply Chain Development Organisation	Yes – Collaborations for various forestry-based issues including logistics and operations.	No	[183]
Ontario Biomass Producers Co-operative Inc.	A group of Ontario based farmers promoting and trying to develop energy crop production in Ontario	No – a co-operative group providing support, resources and lobbying for the development of agricultural biomass in Ontario	No – however there is a focus on grass-based biomass (Miscanthus and Switchgrass_	[184]
Ontario Sustainable Energy Association	Provincial Lobbying Organisation	Yes – Focused on small grants for the generation of renewable energy within communities	No	[185]
Pellet Fuels Institute	Industry Lobbying Organisation	No	No	[186]
Wood Pellet Association of Canada	Industry Lobbying Body	No	No	[187]

Despite the large number of organisations focusing on the bioeconomy and promoting biomass as an energy source, none of the organisations or NGO focus particularly on Agricultural Biomass (SRC willow, poplar and miscanthus) for direct energy generation. Although these crops are mentioned as potential sources of energy and more research is required in to developing the supply chains, testing of varieties, and making the economic case for their production and utilization.

5.6.1 Canadian Funding Opportunities

Focussing specifically on biomass, the Federal Government, while in response to American taxes imposed on imported Canadian forestry products, committed $870 million to support Canadian softwood lumber. The goal of the funding was to ensure that the lumber industry, admittedly one of the largest employment sectors in Canada, employing 230,000 Canadians remained buoyant and did not suffer job losses, however the funding is also a means to help develop and innovate within the forestry industry to support a bio-based economy, including the use of biomass for energy generation [188]

There are currently several different Federal funding streams available within Canada that are either directly or indirectly available for biomass (Table 5.4). These funding opportunities predominantly focus on fuel switching from fossil fuel-based systems, are designed to support research and development (internally within the Government of Canada) and general GHG emission programs which biomass can be linked to or have focused on the forestry industry.

Table 0.4: Federal funding with links to bioenergy generation or biomass development.

Organization	Initiative	Description	Implementation	Ref
Natural Resources Canada/Canadian Forestry Sector	Pulp and Paper Green Transformation Program	$1B funding aimed at supporting and improving energy efficiency within the Pulp and Paper industry	2009 - 2013	[189]
	Investments in Forestry Industry Transformation	$100 m at new technology for bioenergy and biomaterials. Additional $90.4m funding in 2014 and a further $55m in 2017	2010 -	[190]
	Indigenous Forestry Initiative	Instigated to increase Indigenous participation on Canadian Forestry, with a focus on bioenergy, with $2 million having been provided for several norther projects. In 2017 the program was extended with a further $10m to promote participation in the forestry sector and reduce the reliance on fossil fuel heat generation.	2011-	[191]
	Clean Growth Program	Provision of $155m for clean energy research in[191] the energy, mining and forestry sector. The aim is to reduce GHG emissions, improve waste management, the production and use of advanced material and bioproducts and to improve energy efficiency and productivity	2018	[192]

Organization	Initiative	Description	Implementation	Ref
Natural Resources Canada/ Office of Energy Research and Development	Program of Energy Research and Development	Aimed at providing support for Research and Development for biomass feedstock supply, sustainability studies, processing systems and biofuel production. Currently there is no indication of what successes have been achieved.	2015 - 2019	[193]
	EcoEnergy Innovation Initiative	Funding for demonstration CHP systems and included waste-to-energy, anaerobic digestion.	2011	[194]
	Clean Energy for Rural and Remote Communities: BioHeat, Demonstration and Deployment Program Streams	Aimed at reducing the reliance on fossil fuels in remote communities across Canada. The BioHeat Stream focuses on the retrofitting of systems in communities and industry. There is currently no indication of the success of the program	2018 -	[195]
	Clean Fuel Fund	The fund will invest $1.5 billion over five years to focus on building the capacity of biofuel production in Canada, this includes establishing supply chains for “biomass hubs” and developing standards	2021 -	[196]

Organization	Initiative	Description	Implementation	Ref
Indigenous and Northern Affairs Canada	EcoEnergy for Aboriginal and Northern Communities Program	With the aim of GHG emissions reduction the program provided Indigenous and northern communities funding for renewable technologies including biomass systems	2011 - 2016	[197]
	First Nation Infrastructure Fund	Initial provision of \$234m (2007 – 2013) to support on-reservation energy systems including biomass systems. Further funding provided from 2018 onwards.	2007 -	[198]

Organization	Initiative	Description	Implementation	Ref
Agriculture and Agri-food Canada	Agriculture Clean Technology Program	This fund offers two streams, an adoption stream and a research and innovation stream. The purpose of the fund is to promote and develop green energy and energy efficiency, precision agriculture and bioeconomy solutions within agriculture.	2021 -	[199]

Organization	Initiative	Description	Implementation	Ref
National Research Council Canada	Bioenergy Systems for Viable Stationary Applications Program	Initial focus on providing technical and aid in overcoming financial barriers for integrating locally sourced biomass for energy generation. Funding is based upon a collaborative process and is judged on a case-by-case basis. There is currently no indication of what projects are being pursued.	2013, 2018-2019	[147]
	Low Carbon Economy Challenge	The funding will provide \$500m. The project provides part funding to a wide range of different organisations including industry and offers different funding levels through different schemes. Aimed at reducing GHG emissions, the project is wide ranging but has provision for agriculture, fuel switching, self-production of low-carbon fuel for own purposes, the development of district heating schemes. and the generation of electricity and heat and for CHP systems. Regardless of the stream, all participants must clearly demonstrate GHG emissions reduction.	2019 -	[200]

None of the programs available up-until the launch of the 2018 Low Carbon Economy Challenge funding program have specifically referenced agriculture or the production of fuel sources for own purposes [200]. While the program does not specify SRC or any specific energy crop, assessing the potential eligible sectors, SRC production could fit into a number including: "Enhancing carbon sinks in the agricultural sector" of which research SRC willow does act as a sink and the "low carbon fuel production for own use" of which SRC willow is a potential option, with funding liable to significantly reduce establishment costs [200]. The program also supports electricity and or energy production schemes which covers district heating schemes and CHP for own use; both of which bioenergy is an option and which would allow for the production and use of SRC willow as a feedstock.

5.7 Nova Scotia Biomass Policy

Nova Scotia currently lacks of clear policy in relation to agricultural biomass development and usage; despite a number of other Canadian Provinces having adopted biomass/energy strategies [171, 141, 126, 172] and utilizing biomass for electrical generation. However biomass is mentioned in the Nova Scotia Renewable Electricity Plan [203] and Nova Scotia's Natural Resources Strategy [204] mentions biomass in relation to the restriction of forestry biomass for combustion. The Canadian Bioenergy Association previously highlighted that the Atlantic provinces in particular are suffering from a significant number of regulatory issues that are preventing the expansion of biomass, nor is there any clear indication of the development of a regional bioenergy group or network that can advocate, coordinate and help develop the industry [205].

However, as of 2020 there is now the Nova Scotia Innovation Hub, with an objective to "accelerate the growth of Nova Scotia's low-carbon bioeconomy" [206], who are developing a range of partners, information on available feedstocks and help with obtaining funding. Some of the projects supported so far include the 'upcycling of waste food products' [207], the production of biomass pellets, synthetic diesel and capture of recyclable material in Chester, NS [208] and working with a company focused on biochar and ash modification technologies [209]

Within Nova Scotia, there is currently no support or educational schemes to aid farmers in understanding biomass crops or financial schemes to incentivize the uptake of biomass production from outside investors, which contrasts with other parts of the world

Think Farm, a Nova Scotia Government initiative, highlighted in a 2012 publication note that there is currently an under-utilized agricultural land base within the province and for agricultural biomass (grass based) to take off, the industry must be developed in a sustainable manner, slowly and by farmers, for farmers [210].

The 2016 standing policy document of the Nova Scotia Federation of Agriculture (NSFA), in relation to energy production, state that many farmers within the province have the capacity to produce enough biomass for their energy needs and that of their neighbours as they believe that it is necessary for farmers to have access to affordable and sustainable energy sources to ensure a successful farm enterprise [211].

Prior to the 2011, policy framework report ‘Protecting and Preserving Agricultural Land in Nova Scotia’, the Nova Scotia Land Review Committee (ALRC), was given the remit of providing advice, guidance and recommendations for the preservation of agricultural land in Nova Scotia, with one of those recommendations being that the government (NS), should be emphasizing support and development programs to develop agricultural biomass energy systems, as a means of economic development and to preserve and protect Nova Scotia agricultural land [212].

While agricultural biomass was outside the remit of the committee involved in developing the ‘Protecting and Preserving Agricultural Land in Nova Scotia’ policy report, it stated that agricultural biomass would be addressed via the Nova Scotia ‘Homegrown Success’ program, with the Government producing the document, ‘Homegrown Success – a 10-year plan for agriculture’, which states that the government and the energy sector will work with the agricultural industry to explore renewable energy options, including biomass, for the industry [213].

The idea of using agriculture biomass as a means to generate energy, create diversification within the industry and contribute towards a sustainable energy economy within Nova Scotia is not a new idea within the province. The 2002 report, ‘Agricultural Biomass Residue Inventories and Conversion Systems for Energy Production in Eastern Canada’ [214], states in its concluding remarks that while Eastern Canada has the potential for agricultural biomass (residues) to contribute towards energy generation, the development of energy systems in Eastern Canada requires ‘long-term research and a development effort’ and ‘linking the environmental benefits (of biomass) with energy generation’ [214]. In 2008, a presentation at the Ocean Energy Research Association Conference (OERA) [215], suggested that there was the potential in Nova Scotia to develop a bioeconomy, specifically stating the benefits and viability of producing grass and coppice based biomass, but stating that there needs to be development and that development will depend on economic viability and supportive policy [215].

5.8 Recommendations for Nova Scotia

Recalling the production barriers found in the literature; lack of knowledge, lack of market access, farmer resistance for long-term land commitment or cultural reasons and lack of subsidies and even where subsidies did take place in European countries, either through establishment schemes or farm subsidies, it did not necessarily spur the expected growth of agricultural biomass crops like SRC willow, is of relevance to Nova Scotia.

Nova Scotia still does not have a fully-fledged bioeconomy, but nationally there are a range of bodies that aim to promote the bioeconomy, not least Bioindustrial Innovation Canada, that seeks to help Canada convert bioresources in to value-added bioenergy, biofuel, biochemical and biomaterials [216]. Within Nova Scotia there is ResearchNS, a not-for-profit corporation which has a mandate to support, organize and coordinate funding of research in Nova Scotia, with one key theme being on research to develop the bioeconomy, this however primarily focuses on the role forestry can play in this and linking conserving forest ecosystems and conserving biodiversity [217]. Additionally there is the recent Nova Scotia Innovation Hub, with an objective to help grown the Nova Scotia bioeconomy [206], through network development, funding support, partnership development and guidance.

Nova Scotia has little to no commercial energy crop production. Nova Scotia's 2016 cropland components are 23.7% for field crops, 54% for hay and 18.3% for fruits, berries, and nuts [46]. The principle agricultural products are corn for grain and silage covering over 12,100 ha and land fruits, primarily blueberries, apples, and grapes, from horticulture covering just under 20,000 ha [46] which was worth over $60 million in 2016 and $67 million in 2020 [47]. Given the lack of production of energy crops in the Province of Nova Scotia, if it wished to pursue energy crop production, for direct combustion or for other bioprocesses, must start from the ground up. The lessons extracted from this literature review suggest that the focus should be on market development for biomass products and education around what energy crops are, how they are grown and the value of them. With less, or not at all, on subsidies, although that may be necessary in the form of research and innovation funding to help initial production in Nova Scotia by showing that it can be done.

One of the key lessons that can be transferred to Nova Scotia and indeed across Canada in general with regards to SRC willow production is that there needs to be a dedicated and concerted policy direction and incentive not only the establishment of SRC willow (and miscanthus) but the development of the processing and supply chain. To-date, while there is a general appreciation and a desire for biomass energy generation within Canada, this appreciation is distinctly lacking for Agricultural Biomass production, 1) because there is a well-established forestry biomass industry that have years of experience in production, management, harvesting and logistics, a well-defined industry, a large and well-established industry trade body, and well-structured government policy. Without support, and even when comparing the successes and failures of UK, European and American biomass policies, and financial incentives, it is clear that financing and a political will to see agricultural biomass is going to be the key driver in developing an industry.

An alternative option, that seems to be developing in Alberta, that could be transposed to Nova Scotia, is land restoration by using biosolids and the production of energy crops including SRC willow. This has attractive prospects due to the quantity of inactive and marginal agricultural land, and areas where land restoration is necessary in Nova Scotia. Additionally, the Federal Government is developing a Greenhouse Carbon Offset program with protocols in development including one for “Enhanced Soil Organic Carbon” [218], which has a potential link; improving soils, through storing about building up carbon while producing a viable crop for energy generation or other bioproducts.

It must be emphasised that Nova Scotia, does have a thriving agricultural sector for food products, especially high value fruit crops and given Nova Scotia’s relative size, land capacity and forestry industry, while there could be scope for SRC willow for energy generation on a local level, it may be that Nova Scotia and where it’s bioeconomy goes, might be best served through agricultural biomass production for biochemicals and bioproducts, keeping short supply chains, leaving the larger provinces to focus on biofuel and bioenergy production.

Chapter 6 SRC PRODUCTION AND TECHNOLOGY REQUIREMENTS

6.1 Short Rotation Coppice Production

Coppicing is the process of harvesting/cutting-back, typically to just above ground level, fast growing tree species to stimulate further growth over a number of years before re-cutting. This process repeated on a rotational cycle, with the length of rotation relating to the purpose of coppicing and the desired characteristics of the harvested material; typically, the diameter or size of the material. Following the coppicing process, the stump or stool of the tree will generate new shoots, typically an increased number of shoots, which is then be harvested in future years.

Short Rotation woody crops are fast growing woody tree species, commonly willow (*Salix spp.*) and poplar (*Populus spp.*), which are now commonly used for energy generation purposes. SRC willow and poplar are rapid growing tree species, with expected growth rates, after the first-year cutback, ranging from 2-4 m in the first year of regrowth and producers seeing 6-8 m of growth at harvest; commonly in the third year. It can be expected that producers will be able to harvest SRC between six and eight times, with an expected plantation having a lifespan of 20-30 years before productivity/yield decreases [30, 189].

SRC usage has its origins within Europe, where it has been produced and utilized for the last several decades as an energy feedstock, with reports stating that there was historical use of both poplar and willow [103]. The development of SRC taking off in the 1970's due to a shortage of pulp feedstocks for pulp and paper and further developments due to oil shortages in the early 1970s. Since the 1970s SRC has gained traction in the Northern regions of Europe [220] where it is currently being utilized as an energy feedstock, however it has uses as an effective land remediation crop or as a method of amelioration to reduce potential contamination from effluents [191, 192, 193].

Sweden currently has a high rate of SRC willow production with 16,000 ha having been planted by 2003, accounting for 1% of Sweden's wood fuel for energy generation, where a price of 13 Euros per MWh produced, which was comparable to other forestry biomass feedstocks [224]. Within Sweden the majority of SRC willow plantations were grown on private farms but managed through and contracted through a biomass production company (Agrobränsle AB). An early surge in SRC willow production was because of several factor in the 1990s, with a low price for cereals coinciding with Government policy to incentivise the establishment of SRC willow, however due to EU policy of set-a-side under the EU Common Agricultural Policy, the increase in SRC willow plantations did not occur. However with an increase in biomass requirements throughout the EU and other developed countries, the economics of SRC willow has improved dramatically [224].

Agrobränsle set a long-term objective of increasing the area of willow grown in Sweden to 30,000 ha by 2010, which they successfully achieved and aimed to increase this to between 200,000-300,000 ha in the decades that follow, however this has not currently been achieved. Outside of Sweden, Agrobränsle has attempted to establish markets in the UK, Poland, and Baltic states, however due to the lack of financial incentives there is little market penetration.

Furthering the expansion of SRC, to an extent, within the United Kingdom has been the offer of establishment grants and schemes, which lead to an uptake in production, however most schemes have now ceased or are projected to end in the coming years. The United Kingdom ran an 'Energy Crop Scheme' from 2007 – 2013 which resulted in the UK subsidising 40% of the actual establishment cost of SRC willow and miscanthus, with actual payments being calculated on a case-by-case basis, with a benchmark establishment value of $3,392/ha (2006 UK-Canada exchange rate).

The adoption of SRC within North America is relatively recent and is still not a widely adopted method of biomass production outside of the North-eastern part of North America, where a large number of trials ranging from sub-hectare to hectare sized plots, however there is no large-scale commercial production.

Within Canada, the majority of trials and SRC Plantations have been located in the province of Quebec, although other provinces have trialled SRC. SRC willow has been trialled in Southern Quebec since the early 1990's with two trial plantations having been established [225]. Guidi Nissim *et al.* [225] an cultivar of SRC willow (*S. viminalis*) over several rotations under both fertilized (using sewage sludge) and unfertilized conditions and further evaluated nine different cultivars over three rotations. Results indicate that under both fertilized and unfertilized conditions, the yields increased over successive rotations, with the fertilized rotations seeing an increase from 15.1 ODT/ha/year (± 4.2) in the first rotation (3rd year) to 22.5 ODT/ha/year (± 6.3) in the fourth rotation (15th year) with the non-fertilized rotations yielding 10.6 ODT/ha/year (± 4) in the first rotation and 16.8 ODT/ha/year (± 8.1) in the fourth rotation. Guidi Nissim *et al.* (2013)

evaluation of nine different cultivars found that in terms of growth, the number of shoots produced per stool (after each cutback) and biomass yield varied in relation to the cultivar. Cultivar clonal variety SX64 (*S. miyabeana*) yielded 15.2 ODT/ha/year in the first rotation and 24.3 ODT/ha/year in the third rotation.

SRC has several other benefits out with its use as an alternative energy source, with it being increasingly evaluated for and used in land phytoremediation practices from industrial processes where land has become contaminated with metals [196, 197, 198, 199] or as a means to control and reduce landfill leachate [200, 201, 202], with productivity being relatively high regardless of variety used. It has further been used as a means to treat organic wastes derived from agricultural practices [191, 203].

6.1.1 SRC Willow production in Canada (Excluding Nova Scotia)

Agro-Energie, based in Quebec have 300 ha of SRC willow planted, since 2006, and state and planting capability of 1,500 ha. Outside of this there are no large-scale plantations within Canada, however there are various trial -plots spread out across Canada (Table 6.1) for a range of reasons including varietal testing, to evaluate cultivation, planting and harvesting practices and for remediation.

Table 0.1: SRC Plantations in Canada

Location	**Year**	**Landscape Type**	**Purpose**	**Hectares**	**Reference**
Prince Edward Island	2006	Riparian	Research	0.7	[234]
Prince Edward Island	2008	Riparian	Research	0.5	[234]
Prince Edward Island	2008	Riparian	Research	0.3	[234]
Prince Edward Island	2008	Excessive Slope	Research	1.55	[234]
Alberta	2005	Agricultural	Research	2	[235]
Alberta	2005	Agricultural	Research	6	[235]
Alberta	2010	Agricultural	Research	6	[235]
Alberta	2010	Agricultural	Research	4	[235]
Alberta	2010	Agricultural	Research	4	[235]
Alberta	2010	Agricultural	Research	4	[235]
Nova Scotia	2010	Agricultural	Research	0.9	[236]
Nova Scotia	2010	Agricultural	Research	0.9	[236]
Nova Scotia	2010	Remediated Mine	Research	0.9	[236]
Nova Scotia	2011	Agricultural	Research	0.9	[236]
Nova Scotia	2010	Agricultural	Research		[236]
Nova Scotia	2010	Agricultural	Research		[236]
Quebec	2011	Agricultural	Research		[237]
Quebec	2011	Agricultural	Research		[237]
Quebec	2011	Agricultural	Research		[237]
Quebec	2011	Agricultural	Research		[237]
Manitoba	2006	Agricultural	Commercial		[238]
Ontario	2006	Agricultural	Research	2	[239]
Ontario	2006	Agricultural	Research	1.9	[239]
Ontario	2006	Agricultural	Research	2	[239]
Ontario	2006	Agricultural	Research	3.83	[239]

6.1.2 PEI

SRC willow has been planted in Prince Edward Island for several reasons including to improve riparian zones and improve water quality, as a means for windbreaks and snow fences, as a means for nutrient and waste management, to enhance biodiversity and as a means for phytoremediation. Prince Edward Island ran a program called the Bioeconomy Crop Initiative between 2010 and 2014 [169], with the stated aim of conducting commercial research to identify the economic and environmental benefits of perennial crops, specifically perennial grasses and SRC willow. The initiative offered funding on a first-come-first-serve basis, with a total funding pot of $2.9 million, towards the conducting of trials, demonstrations, and pilot project, with the objective of developing potential biomass markets on the island.

The program offered funding annually, with primary producers and agribusinesses receiving 50% funding and agricultural industry organisations receiving full funding, with site preparation, cost of SRC willow cutting, planting costs, crop maintenance and harvesting all being covered under the funding. One of the key areas to note, is that the initiative recognised the cost of planting and harvesting equipment and allowed for the funding to cover the leasing of equipment under the proviso that the equipment would be available at the required times.

Research conducted by Lantz (2014), in his evaluation of SRC willow, states that there is interest in production, from the common reasons of energy security, sustainability and emissions reduction and as a means to stimulate rural economies. In evaluating the economic attractiveness of SRC willow on PEI, multiple scenarios based upon the trial plots present in PEI were evaluated with on-farm and off farm usage, varying land types and varying plantations sizes ranging from 3 ha to 9 ha and for off farm usage, the SRC would be sold to PEI Energy Systems Waste Plant at $50/ODT [240].

Lantz drew the conclusion that it would not be economically viable to produce SRC willow under any of the scenarios for off-farm usage, siting payback periods ranging from sixteen years to no payback period. The economic failure relates directly to the purchase price of the SRC at $50 per ODT, with breakeven being found between $58 - $93 depending upon the production system and the plantation location and land type. Similarly, the price of traditional fossil fuels, of which PEI currently use a significant proportion of diesel is still too economically favourable to justify switching fuel sources.

Despite the failure of off-farm production, Lantz found that SRC production and on-farm utilization would be favourable given the oil fuel price for heating and estimated an average payback period of five years regardless of the production system and land type.

6.1.3 Quebec

There have been several research studies conducted into the establishment and production of SRC willow in Quebec as well as some varietal studies. Guidi Nissin *et al* (2013) assessed the long-term biomass productivity of SRC willow in southern Quebec, using fertilized and unfertilized sites and using several different cultivars. The found that the cultivar SX64 had the highest yield of 15.02 ODT ha/year increasing to 24.3 ODT ha/year, stating that these are significantly higher than European yields, attributing it to the small plot sizes and the need to extrapolate for yield per hectare [225].

Lafleur, Lalonde and Labrecque (2017) established eight plantation sites across Quebec to evaluate different SRC willow cultivar across a large climate gradient, from a latitude of 45° 35’ to a latitude of 48° 40’. The study found that climate conditions including rainfall and heating degree days had significant impact on stem growth and planation yield, they additionally found that the soil variables including pH and clay content factored in to yield. Of the SRC willow varieties evaluated they found that the cultivar SX61, had the best performance in terms of height in seven out of the eight plantation sites, and the best yield in two of the sites, one at 45° 49’ and one at 48° 04’, suggesting tolerability under a range of climate conditions [241].

6.1.4 Manitoba

A farm in Manitoba, planted an experimental plot of 26,000 willow to demonstrate the viability of SRC as a heating fuel source, however there was a massive crop loss with little surviving [238]. The farmer planted 50,000 more in subsequent years, suggesting a total hectare area of approximately 3 – 4 ha assuming a planting density of between 12,000 – 15,000 stems per hectare. From this first year coppicing resulted in 27 tonnes per hectare (Salix Viminalis) and 14.8 tonnes per hectare (Salix Acute). The challenges identified by the farmer suggest that access to planting, with all of the planting occurring by hand, access to dedicated harvesting machinery, however the farmer reported success with a forage harvester and access to markets [242].

6.1.5 Ontario

Through Natural Resources Canada, four trial plots were established in Northern Ontario to evaluate the growing conditions of Northern Ontario, to evaluate different SRC willow varieties, with results indicating relatively low yields. The 2011 Bioenergy Plantation Program concluded that SRC willow plantations have the potential to supply a significant amount of biomass within Northern Ontario, with the research demonstrating high yields, and good survival rates of different varieties.

6.1.6 Saskatchewan

Saskatchewan has had a number of SRC willow trials, Amichev *et al* (2015) assessed thirty different cultivars of SRC willow in central Saskatchewan, as part of the Government of Saskatchewan's evaluation of biomass crops. Each cultivar was planted on a 7 m by 9 m plot with four replications and harvested on a three-year cycle. Of the cultivars assessed they found a first harvest yield range of between 5 tonnes/ha and 17 tonnes/ha, with a variety called "Tully Champion" performing the best in terms of yield and survivability, the cultivar SX61 had high survivability with a lower yield of 8 tonnes/ha [243]. The study suggested that the lower yields presented, for example the cultivar SX61 may have been lower due to herbicide damage during the establishment year, heavy clay soil conditions restricting root extension or low nitrogen availability.

6.1.7 SRC willow production in Canada

SRC willow production in Canada is still predominantly focused on the pilot phase, with testing of equipment, testing of different varieties, evaluation of ecological impacts and benefits, for use in riparian zones and for phytoremediation, with there being a small number of landowners/farmers having attempted to produce SRC willow, with one grower in Nova Scotia and one small nursery plantation that is now no longer being managed.

6.2 SRC Characteristics, varieties, and yields

It can be expected that a wide range of yields will be achieved in relation to cultivar, climate, site characteristics and selection (Table 6.2), planting densities, coppicing cycle, and management practices, with ranges of between 7-12 ODT/ha/year: equating to 21 – 36 tonnes of dry matter on a three-year harvest cycle. However due to the successful nature of SRC and the increasing demand for biomass for energy generation, significant work has been conducted on the development of new cultivars to achieve high yields, high energy content, lower moisture content and good bulk density.

Of relevance to Nova Scotia, has been a study conducted by the Prince Edward Soil and Crop Improvement Association, The Government of Prince Edward Island and Agriculture and Agri-food Canada. Four SRC willow demonstration sites were established in 2006 and 2008, on varying landscape types (riparian, wet spot and high sloped) at varying planting densities (4000 stems/ha to 12000 stems/ha), with an accumulative planted area of 3.05 ha [244].

Evaluation of Agriculture and Agri-Food Canada research indicates the SRC willow and other short-rotation species production is still under evaluation through-out Canada (Table 6.2) [245]. The objective of the AAFC is to evaluate technical, economic and policy issues that would determine the viability of large-scale establishment of SRC species. The research components have consisted of 'testing SRC willow varieties for large scale operational deployment within Canada', 'an evaluation of short rotation intensive culture of willow in Quebec', 'short-rotation woody crop (SRWC) practice issues: clone certification, yield, input, costs, site sustainability and output values, including carbon capture', 'biomass production in agroforestry systems: barriers to adopting in agricultural lands in Canada', 'harvest and post-harvest methodologies' and evaluating the 'economic opportunities and barriers to adoption of bioenergy production systems on agricultural lands in Canada'

Table 0.2: Estimated yields of SRC willow varieties and Cultivars.

Variety/Cultivar	**MJ/kg**	**Yield 1st rotation (ODT/ha/year)**	**Yield 2nd Rotation (ODT/ha/year)**	**Avg. Dry Matter (%)**	**Bulk Density (kg/m^3)**
Beagle	17.7	10.2	11.14	48	157
Endeavour	18.6			51	179
Gudrun				49	
Inger	16.6			47	176
Olof	17.7	10	11.04	45	161
Resolution	16.8	10.53	12.73	47	161
Sven	16.9	10.65	13.09	44	184
Terra Nova	18.4			45	170
Tora	16.8	10.52	12.8	44	171
Tordis	17.7	10.54	12.11	45	138
Torhild	17.6	9.27	11.84	44	169
Advance		10.62	12.39	49	
Endurance	18.3	10.6	14.32	50	172
Meteor		10.18	12.67	48	

6.3 SRC Production Requirements

SRC willow is a C3 temperate climate crop capable of being grown on marginal land, where traditional crops would not be suitable, with research demonstrating productivity in a wide variety of soil types, climatic and environmental conditions. The following steps outlines the basic procedure for achieving successful establishment of an SRC willow plantation and the varying factors that need to be considered when designing a plantation, beginning with site selection through to delivery to the end-user.

6.4 SRC Site Selection and Land Preparation

From a site selection standpoint, there are a significant number of variables to consider that will have an impact upon crop performance, logistical and time performance and economic viability. Productivity, in the form of acceptable biomass yields in relation to expected yields for a given variety will be largely determined by soil characteristics and fertility, temperature and the availability of water and light. The ultimate goal will be to achieve a high yield with reduced inputs for cost effective production, energy input to energy output and carbon emissions.

Soil characteristics can be broadly broken down in the texture/type of soil, its structure, drainage ability, the pH, and the depth available for planting (Table 6.3).

Table 0.3: Soil Characteristics for SRC willow Production (Adapted from Abrahamson et al (2002) [246]).

Soil Characteristic	**Desirable Characteristics**	**Undesirable Characteristics**
Texture/Type	Loams, sandy loams, loamy sands, clay loams and silt loams	Coarse sand, clay soil
Structure	Open, well developed	Significant compaction, no structure,
Drainage	Moderate drainage	Excessively rapid or no drainage
pH	5.5 – 8.0	<5.5, >8.0
Depth	0.45m +	<0.45m

6.4.1 Impact of Soil Texture on Crop Production

SRC willow has the benefit of being capable of growing on a wide variety of different soil types from sandy-clay loams to heavy clays, however sites with coarse sandy soils and heavy clay soils are poor locations for crop establishment. The use of heavy clay soils can at the outset result in reduced water infiltration resulting in surface run-off with regards to rainfall and application of fertilizers, risk of surface soil erosion and a risk of soil plating. Studies conducted have demonstrated that the efficacy and penetration of fertilizers is significantly reduced in sites with sandy soils [247].

As with traditional crops, the application of fertilizers to an SRC willow plantation has the potential to boost yield performance, a study by Sevel *et al.* (2014) found that the application of the application of Nitrogen, whether through the application of N fertilizer, sewage sludge or manures will result in increased yields. Sevel *et al.* (2014) applied N in varying quantities from different fertilizer mediums finding that the application of 60 kg of Nitrogen ha/year resulted in yield of 11.9 ODT/ha/year but higher concentrations demonstrated no advantageous benefit [248].

6.4.2 Impact of Soil Structure on Crop Production

Soil structure is defined as the arrangement of soil particles into aggregates, with aggregates varying in size, shape, distinctiveness. Poor soil structure will have a great influence on the establishment and growth yield performance of crops, with a reduction in yields to be expected regardless of climatic conditions [249]. The causes of soil compacts are well documented with typical causes being as a result of heavy wheel traffic from tractor use on particularly on wet soils, with compaction also caused through poor tillage practices and excessive livestock grazing [250] [251]. Soils with poor/low organic matter and heavy clay soils are particularly prone to the risk of compaction. The results of soil compaction are increase in bulk density within the soil, reducing the air space and water infiltration; consequently, compaction can be one of the risks causing poor soil drainage [251].

The relationship between soil drainage and crop performance is well documented, with good soil drainage being vital in crop production [252]. With a poorly drained soil, the risk of saturation or over-saturation occurs leading to a reduction in available oxygen for growth.

The rate of soil moisture movement within the soil structure is directly related to soil structure with the spacing and distribution of pore spaces in relation to particle size and particle type being the key factor in flow rates. In sites with heavy clay soils and suffering from compaction resulting in large particle sizes and reduced or no pore spaces, soils will become waterlogged. Conversely, in sandy and gravelly soils, with small particle sizes and very open pore structures, flow rates are significantly increased resulting in a risk of drought situations [253].

Poor soil structure does not preclude the establishment of an SRC willow plantation on a specific site as evidence suggests that SRC willow can tolerate a wide range of differing site conditions, however it can be expected that there would need to be significant site preparation and remedial action to bring a site into effective production. The improvement of soil structures is feasible with the addition of appropriate organic matter from manures, using correct tillage practices and several years of effective annual cover cropping prior to SRC establishment [253].

The application of manures and organic matters improve soil structure through increasing soil infiltration and water-holding capacity in sandy soils, builds-up beneficial soil microorganisms and increases nutrient retention. While amendments may be necessary, of critical importance to the establishment of SRC, is reducing competition from weed species in the establishment year; therefore, careful consideration needs to be made with regards to the application of manures and organic matter which would facility weed production. The use of cover crops, in land that has poor soil structure or that needs remedial action, is beneficial in several ways from indirectly contributing nutrients (nitrogen via legumes), reducing risk of soil erosion, help manage and reduce soil compaction and contributing towards long-term build-up of organic matter [253].

6.4.3 Impact of pH on Crop Production

Soil pH is an important factor with regards to plant nutrient uptake, with soils having a pH of less than 5.2 resulting in nutrient availability and accessibility (Calcium, magnesium, nitrogen and phosphorous being the major examples) being significantly reduced, while simultaneously making elements including copper and iron which can be toxic to some plant species [254]. In soils with moderately raised alkalinity of between 7.3 – 8.2, the solubility of elements including zinc, iron and copper is reduced, which can lead to the reduced uptake by plant species, in strong alkaline soils Phosphorus becomes insoluble, again being inaccessible to plants.

Within the Atlantic Canada region, most agricultural soils are considered to be acidic due to the relatively high precipitation rate within the Atlantic region, causing the leaching of elements including calcium, magnesium and potassium from the soil surface which leads to relatively infertile soil, unsuitable, without remedial action for direct crop production. A soil pH level of between 5.5 and 8.5 is acceptable for SRC willow production, which makes it an ideal, crop for low grade-acidic land. Research conducted by Laureysens *et al.* (2004) indicate that poplar (a similar SRC species) was capable of acceptable growth with yields of between 8.0 and 11.4 ha/year in high pH soils with heavy metal contaminants. It should be noted however, that while production of SRC willow on acidic is viable. Where sites need an increase in soil pH, the application of Lime is the most effective management method [255].

While the chemical characteristics of pH and organic matter can be altered and the physical characteristics of drainage and soil structure can be modified by a producer to produce acceptable site characteristics, several factors of slope, soil depth and soil texture cannot be economically modified.

6.4.4 Impact of Depth on Crop Production

Poor soil depth suppresses the development of root growth, leading to stunted growth and poor yield performance, therefore sites should be selected with care. Available depth of planting is important for SRC willow production due to its potential maximum root depth of 2.5 m [256] which aids in the extraction of ground water, however care should be taken on potential sites with field drains.

The ability of SRC willow to produce reasonable yields with relatively low nutrients due to the nutrient cycling of the species, there can be more flexibility in site selection, with options of production on what may traditionally be considered unfavourable for food crop production or is considered marginal land [257].

From an economical, logistical and management perspective, site selection should be constrained by field capacity size (with influence of field access), travel distance to respective fields and travel distance to storage depots, processing sites and to the end-user.

Land preparation prior to the planting is of critical importance to ensure that SRC willow or poplar have the opportunity for proper establishment with minimal loss. It is recommended that fields that are planned for SRC production are left fallow for at least one year. All sites should be ploughed (and where necessary sub-ploughed), harrowed and levelled out and where necessary.

6.5 Climatic Conditions and Nova Scotia Conditions

SRC willow requires a significant amount of water to facilitate growth, therefore sites should be selected that have good soil moisture retention, a reasonable water table and in areas where there is adequate rainfall of between 900 mm – 1100 mm/year. Across the province of Nova Scotia, rainfall amounts annually were on average, between 1980 and 2018, 1365 mm/year [258] with an average historic annual number of rainfall days totalling 131.6, which is projected to increase to 142.4 days by 2020, increasing to 146.5 days by 2050 (Table 6.4).

Table 0.4: Nova Scotia Precipitation Values.

	Historical 1980s	**Projected 2020s**	**Projected 2050s**	**Projected 2080s**
Winter	382.1 mm	398.4 mm	407.7 mm	428.1 mm
Spring	327.4 mm	337.8 mm	343.1 mm	356.3 mm
Summer	277.4 mm	282 mm	280.1 mm	280.4 mm
Autumn	365 mm	368.1 mm	367 mm	374.2 mm
Annual	1351.8 mm	1385.2 mm	1396 mm	1435.3 mm

Average temperatures for Nova Scotia in the summer months are projected to increase to 17.9C in the summer, up from 16.9c in the 1980s, with 2050 projections estimating that summer average temperatures will reach 19C. Winter months see an average projected temperature of -2.9 increasing to -1.5 by 2050 (Table 6.5).

Table 0.5: Nova Scotia Temperature Values.

Season	**Historical 1980s**	**Projected 2020s**	**Projected 2050s**	**Projected 2080s**
Winter	-4.1°C	-2.9°C	-1.5°C	-0.2°C
Spring	4.2°C	5.1°C	6.2°C	7.4°C
Summer	16.9°C	17.9°C	19°C	20.1°C
Autumn	8.8°C	9.8°C	11°C	12.2°C
Annual	6.4°C	7.5°C	8.7°C	9.9°C

Further exploring average weather data within the province; indicate a growing season length of 192.2 days per annum by 2020, increasing to 209.2 days per annum by 2050, where the growing season length is defined as those days where daily temperatures exceed 5C. Exploring ‘effective growing degree days within Nova Scotia” (EGDD) for spring seeded small grain, using the “A2 climate change scenario” [229, 230], there has been a marked change between “1971 – 2000” baseline growing degree days and those projected for between “2010 – 2039”. This has significantly raised the number of growing degree-days throughout the province, raising a significant proportion of the province from having ‘moderate limitations (Class 3)”, where effective growing degree days were 1,400 – 1,600, as outlined in the “Land suitability Rating System for Agricultural Crops”.

This has increased to >1,800 EGDD in the Southern and Western regions of Nova Scotia and between 1,600 – 1,800 EGDD in Central and Northern Nova Scotia, dropping to 1,400 – 1,600 EGDD in the Cape Breton region, classifying Nova Scotia as a “No limitations (Class 1)” region.

Average climactic data for Nova Scotia is favourable for the production of SRC willow, although average precipitation is higher than that indicated by Abrahamson *et al.* [246].

6.6 SRC Production Processes

Unlike conventional seed-based crops that utilizes a seed drill, SRC willow requires, due to the nature of the stem that is planted, specialized planting equipment for planting. While there are a wide range of commercial planters available that either plant a 'plug' or large seed crops, with one of the most common examples being the potato planter, the availability of SRC willow planting equipment is limited.

6.6.1 Pre-planting

Sage (1999), states that poor site preparation, with specific reference to a lack of removal and control of weed species can result in a growth loss of between 50 and 90% in any given plantation, due to the competition for light and space [261].

With SRC plantations being a long-term commitment of up to 25 years, pre-planting land preparation is vital in ensuring a high rate of establishment and allowing for effective management and harvesting in subsequent years. Regardless of whether current cropping land is to be taken out of production, pasture-land is to be converted or disused marginal land is to be brought back into production, there needs to be effective pre-planting site preparations therefore current recommendations and best practices suggest at minimum, there should be the application of weed control herbicides and mouldboard ploughing.

For sites that have been out of arable production for significant time (pastureland and fallow land), the application of a broadcast herbicide such as glyphosate should be applied during active vegetal growth phase to reduce the presence of perennial weeds, which based on planting schedules should occur in the summer prior to planting (Year 0). Where land has considerable vegetation that broadcast herbicide application is costly or unlikely to fully control weed growth, it is necessary to undertake mouldboard ploughing. In addition, where arable sites or marginal land has been out of production, it is likely that subsoiling may be necessary to remove any plough pans or soil compaction that would inhibit root development. Subsoiling should occur in the summer months when the soil is relatively dry to minimise the risk of damage to the soil structure.

On suitable soils, the site should be plowed to a minimum depth of 0.25 m and power harrowed or cross discing, and a seedbed prepared six weeks before planting. The germinated weeds can then be sprayed off prior to planting using glyphosate. Sites should be inspected to remove large rocks and stones to reduce impact of planting failure or damage to planting machinery.

While current best practices state the importance of effective pre-planting site preparation, according to a study conducted by Schulz *et al.* (2016), there has not been any significant studies conducted in-to different establishment methods of planting SRC, specifically in reference to pre-planting site preparation [262].

The German study, beginning in 2010, evaluated several different methods of SRC willow establishment; traditional mouldboard ploughing, chisel plough with an under-grow crop and a no-till system with varying permutations of chemical herbicides and mechanical weed control methodologies. Results indicated that, while there was some success in no-till planting with broadcast application of herbicides, the most effective method is still through current best management practices of mouldboard ploughing and power harrowing/cross discing [262].

6.6.2 SRC Preparation and Planting Designs

The design of an SRC willow plantation should be extensively evaluated prior to actual planting and establishment due to the long-term commitment of between 22 – 25 years, with an incorrect planting design having negative impacts with regards to management and harvesting in subsequent years of the plantation life-cycle.

SRC willow planting stock is traditionally provided as ‘planting rods’, which have been derived from a nursery and are first year cuttings (year one in an SRC willow cut-harvest cycle). Depending on the supplier and the method of planning SRC willow planting rods can be provided in long lengths (whips) of between 1.5 m and 2.5 m before being cut to planting lengths of between 0.25 m and 0.3 m, through a dedicated SRC willow planter. The dimensions of the planting rods are typically dictated by the planting machinery but will typically be between 9 mm and 20 mm in diameter.

There are a wide range of differing view-points on the correct planting densities of SRC willow with ranges from 11,000 rods/ha to 18,000 plants/ha and a number of different planting design configurations [263]. Armstrong and Johns [264] evaluated spacing and cutting cycles with relation to both poplar and willow species, found that first harvest yields increased with densities ranging from 4,500 stools per hectare to 15,625 per hectare. Bullard *et al.* evaluated multiple different planting densities of between 10,000 plants per hectare and 111,000 plants/ha, with higher annual yields being found in more densely packed plantations, however from an economic standpoint the high densities in excess of 15,625 stools/ha do not make economic sense due to the significant cost in planting and harvesting [265].

Bergkvist and Ledin (1998) evaluated biomass yields and canopy closure of multiply SRC willow varieties using different planting distances and densities, using single and double row spacing and, finding that closer planting densities resulted in the canopy closing faster but that there was no discernible difference in overall yield per hectare, despite increased risk of weed competition [263].

There have been numerous options in plantation design, starting with traditional block design, however for purposes of management and harvesting, it is prudent to plant in relation to equipment operation and tractor/harvesting machinery dimensions. Within Europe current planting designs, have a 0.75m spacing between rows, a 1.5 m between twin rows and 0.59 – 0.6 m spacing between each cutting/planted rod giving a density of 15,000 cuttings/ ha (Figure 6.1 and 6.2).

Plantations in North America are similarly recommended to have this plantation design. Ideally, the row length should be as long as possible to reduce the need for continual turning at the headland, however there should be breaks within each row every 150 m – 180 m to allow for machinery access and crop removal. Headland/buffer zone should be at a minimum of 10 m to allow for effective turning of equipment [265].

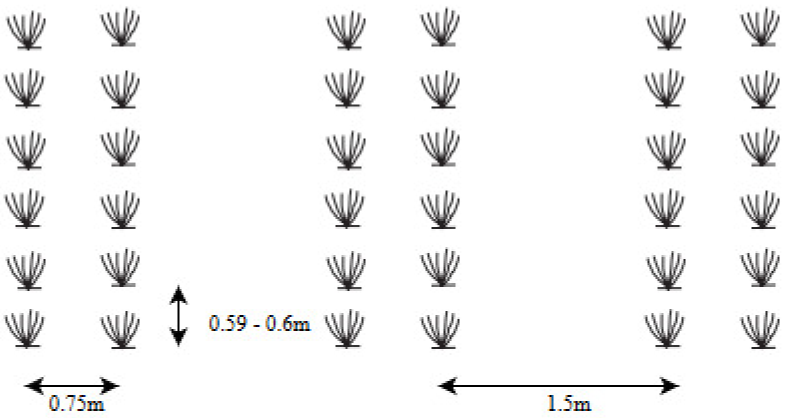


Figure 6.1: Recommended planting design.

Planting should take place between the end of April and the beginning of June, prior to these months, the ground may still be hard due to frost in the Atlantic Canada region, or it may be waterlogged, with the result being difficulty in access, risk of soil compaction and poor establishment. During this period, soil moisture should be sufficient to support plant and root development, with sprouting to occur between one and two weeks of planting but can occur sooner given the right soil and climatic conditions. There is currently no evidence indicating successful Fall planting, therefore it can be considered that SRC willow has a relatively short time period in which planting should occur.

Figure 6.2: Field Preparation for SRC willow [266].

Three options of plantation are commonly practised; hand-planting, which is acceptable for small trial plot sites, semi-automated and fully automated systems. In commercial planting, the most widely available type is semi-automated, that requires varying manpower depending upon the plantation design required and the planting system used. Figures 6.3 and 6.4 demonstrates a common step-planter system, feeding in rods, which are cut at pre-determined lengths or typically 20 cm before being compacted on either side of the planter rod. Step-planters are the most effective for large-scale, high-density plantations. The use of rotor planters is effective where there are smaller densities and on more difficult terrain.

Figure 6.3: 3 Row step planter [267].

Figure 6.4: 2 Row step Planter [268].

Lignovis, one of the most established SRC management companies within Europe operate six different planting system configurations tailored to different planting designs, planting densities and site conditions [269] (Table 6.6):

Table 0.6: Lignovis planter types [269]

System	**Planting Configuration**
Ligno-Planter	3 Single Rows
Step-Planter	3 Single Rows or 2 Double Rows
Step-Planter	2 Single Rows or 1 Double Row
Rotor-Planter	2 Single Rows
Rod-Planter	2 Rows

6.6.3 SRC Management

SRC willow, in similar fashion to poplar and miscanthus undergo Nitrogen and nutrient cycling through translocation to the root system from the foliage during the leaf senescence phase of growth in the lead up to the winter months when the harvesting is undertaken. Nutrients not translocated and lost via leaf senescence and abscission will fall as leaf litter, acting as a source of organic matter and nutrient cycling within the soil, with a secondary benefit being weed suppression post-harvest in the harvest cycle years.

Pests

Research for the North American market, state that there have been no significant crop pests found in SRC willow plantations, however during the first year of growth and after each subsequent harvest, mitigation for grazing by rabbits, snowshoe hare and deer may have to be considered. Within Europe, there are a number of common pests that have not made their way to North

America including leatherjackets, the larvae of craneflies (*Tipulidae*), which would feed on the roots and shoots of newly established SRC willow, where there are no other available food sources. In such instances, there may be need for the application of a broad-spectrum insecticide, which should be applied prior to plantation establishment. Protection from mammals can be managed through the installation of wire mesh fencing, including extending underground to prevent burrowing from rabbits/hares.

6.6.4 SRC Harvesting

Harvesting is conducted after leaf fall in the winter months, between the months of November/December and April depending upon weather conditions, which typically coincides between leaf senescence/abscission and the development of new buds in the spring (Figure 6.5). Under ideal conditions, harvesting should occur every three years, however due to weather conditions, drought or poor site conditions, harvesting may be increased to every fourth or fifth year.

Figure 6.5: SRC willow stand - between rows [266].

Figure 6.6: SRC willow stand - 1 year growth [266].

There are several harvesting options available, however for large-scale production and harvesting it would be necessary to source a dedicated harvesting system.

During the first year growth phase (Figure 6.6 and 6.7), it can be expected that there are 3-4 stems per stool/plant, to facilitate further growth and stem development (8 to 10 stems per plant/stool, and to encourage rapid growth and canopy development the plantation should be harvested two weeks after leaf fall and before bud establishment in the spring [246]. Abrahamson *et al.* recommend that the most time effective and cost-effective method of first year harvest is through the use of a sickle-bar mower or rotary mower.

Figure 6.7: SRC willow Stand - 1 year growth [266].

6.6.5 Harvesting equipment

The harvesting of SRC willow is a relatively straight forward process, with the SRC willow plantations being harvested on a three-year cycle. SRC willow is available to harvest after leaf fall has occurred, where the diameter of the trunk should be more than 65 cm. After leaf fall, harvesting can occur at any time before new shoot and leaf development occurs in the spring.

While the window for harvesting is relatively long, harvesting operations will be dictated by climactic conditions, field access and field conditions.

There are several harvesting options for SRC willow; modified forage harvesters incorporating a chipping system specific for SRC willow and poplar, a small scale harvester and chipper attachable to a conventional tractor with PTO shaft, an SRC cutter and baler, a grip and cut head or manual harvesting, with detailed research having been conducted in to different harvesting methods and performances [204, 209, 239, 240, 241]. Research conducted by Vanbeveren *et al.* evaluated seven of the most available and effective harvesting systems that have been on the market for a number of years, finding forage harvesters to be the predominant systems [271]. Vanbeveran *et al.* (2017) state that the most common and the market dominating technology is the single pass cut and chip harvesting, followed by double pass cut-and-store forage harvesting [271].

Forage harvesting systems operate under the principle of using dedicated cutting headers to first cut down SRC, push the stems down as the system moves forward before continuously feeding the stems in to the system where they can be subsequently chipped in to either a trailer being towed behind the system or blown in to a dumper truck being separately operated along-side the harvester [272] .

Mower choppers are typically tractor mounted or pulled systems and operate under a similar principle as forage harvester, but typically produce larger chip sizes than forage harvesters however according to Pecenka and Hoffmann (2015), there has been significant developments in the technology allowing for vertical harvesting and chipping which has several advantages including the ability harvest denser and older plantations and an increased flexibility in deployment [272]. The cost for a forage harvester is in the range of $50,000 - $1,250,000 per unit [204, 239], however these systems are manufactured and produced within Europe and this cost does not take in to account any import taxes or shipping expenses (Table 6.7).

Table 0.7: Average cost of SRC willow harvesting equipment [273].

	Bio-Baler	**Small-scale Forage Harvester**	**Medium Scale Forage Harvester**	**Large Scale Forage Harvester**	**Billet Harvester**
Cost $/ha	830	900	570	623	934
Speed of Harvesting Km/hr	2.2	2.6	4.5	5.6	4.5
Fuel Used (1/ha)	196	231	109	97	101
Time taken for harvest	5	4.2	1.7	1.4	1.7
No of Operators	2.5	2.25	3.25	3.25	3.25
Capital Investment ($000)	760	497	1,067	1,258	1,018
Specific Capital Investment ($000)	289	46	169	259	539
Product	Round Bale	Chips 3 – 15mm	Chips 3 – 15mm	Chips 3 – 15mm	Billets (120 – 200mm

The PEI study in to SRC willow production [234] evaluated a harvesting head traditionally used for forestry, which operate using an articulated arm with a grabber and a mechanical saw, where the harvested stems can either be stored as large stem, placed directly onto an adjacent loader or the stems can be fed in to a chipper before being deposited in a n adjacent dump loader. This system can be mounted on to a tractor but will require a dedicated trained operator and it can be expected that the harvesting time would be significant due the limited volume of material that can be harvested at a given time and the experience of the operator. The study priced the system at $8,000-$9,000 per unit [234].

Figure 6.8, developed by Innotech Alberta, is a combined harvester and chopper that can be mounted on to a conventional tractor via PTO shaft; with the system designed to be pulled behind a tractor, specifications indicate that 2.02 ha could be harvested in a standard eight-hour period (Figure 6.8).

Figure 6.8: Prototype willow harvester [274].

Figure 6.9: Harvest and chipping system [275].

One of the advantages found within the European Union that has not translated to the North America is the development and use of planting and harvesting machinery. The majority of SRC willow harvesting technologies are developed and manufactured in Europe, with notable producers of the technology being Henriksson Salix AB Henrik (Figure 6.9) [276], who have developed a chipping header which can be attached to self-propelled forage harvesters. The current costs are estimated to be $540,000 per unit with the system capable of harvesting at a rate of 1.7ha/hr also produces a billet harvester, capable of producing billets (cuttings) of different lengths (12-15cm, 18-22cm and 25-30cm). Cuttings (billets) are capable of being combusted in CHP systems provided the system is designed to do so, however the main benefit to the billet harvester would be for SRC willow nurseries, with production and preparation of billets liable to being sped up, reducing the time it takes for cuttings to reach refrigeration.

Within Canada there is currently limited planting and harvesting technology available, with the majority of SRC willow research, having been conducted using either imported equipment from the United States of America or Europe or hand-planting and harvesting. However there is currently one manufacturer of dedicated harvesting technology in Canada which was utilized in the Northern Ontario Study, the manufacturer GR Anderson has produced a compact harvesting and baling system called the Biobaler [277].

According to GR Anderson the Biobaler has advantages over traditional forage style harvesters as it can be towed behind a tractor, and using a single pass, with one operator it will cut, and compact biomass (SRC) in to 500-600 kg bales, which can either be directly collected or left in-situ for drying purposes. The company state that by producing round bales of biomass, bale moisture content will drop from 50-55 % to 18-20 %. The company further produce a dedicated self-loading bale carrier, to make the transportation of bales easier.

6.6.6 SRC Storage

SRC willow cuttings acceptable for planting are produced in nurseries, therefore within Canada there are only a limited number of SRC willow cutting suppliers. SRC willow stems and cutting are harvested during the dormant phase of plant in the winter months, generally after 1 year's growth. After nursery harvest, the SRC willow feedstock is typically wrapped in plastic followed continued refrigeration/freezing (-1C – -4C) to ensure viability and retain moisture content is maintained [246]. Due to the nature of the stored SRC willow feedstock and the recommendation that it is not thawed and refrozen, it is necessary to have as short a time as possible between being shipped from the nursery to the plantation site. Planting stock needs to be maintained in a refrigeration state where it will remain viable for several weeks to accommodate planting schedules. Where refrigeration is not possible, SRC willow feedstock can be held in a cool and moist environment for approximately one week; exposure to excess heat or direct sunlight will significantly reduce establishment viability.

6.6.7 Post-harvest storage

Moisture content directly impacts the calorific value of a wood fuel due to the energy requirements used in evaporating the moisture content which is defined as the latent heat of evaporation. In biomass with high moisture content, the net calorific (or useable energy) will be reduced with a high moisture content, therefore it may be necessary or desirable to reduce the moisture content through either passive or active drying.

Figure 6.10: Baled SRC willow.

Depending upon the requirements of the final user, SRC willow may be either harvested and stored as bundles prior to further processing or directly chipped then stored prior to being sent to the end-user. Where there is a need for drying, SRC can be stored in bundles or bales around the headlands of the SRC plantation site to allow for natural air-drying (Figure 6.10). Relocating SRC willow to a storage site will require SRC bundles to be raised from the ground to facilitate natural air-drying. From the point of harvest, moisture content can be expected to be around 50% depending upon the variety used, with moisture content dropping to 20% by the beginning of fall, should a further moisture content be required it is recommended that bundles be stored in a covered area with adequate airflow.

Where chipping is conducted in conjunction with harvesting, a minimum of two tractors with trailers is required to ensure continuous harvesting, while SRC is delivered to storage for use or drying. The drying of SRC wood chips follows the drying of any standard wood chip product, requiring covered storage. The drying process for chipped biomass occurs in two stages starting with the ‘constant drying rate’, which is the evaporation of water from the chip’s exterior surface. The second stage is termed as the ‘falling drying rate’, which relates to the diffusion of water from within the chip to the external surface of the chip. Drying options can be passive through natural ventilation or the drying process can be facilitated with heating and forced air.

6.6.8 SRC Transportation

The transportation of SRC willow from production location to the end-user of central storage facility is dependent upon any processing that occurs during harvesting. The most common options are cut-and-store cut-and-bale and cut-and-chip. Depending upon the harvesting system, the harvester can simply cut the standing SRC willow, placing the cut material directly on to flat bed, followed by the removal of the cut willow by a fork-lift to be deposited at locations within the field or at a nearby storage site. An example of the cut-and-store system is through the utilization of the 'Stemster MKIII harvesting system [278]. Cut-and-bale systems incorporate both cutting and baling typically within one system, with the "Biobaler WB55' system depositing the bale directly on to the site, requiring removal prior to new shoot development of there may be need for a separate bale [277]. Both Cut-and-Store and Cut-and-Bale systems require additional equipment to facilitate the removal of the cut biomass from the plantation area, either to areas around the field or to a centralized storage area. Cut-and-Chip systems, require the use of a high-capacity forage trailer for transport and temporary storage. The benefits of using a Cut-and-Chip system are the higher bulk density allowing for transporting greater weight per unit volume thus reducing transportation costs, reduced storage requirements for the end-user and a reduced need for processing equipment on the end-user side.

6.6.9 SRC Production Timeline

The production of SRC willow for one specific plantation accounts for, on average, 23-24 years (Figure 6.11), with a first harvest seen in year 4, based upon a typical three-year harvest cycle, for commercial producers of SRC willow, to meet demand, producers are required to have multiple plantations to ensure yearly harvests from year 4 of the first planation.

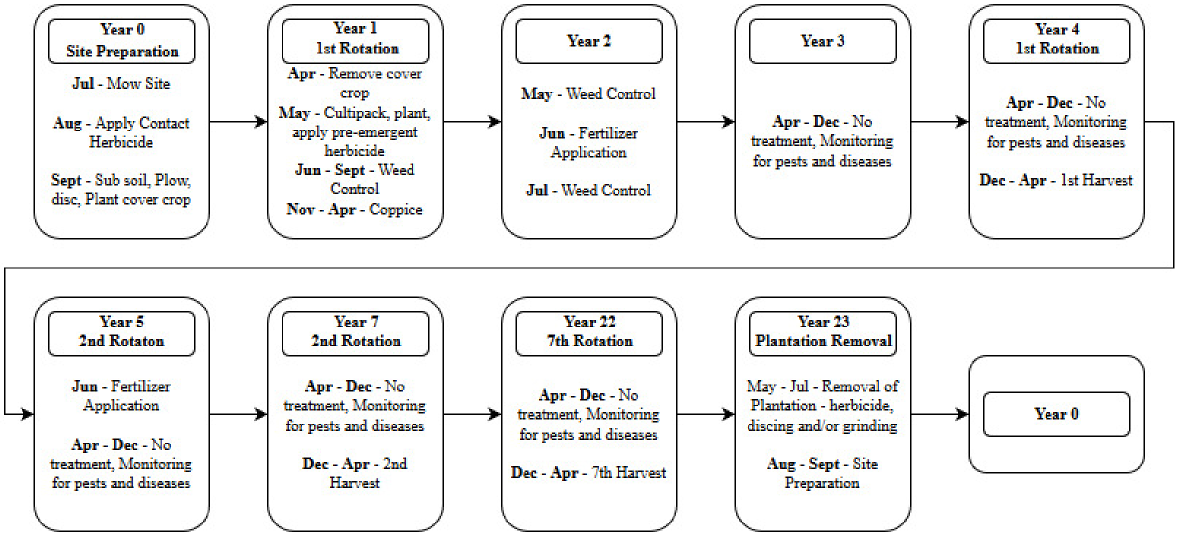


Figure 6.11: SRC willow Production Timeline - Adapted from Abrahamson et al (2002) [246].

6.7 Economics of SRC willow

The economics of SRC willow production are more complicated than traditional crops, with several factors influencing the financial success of production and the return-on-investment not being realised in the first several years of production, often requiring some form of future forecasting based upon potential yields and estimated financial costs. Traditional crops typically operate on a short-time frame, e.g., planting in May, harvesting in October/November of the same year, with well-established markets for crop products.

Currently there are a very limited number of accessible financial models available to evaluate production and distribution of SRC willow or poplar, due to their being relatively limited production within North America or indeed the EU. Where there is a reasonable concentration of production, as in the case of the Swedish company Lignovis, there will likely be internal financial models evaluating production and logistics.

6.7.1 Economic Forecasting and Modelling

Decision support systems (DSS), defined as information systems that provide guidance in decision-making activities and include economic analysis, cost/benefit analysis and can provide analysis of different pathways for decision makers. Decision support systems should be able to compile and generate useful and meaningful information and offer viable options or outcomes through the analysis of raw data and via allowing the user interaction to evaluate different courses of action.

There are a wide range of DSS that are used across all sectors (business analysis, financial, risk management, policy analysis and it is now increasingly being applied to social decision making all of which use a wide range or combination of different Multi-criteria decision analysis (MCDA) methodologies - goal programming (GP), analytical hierarchy process (AHP), and multi-attribute utility theory (MAUT). DSS have also in recent times been applied to evaluate various angles of the biomass industry. Table (6.8) provides examples of some DSS that have been developed for the use of using both forestry and agricultural biomass.

Table 0.8: Example of DSS for Biomass. Adapted from Mitchell (2000) [279].

Existing Model	**Description**
AUHDSS	Aberdeen University Harvesting Decision Support System – used for the development of wood fuel supply strategies from conventional forestry.
BEAVER	Biomass Economic Evaluation and Appraisal Expert System – an expert system to estimate the cost of biomass production in Europe
BIOCOST	Bioenergy Crop Production Costs Model – Economic cost accounting tool for biofuel production in America and Canada
BRAVO	A GIS decision support system for calculating transport and delivery costs from field to end user.
CDSS	Coppice Decision Support System – evaluates economics of coppice production
CHDSS	Coppice Harvesting Decision Support System – An economic model for coppice production, harvesting, storage and transport
Ecowillow 2.0	Basic Financial Model
Electricity from SRC	Models the energy rate of return for using coppice for electricity generation via gasifier.
SRC poplar	Used to estimate the cost of harvesting SRC

Each of the above specific DSS are location and operation specific and while there are a wide range of different DSS and methodologies available, none of the decision support systems function in relation to the specific needs of Nova Scotia and due to the varying requirements, that need to be met to enable a productive and effective DSS; no one specific MCDA methodology is suitable. In addition, there is a lack of availability of decision-making models to evaluate SRC willow production. Within Canada the development of DSS tools is minimal, with the exception of the commonly used Decision and Analysis Tool RETScreen Software [280] which looks to aid the user in project feasibility analysis for renewable energy projects, however there is limited scope for biomass application. The University of British Columbia is currently in the process of developing a DSS for biomass with desired outcomes of profit maximization and environmental impact minimization [281], however it is unclear what the scope or reach of the DSS is. The State University of New York have developed a basic economic model, designed to evaluate the cost production of SRC willow, modelled on a traditional crop production model but incorporating SRC willow specific production methods and providing guided suggestions on potential costs and is intended for the American market.

6.7.2 Cost of SRC willow

The cost of SRC willow cuttings and rods will vary region to region and will depend upon variety. Of available crops, SRC willow cuttings and rods are considerably more per unit in relation to other agricultural crops. Within the United Kingdom, one of the largest suppliers of SRC willow cuttings offers thirteen different varieties of SRC willow, which offer a scaling price in relation to the number of units purchased (Table 6.9).

Table 0.9: UK costs of SRC willow cuttings.

NUMBER OF UNITS	PRICE PER 20 CM CUTTING	PRICE PER 40 CM CUTTING	PRICE PER 60 CM CUTTING
45 000 - 150 000	\$0.15	\$0.27	\$0.39
5 000 - 45 000	\$0.19	\$0.32	\$0.46
1 000 - 4 999	\$0.27	\$0.50	\$0.70
500 – 999	\$0.43	\$0.70	\$0.91
50 – 499	\$0.51	\$0.77	\$1.01
< 50	\$0.94	\$1.42	\$1.83

Table 0.10: UK costs of SRC willow rods.

NUMBER OF UNITS	PRICE PER 1.4 M ROD	PRICE PER 2.0 M ROD
> 15 000	$0.87	-
4 500 - 14 999	$1.01	$1.23
1 500-4 499	$1.33	$1.44
500 - 1 499	$1.80	$2.19
50 – 499	$2.15	$2.79
< 50	$3.28	$3.42

Commercial SRC willow varieties within Canada similarly range widely depending upon variety and the location of the supplier (Table 6.10). While not a biomass-to-energy supplier, Lakeshore Willows provides cuttings of SRC willow at $1.75 per rod [282]. The cost of SRC can be attributed to several factors including the relatively small number of suppliers, the cost of planting and harvesting, the storage cost including the requirement for continual refrigeration.

One of the issues surrounding crops harvested on a multi-year cycle, relates to the income occurring only on the harvest years, assuming the biomass is being directly sold. The cash outgoings for SRC willow are predominantly skewered to the establishment years, followed by the harvesting years within the interim year seeing reduced outgoings for SRC growth years. In practicality, planting and establishment must occur on staggered years to ensure a continuous supply of biomass feedstock, with the first harvest being in the fourth year. In the case of SRC willow cash incomes, incomes will be received every three years or at the point of harvest and delivery. Cash outgoings for SRC willow are heavily skewered towards the establishment year, followed by the harvesting years. Interim years will see reduced costs for the specific fields in production.

The planting of SRC involves significant upfront costs, however a number of the costs are well defined due to being common practices, including mowing, ploughing, subsoiling and the application of fertilizers, herbicides, and insecticides. The costs that are currently highly variable relate directly SRC willow production; the sourcing of planting material, planting, harvesting, crop maintenance and the storage and drying of SRC where necessary. The high variability and undefined costs for SRC willow production can be attributed to the lack of commercial production within Nova Scotia and Canada in general.

6.7.3 Field Preparation

Each of the field preparation costs require standard farming equipment, therefore for an existing farmer/landowner the equipment should be readily available, with the necessary field work being achievable by one operator with 1 piece of equipment available. Typical Canadian costs are presented in Table 6.11 and are general consistent throughout Canada, with fuel and labour cost being the main variables.

Table 0.11: Average field preparation costs within Canada.

Operation	**$/ha**
Mouldboard Plow	71
Chisel Plow	59
Disc	39
Subsoil	72
Packer/Roller	19
Harrowing	14
Tillage	42
Mower Pull Type	47
mower self-propelled	57
Herbicide Application	24
Inter-row Weeding	35
Rotary hoe	20
Fertilizer Application	29
Insecticide	109

6.7.4 Planter Costs

Arguably the costliest factor in establishing a SRC willow plantation is planting the rods, with the options being hand planting, requiring a dedicated team of planters with a planting rate of 20 stems per person per hour or the use of a step planter system. Financially the cost of a planter can be more than $250,000, which would not be financially prudent if the system was not being in continual use.

Within Europe, with an already established SRC willow market, the alternative to a direct purchase is outsourcing or lease a dedicated planting system from a dedicated SRC willow management company. Within Sweden, the largest provider of SRC willow services is Lignovis, who operate nine different planting machines of varying design depending upon the plantation design. This method of leasing equipment circumnavigates the direct purchase cost for a limited use piece of equipment, however currently such options are not available, certainly within Nova Scotia.

6.7.5 Harvesting

Access to planting and harvesting technology is one of, if not the biggest barrier to individual or farmer co-operatives producing SRC willow [283]. Pecenka and Hoffmann (2015) state the access to harvesting equipment on a farm or in a given region where SRC willow is to be produced will be a critical factor in SRC willow production [272]. Vanbeveren *et al.* (2017), state a similar case of farmers or producers being reluctant to produce SRC willow or poplar, stating that the planting and harvesting costs will influence production but the availability of a planter and harvester locally, even on a rental basis, will improve the economic viability of SRC willow production [271]. However, it is further stated that there needs to be a wise selection in the choice of harvesting equipment, in relation to equipment size and field conditions, stating that harvesters will function properly only of frozen, hard, or at least dry soil.

6.7.6 Drying

Drying costs vary significantly, depending upon the drying system, current moisture content of the SRC willow, harvested condition and intended moisture content, within Ireland the average cost of drying is \$44 per tonne based upon a chipped, stored, and covered system with no automated drying and periodic mechanical turning of biomass piles using front-end bucket loaders. Field drying in bales, accounts for little-to-no cost, but will take longer for the desired moisture content to be reached.

6.7.7 Financing Planters and Harvesters

There are a number of options available for ensuring economically viable harvesting (and economical planting at the outset). Ensuring economies-of-scale for biomass production is a clear path forward; having the requisite land –based resource, a clear market outlet and significant capital funding available for large-scale production would make the purchasing of equipment economically viable. Examples of this can be seen within Europe, with the Swedish company Agrobransle, in conjunction with contractors, being able to manage and harvest the majority of SRC plantations throughout Sweden, operating seven harvesting machines since 2003. This is achieved through having centralised production and management control of SRC willow production, with minimal or no-input from landowners or farmers.

Lignovis, operate a similar approach to SRC willow production, but in addition, currently offer a wide range of services across Sweden, from the provision of SRC willow planting material, to the rental of planting and harvesting equipment (with trained labour) to the full on management of SRC willow from Site Selection to the delivery of SRC willow to the End-user [269]. This is a prime example of a commercial enterprise being able to provide a vertically integrated, multi-layer service within Sweden, controlling all aspects of the supply chain.

Within Atlantic Canada, and North America in general, there are currently no enterprises involved in large-scale production of SRC willow, nor any enterprises that offer rental services for SRC willow planting and harvesting equipment, therefore alternative options of obtaining machinery, precluding direct purchasing, would need to be considered. Two options for obtaining machinery that have precedence are through Government-owned equipment stores or through the formation of cooperatives. As highlighted through the UK example, there is precedence for equipment to be purchased by a government for use by agricultural producers, however this is an unlikely option for Nova Scotia, based upon there being no current programs offered by the province for equipment in any industry.

6.7.8 Purchased by a Group of Farmers on a Co-operative Basis

Removing the need for government-backed programs offering services, would be through the use of cooperatives; used for the purchasing and pooling of resources. Cooperative structures are used within the agriculture industry and result in individuals agri-enterprises reducing their expenditure and need for heavy investment in equipment and machinery, while obtaining access to larger, more efficient, and advanced machinery that may otherwise be unobtainable. Cooperatives can operate under a closed system, with a clearly defined number of participants, or operate an open system, allowing for new participants. Both forms of Co-ops typically operate under a buy-in, with participants agreeing to a defined usage period proportionate to their investment [284].

Within Quebec, Canada, the Co-opérative d'utilisation de matériel agricole, developed and managed by the Ministère de l'Agriculture, des Pêcheries et de l'Alimentation [285], are legal co-op structures used to ensure low costs within the Quebec agricultural industry. Within Quebec, CUMAs are developed between, at minimum, five agricultural enterprises, who aim to share the costs and benefits of joint ownership of machinery, equipment, inputs and tools; demonstrating their use in Canadian agriculture. The use of co-op structures has appeal for SRC willow harvesting technology, due to the high cost of harvesting equipment, given their limited annual usage time for harvesting but long-term service requirement

While there are a number of dedicated harvesting systems available, developed predominantly within the European market, access within Atlantic Canada is currently limited. Currently within Ireland, whole stem harvesting costs are estimated to be $53 per dry tonne of harvested material, assuming a field drying process. Chipping post-harvest is estimated to be $18 per fresh tonne of SRC willow. The cost of direct chipping upon harvest is estimated to be $44 per dry tonne.

Based upon the current price of SRC willow planters and harvesters, the most economically viable option, without the need to provide subsidies for production or tax incentives, or the reliance of heat or energy generating incentives would be to have available SRC equipment available in the province. Located in the centre of the province; most areas of Nova Scotia (and parts of New Brunswick) can be reached in four hours funded by Commercial Enterprise.

CHAPTER 7 EVALUATION OF NOVA SCOTIA – CAPACITY AND VIABILITY

7.1 Nova Scotia Land Capacity

In evaluating the potential for SRC willow production in Nova Scotia there needs to be an initial sound basis for production in the form of a market or a user of biomass and capacity for production. Nova Scotia comprises of 5.52 Mha of land of which 4.27 Mha is forestry land [286], both public and private, of agricultural land there is approximately 403,044 ha in various states of production or use including; arable land, dairy, poultry, hog and mink farming and woodland lots, managed and operated by close to 4,000 farms [171, 115]. As of 2019 there were one hundred and fifty-eight 'Registered Buyer' users of Primary Forestry Products (PFP), using a minimum of 1,000m^3 per annum, sharing the reported provincial PFP harvest of 3,314,626 m^3 (covering approximately 29,210 ha) which relates to 0.7% of the 4.27 Mha of forestry within the province (Figure 7.1). Of the total 2019 harvest, 6.1% went to energy generation; similar to 2014 after a dip in biomass to energy generation in the intervening years. Nova Scotia has seen a decrease in the forestry industry resulting in the closure of a number of mills, therefore forestry harvesting has dropped significantly since 2005 (Figure 7.2).

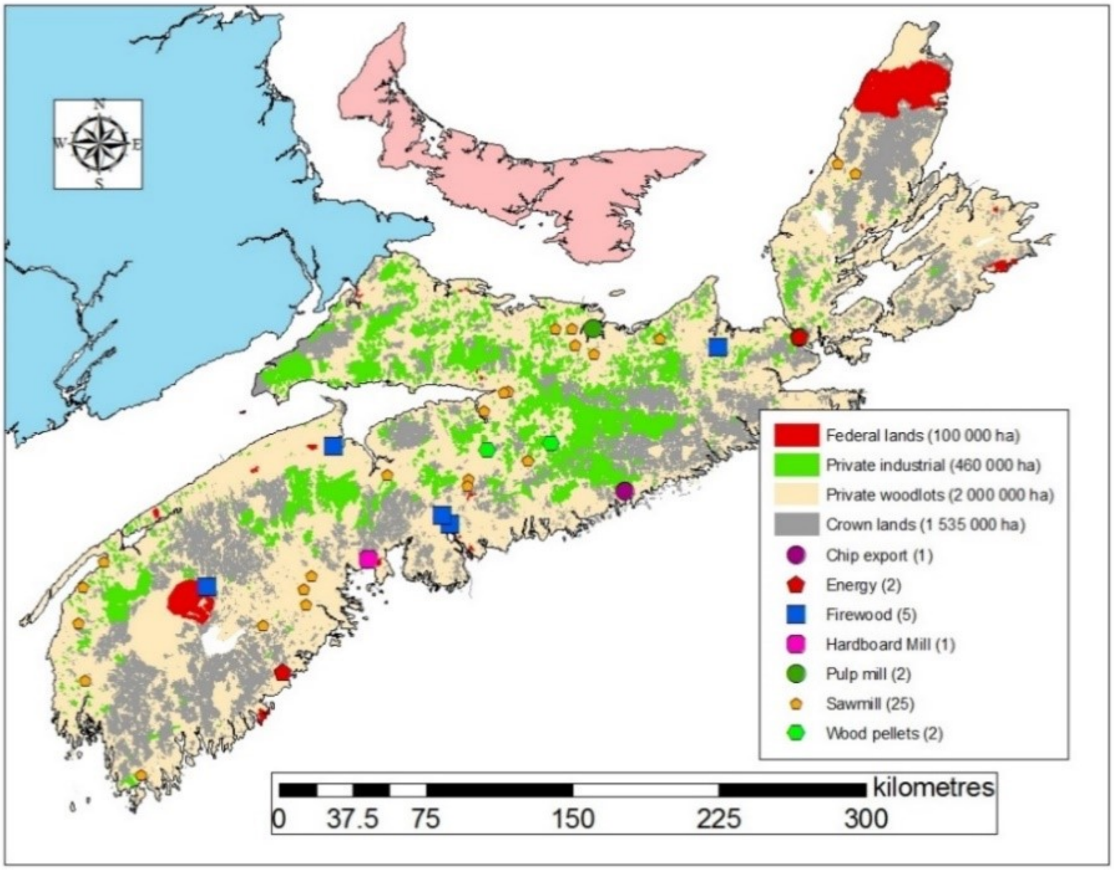


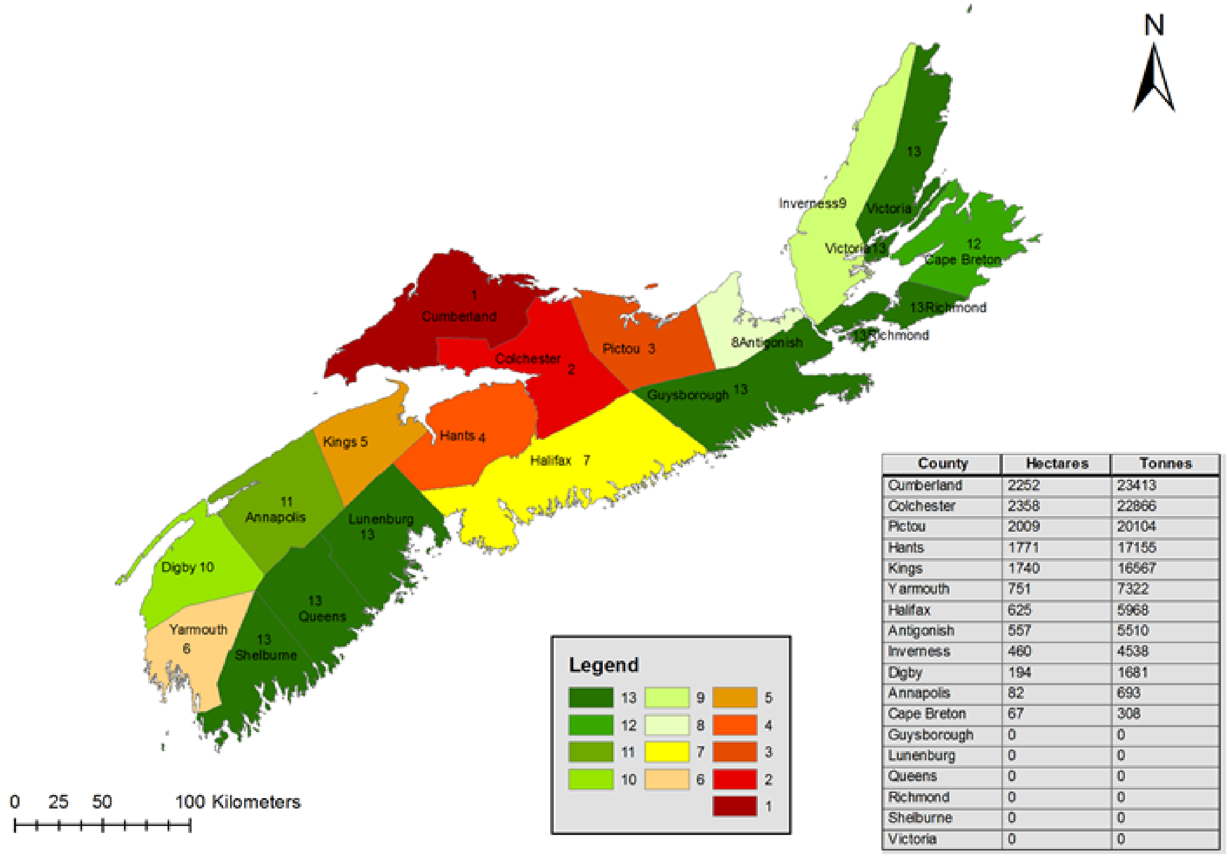
Figure 7.1: Forestry biomass in Nova Scotia.

Considering the availability of forestry biomass as a resource, 736,800 ha of the forestry is unavailable for harvesting due to protected status (e.g. Cape Breton National Park, Kejimkujik National Park) and 604,00 ha of public forest is subject to forest management agreements [286], 2013 data classifies 1.4 m hectares as ‘Certified Sustainable’ through either the Canadian Standards Association, Sustainable Forestry Initiative or the Forest Stewardship Council [288].

Figure 7.2: PFP production and harvest data [173].

Of the 403,000 ha in agriculture it is estimated that there is approximately 235,000 ha of arable land [289] in various states of use, including; rotational land, long term use land for blueberry production, orchards and viticulture, silage production and inactive land. However, it should be noted, that this estimate is based upon the previously completed Agricultural Land Identification Project completed by the Nova Scotia Department of Agriculture in 1997 [289]. Research is currently being conducted by the Applied Geomantics Research Group to identify Agricultural Land Use within the province [290], which will hopefully update the previous 1998 research.

Based on available GIS data for land classes (drainage, slope, stoniness, water table) and soil characteristics, types and quality [176, 177] and agricultural land usage [291], a hotspot analysis performed identifies the quantity of suitable inactive land in relation to field-to-field proximity, in relation to road access and to approximate potential yields (SRC) based upon land class and soil characteristics (Figure 7.3). Analysis suggests that the most viable county for production within the province would be Cumberland County with 2,252 potentially available hectares with a potential 23,413 tonnes/year, followed by central Nova Scotia counties, however there are six counties where there is no suitable inactive land for production.



County	Hectares	Tonnes
Cumberland	2252	23413
Colchester	2358	22866
Pictou	2009	20104
Hants	1771	17155
Kings	1740	16567
Yarmouth	751	7322
Halifax	625	5968
Antigonish	557	5510
Inverness	460	4538
Digby	194	1681
Annapolis	82	693
Cape Breton	67	308
Guysborough	0	0
Lunenburg	0	0
Queens	0	0
Richmond	0	0
Shelburne	0	0
Victoria	0	0

Figure 7.3: Hotspot analysis of Nova Scotia agricultural land.

Nova Scotia Forestry is considered to be of Nova Scotia's greatest resources, used for economic purposes, as important environmental habitats and for recreational purposes, however with the increase in biomass energy systems, especially those run by NSPI, there is growing concern that biomass energy derived from forestry is negatively impacting upon Nova Scotia's environment. The greatest concern relates to the environmental impact which has been the focus of a number of environmental/ecological organizations and the potential environmental impact has been taken up by the media, with an increasing number of articles and published statements in relation to the sustainability of PFP for electrical generation [179, 180].

One of the largest Biomass Facilities in the province (Port Hawkesbury) is reported to consume between 650,000 and 750,000 green tonnes of biomass per annum [294]. According to Nova Scotia Power, prior to the facility going online, the biomass feedstock to be utilized by the facility would be from wood waste; wood that has no other commercial use due to defects or forestry residue.

However, despite this commitment, in a 2015 newspaper article, NSPI stated that only half of the plant's requirement was being met using wood waste from Port Hawkesbury Paper, sawmills and other wood using enterprises within the province. This leaves half of the facilities fuel requirements coming from PFP either from within or out-with the province [182, 183]. Opposition to the practice of using PFP for the facility claim that it leads to a reduced availability for other operators and impacts upon recreation and forest sustainability [182, 180, 179].

While there are opponents suggesting that biomass for electricity is unsustainable, the arguments against biomass energy generation haven't been proven within the province and data demonstrates that a large proportion of NS forestry is either protected or sustainably managed, with harvest data demonstrating that the yearly harvested areas for the last four years (2016 – 2020) are at their lowest compared to a peak of 69,761 ha in 1997 (Figure 7.2) [297].

While there are conflicting opinions on whether forestry biomass and in particular PFP is desirable/suitable for electricity generation and its potential impact on forestry sustainability, the technology is unlikely to be removed, however due to public concern the Nova Scotia Government has removed the 'Must-Run' legislation that requires NSPI Port Hawkesbury 60 MW biomass generating power station from operating at full capacity, with the released statement citing concerns from Nova Scotians surrounding the potential impact of using Primary Forest Products for energy generation [298].

Concerning the use of agricultural land for biomass production, whether at an individual farm scale for use on farm or for large scale production and usage, there needs to be a clear indication that on Nova Scotia land, there is the potential to produce biomass crops (SRC willow or miscanthus) and that potential yields can be predicted to a degree of accuracy. Having accurate yield predictions, through accurate crop modelling, crop trials and literature data gathered from nearby locales with a similar climate (e.g. Prince Edward Island, New Brunswick, Quebec) will help to improve investor confidence in establishing businesses that produce and utilize agricultural biomass [299].

Trials of SRC Willow in Southern Quebec and New York State suggested that there is the potential to achieve yields of up to 24-30 ODT/ha/year based upon specially selected varieties and under controlled conditions [300] but that yields are more likely to be in the range of 10-12 ODT/ha/year [187, 188]. In a long-term trial conducted by Labrecque *et al.* have demonstrated that yields of 10-15 ODT/ha/year can be achieved with various varieties of SRC willow [303]. Miscanthus, another popular agricultural biomass crop has also been trialed in Canada, with yields greater than 30 ODT/ha/year being achieved in Southern Ontario [304] and a crop that has been trialed in Nova Scotia [305].

7.2 Nova Scotia Energy Generation and Current Biomass utilization

Nova Scotia, has an energy mix of 69.7% from fossil fuels, 3.7% from imports and 26.6% from renewable energy sources of which biomass represents 2.8% [306]. The Nova Scotia Government aims to reduce the province's reliance on fossil fuels with a target of 40% of energy produced through renewable means by 2020 [203], of which biomass energy generation will be a contributor. Biomass usage within the province is considered a significant fuel resource especially within the residential sector where 26% of home heating systems use wood or wood pellets, with only Prince Edward Island (PEI) using more wood based heating systems (36%) [307]. As of 2016 Nova Scotia Power Inc (NSPI), have two biomass facilities; the 63.1MW NSPI Port Hawkesbury Biomass System and the 27MW Brooklyn Energy Centre.

In 2010 the Nova Scotia Government began the Community Feed-in Tariff (COMFIT) program, which aimed to develop the renewable energy capacity of Nova Scotia, by encouraging groups within the province to invest in and install renewable energy technologies including; wind turbines, hydro power, solar panels and biomass systems. There were a total of one hundred and thirty approved COMFIT applications as of the end of 2015 (Figure 7.4); while wind turbines were the predominant technology approved within the province with one hundred and seven wind turbine systems ranging from 1M to 10MW, there were sixteen biomass systems approved under the scheme which includes CHP, biogas and municipal solid waste systems (Figure 7.5).

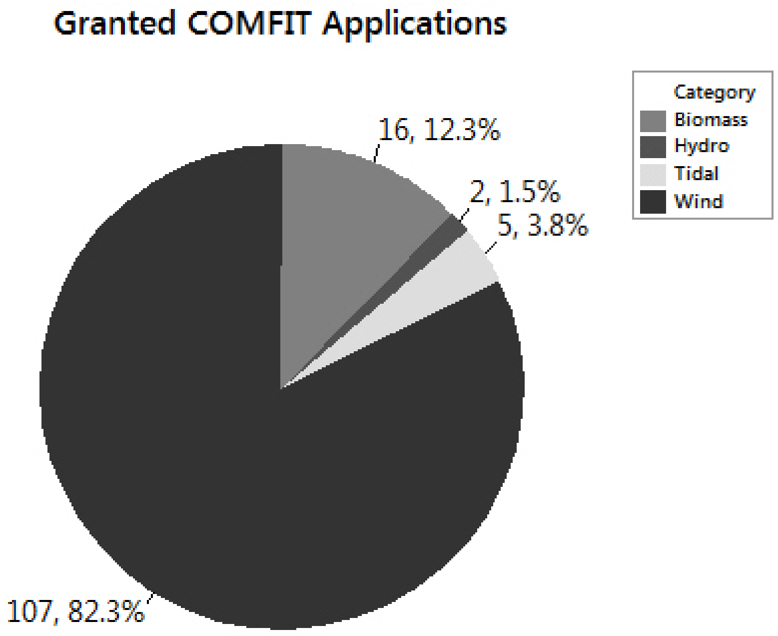


Figure 7.4: Awarded COMFIT applications [49].

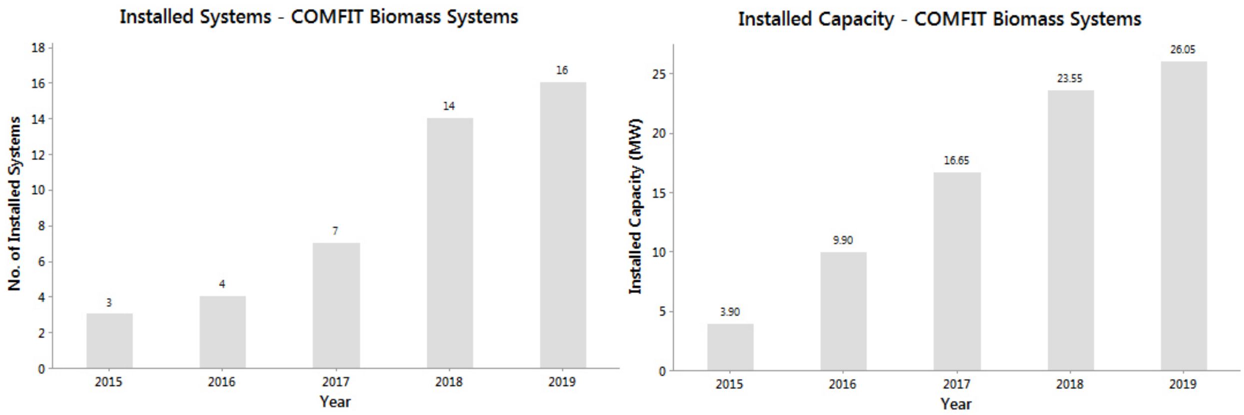


Figure 7.5: Approved Biomass COMFIT Applications and Installed Capacity [49]

This will take the existing installed biomass generating capacity (COMFIT and NSPI Facilities) from 105 MW as of 2015 to an estimated 139.4 MW by 2018. The COMFIT program is now closed to new applications as of early 2015, with the Nova Scotia Government citing that the program had achieved its aim of the program and that to continue, there may be a negative impact upon Power Rates within the province [308].

Nova Scotia currently has an aged electrical distribution system, which restricts the available capacity depending upon location which limits not only the installation of biomass energy generating facilities but reduces the ability of applying all other renewable energy technologies. Currently there is an estimated 298 MW of available grid capacity throughout the province (Figure 37), with the greatest capacity being within Halifax Regional Municipality with 209 MW available of which the majority can be found within Halifax and Dartmouth, however due to the built-up environment, the potential for installing biomass facilities is greatly reduced due to the typical sizes of biomass systems, the need for storage and access. Ranking second is the county of Cape Breton, where the grid capacity is estimated to be 24.9 MW; this capacity can be found within the city of Sydney and surrounding environs.

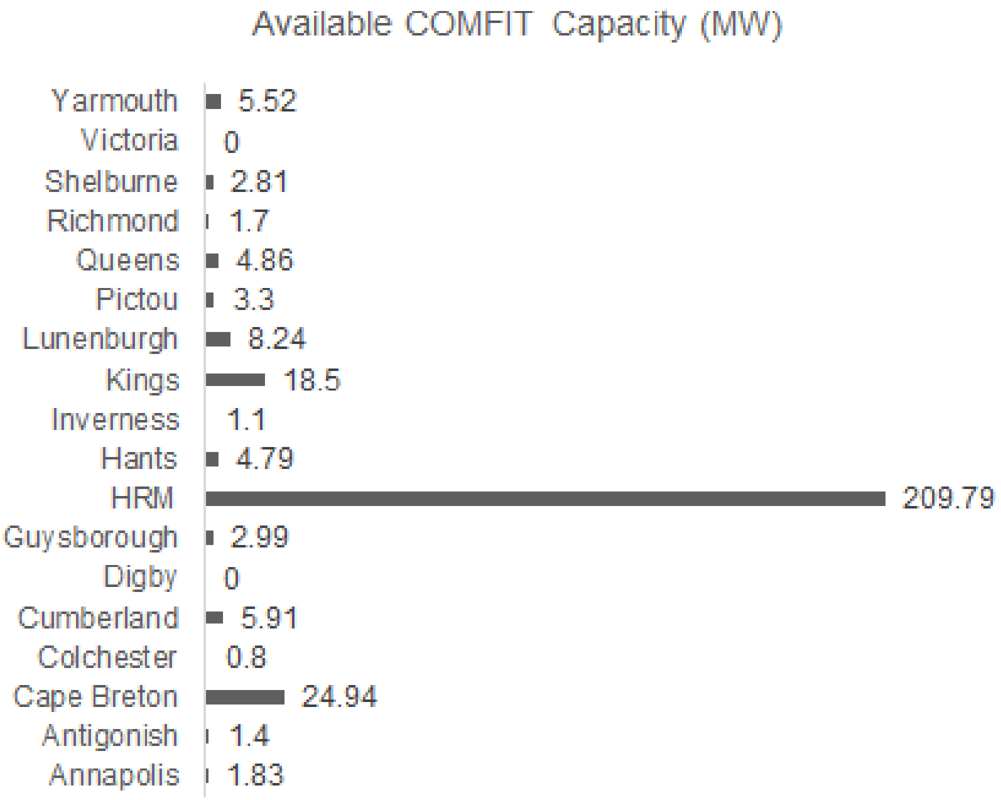


Figure 7.6: Available grid capacity [309].

While Nova Scotia has an aged infrastructure, NSPI is in the process of upgrading the grid infrastructure, with a forecasted $281 Million to be spent on transmission systems for load growth, system reliability and for renewable energy integration between 2015 and 2019 and $421.6 million on distribution systems focusing on load growth and reliability between 2015 and 2019 [310].

Due to the small and relatively dispersed population, the funds necessary for expediting the rate of infrastructure improvements is not available due to NSPI being unable to increase electricity rates much further. Nova Scotia rate payers have already received a 3% increase, seen in both 2013 and 2014, and further of 1.7% in 2016, 2017 and 2019 to deal with the closure of several large power users, of which significant revenue were previously taken. The increase in coal prices, the mandated emissions reduction targets and a need for energy security leading NSPI to heavily investing in renewable energy technologies and associated infrastructure, will see rates increase in the short to medium term [311], which will see grid capacity for individual power producers limited.

7.3 Nova Scotia Land Capacity

Identification of Land for biomass production was easily identified as the values had previously been identified through statistical means, Figure 7.7 shows all agricultural land and Figure 7.8 shows Inactive Land only, both highlighted in dark grey, based on the objective 24,499 ha of inactive of land are available.

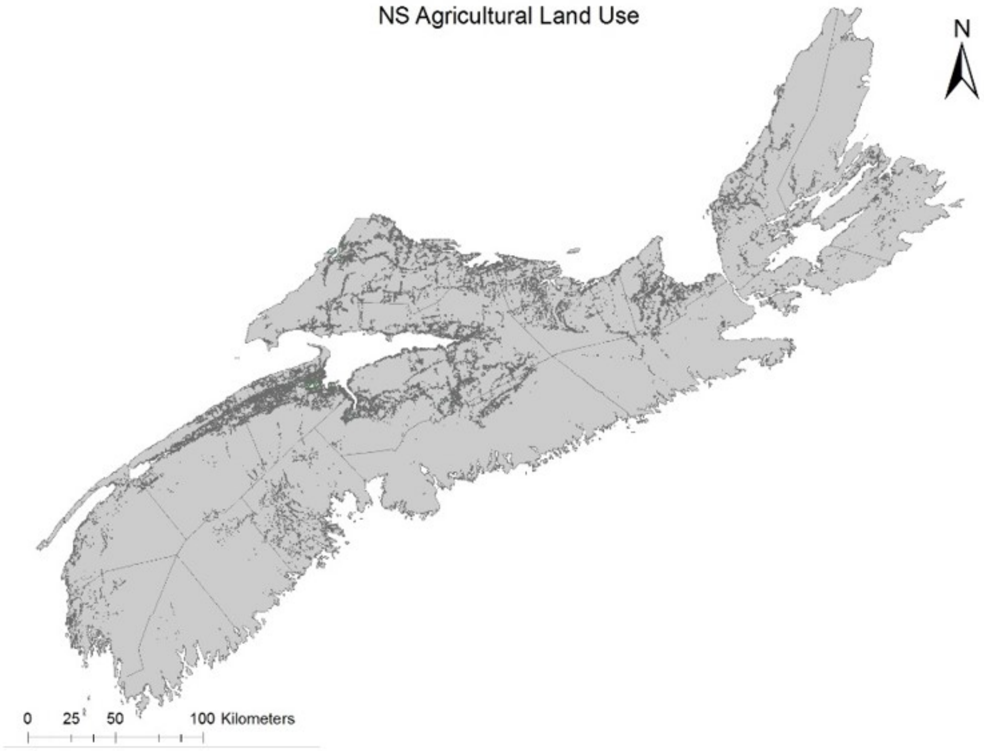


Figure 7.37: ALIP - All agricultural land use.

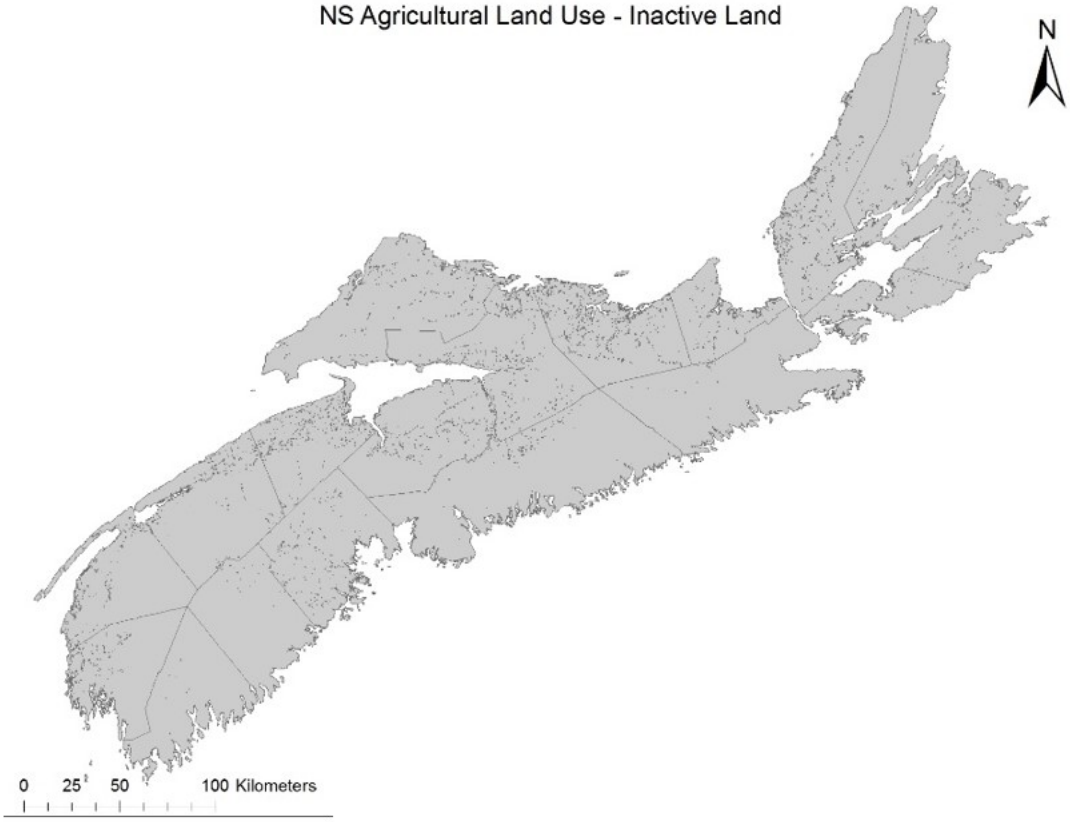


Figure 7.8: ALIP - Inactive land only.

Using the weighted overlay analysis process each inactive field was classified with regards to suitability of land for growing SRC Willow, giving five of seven available new classes, with Class 6 indicating a high suitability and Class 2 Indicating low suitability. Looking at the whole province, 2,061 ha were assigned to Class 6, 13,277 ha to Class 5, 4,747 ha to Class 4, 2,607 ha to Class 3 and 1,150 ha to Class 2. Figure 7.9 covers the area of Kings County and shows the variation in land suitability in the area.

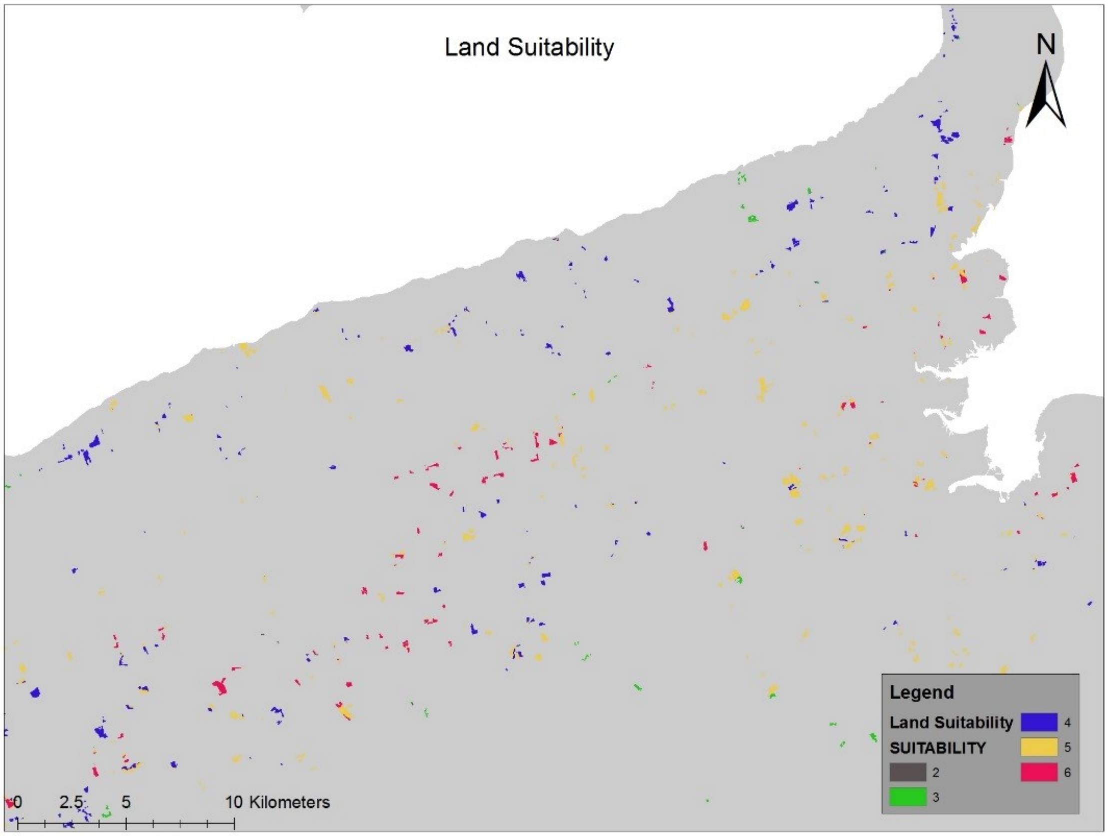
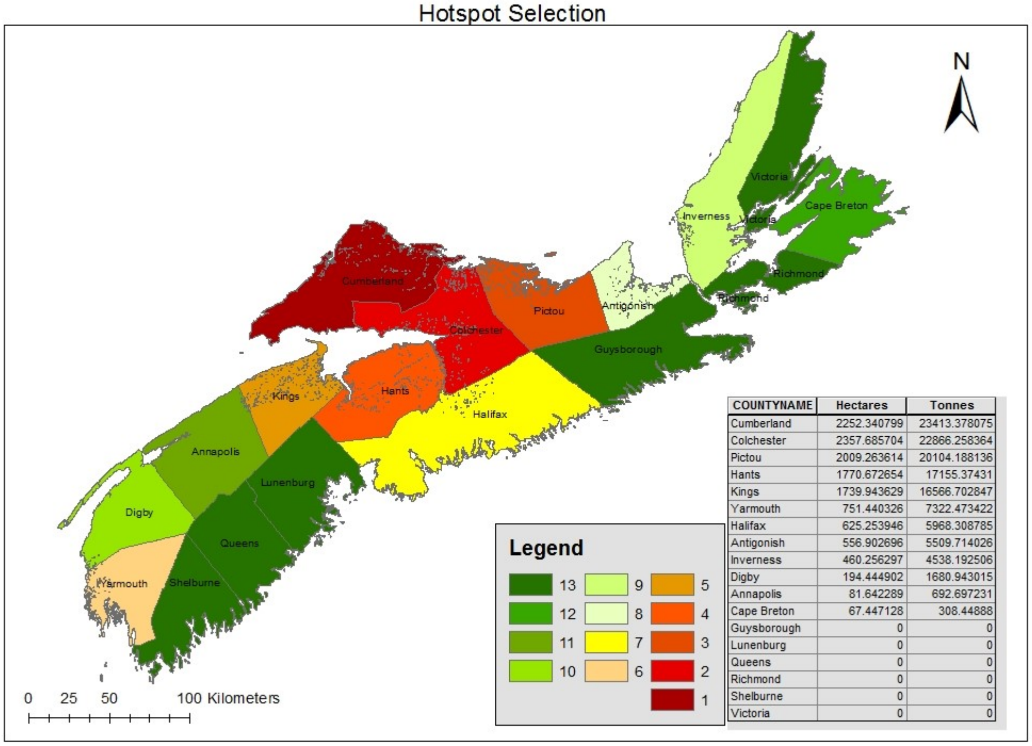


Figure 7.9: Land Suitability - Kings County.

Each of these different classes were assigned a tonne value; 6 = 12 tonnes, 5 = 10 tonnes, 4 = 8 tonnes, 3 = 6 tonnes and 2 = 4 tonnes. The tonnes assigned were based on average yield values per year as noted by Best Practice Guidelines for SRC willow (Caslin *et al., 2010)* and research conducted by Aylott *et al* (2008), Tenerelli *et al.* (2012) and Bauen *et al* (2010) from Europe [26, 27, 199, 200].

It should be noted however that these yield values, research derived, are based upon European growing and field conditions and the yields assigned to each land suitability value is not necessary correct, current SRC yield data from Canada is limited to first and second harvest data from Saskatchewan and Quebec. However, the key purpose here is to a demonstrate the process of assigning yield values to land suitability classes; to refine and properly determine a link between land suitability and yields, field trials will be necessary. Based on this work, Pictou County has been identified as the County with the greatest number of fields (3,676 ha) and highest production numbers (34,232 tonnes).

Using the above data, the hotspot analysis was used to determine the counties that had the highest available tonnage (or suitability class) produced within reasonable distance (field to field) to one another. Figure 7.10 shows the province and ranks each county with regards to hectares available and tonnes produced. From the results, Cumberland County is ranked number 1 and several Counties do not have any fields that are considered in close proximity and have a high suitability rating.

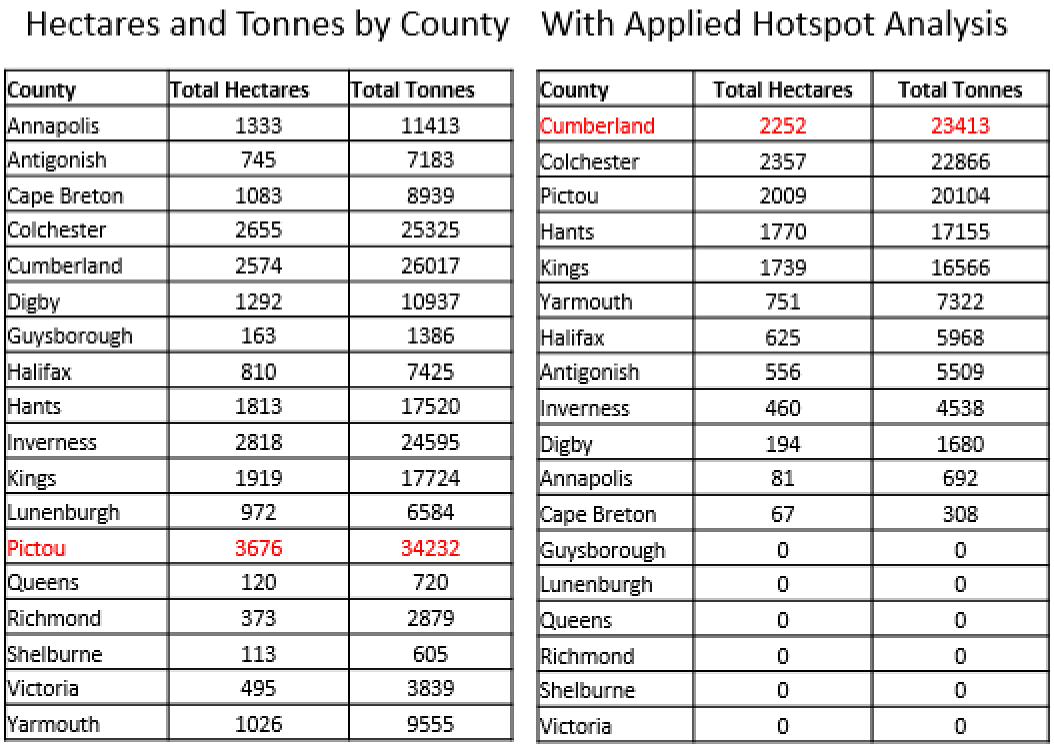


COUNTYNAME	Hectares	Tonnes
Cumberland	2252.340799	23413.378075
Colchester	2357.685704	22866.258364
Pictou	2009.263614	20104.188136
Hants	1770.672654	17155.37431
Kings	1739.943629	16566.702847
Yarmouth	751.440326	7322.473422
Halifax	625.253946	5968.308785
Antigonish	556.902696	5509.714026
Inverness	460.256297	4538.192506
Digby	194.444902	1680.943015
Annapolis	81.642289	692.697231
Cape Breton	67.447128	308.44888
Guysborough	0	0
Lunenburg	0	0
Queens	0	0
Richmond	0	0
Shelburne	0	0
Victoria	0	0

Figure 7.10: Hotspot analysis.

Table 7.1 provide a full listing of each county with regards to hectares and tonnes by county and the available hectares and tonnes as identified with the Hotspot Analysis. The hotspot analysis is particularly useful as it indicates that if a biomass processing facility was being considered for the province based upon these factors alone, then Cumberland County would perhaps be the optimal choice due to good yields and field to field proximity.

Table 7.1: Hectares and tonnes by County and applied hotspot analysis.



Hectares and Tonnes by County

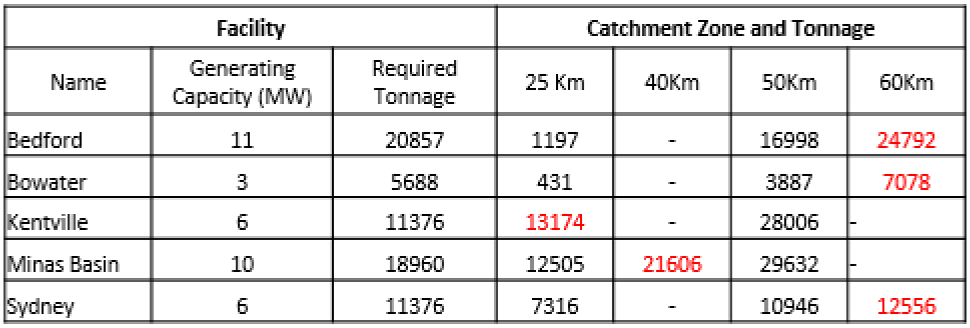
County	Total Hectares	Total Tonnes
Annapolis	1333	11413
Antigonish	745	7183
Cape Breton	1083	8939
Colchester	2655	25325
Cumberland	2574	26017
Digby	1292	10937
Guysborough	163	1386
Halifax	810	7425
Hants	1813	17520
Inverness	2818	24595
Kings	1919	17724
Lunenburgh	972	6584
Pictou	3676	34232
Queens	120	720
Richmond	373	2879
Shelburne	113	605
Victoria	495	3839
Yarmouth	1026	9555

With Applied Hotspot Analysis

County	Total Hectares	Total Tonnes
Cumberland	2252	23413
Colchester	2357	22866
Pictou	2009	20104
Hants	1770	17155
Kings	1739	16566
Yarmouth	751	7322
Halifax	625	5968
Antigonish	556	5509
Inverness	460	4538
Digby	194	1680
Annapolis	81	692
Cape Breton	67	308
Guysborough	0	0
Lunenburgh	0	0
Queens	0	0
Richmond	0	0
Shelburne	0	0
Victoria	0	0

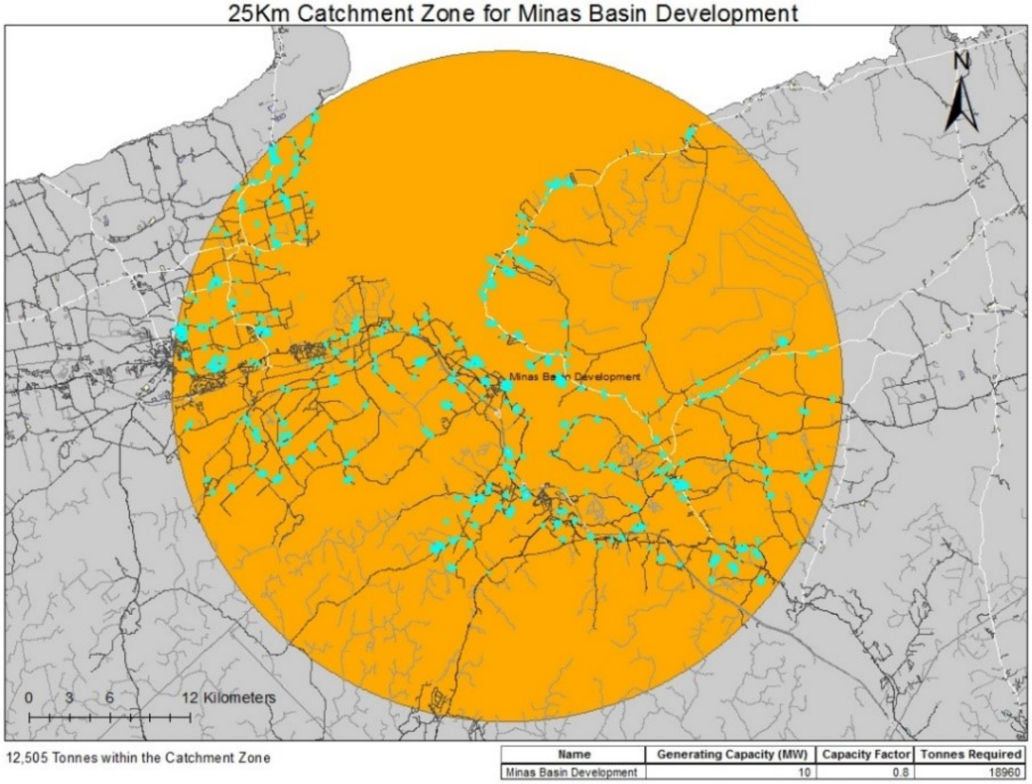
Using Buffer Zones for each of the different biomass facilities, it was identified that Kentville was capable of obtaining it’s biomass within a 25km zone, Minas Basin 40Km and the remainder within 60Km of their locations. Table 7.2 shows the catchment zones and their respective tonnage within the area.

Table 7.2: Catchment zone and tonnage produced.



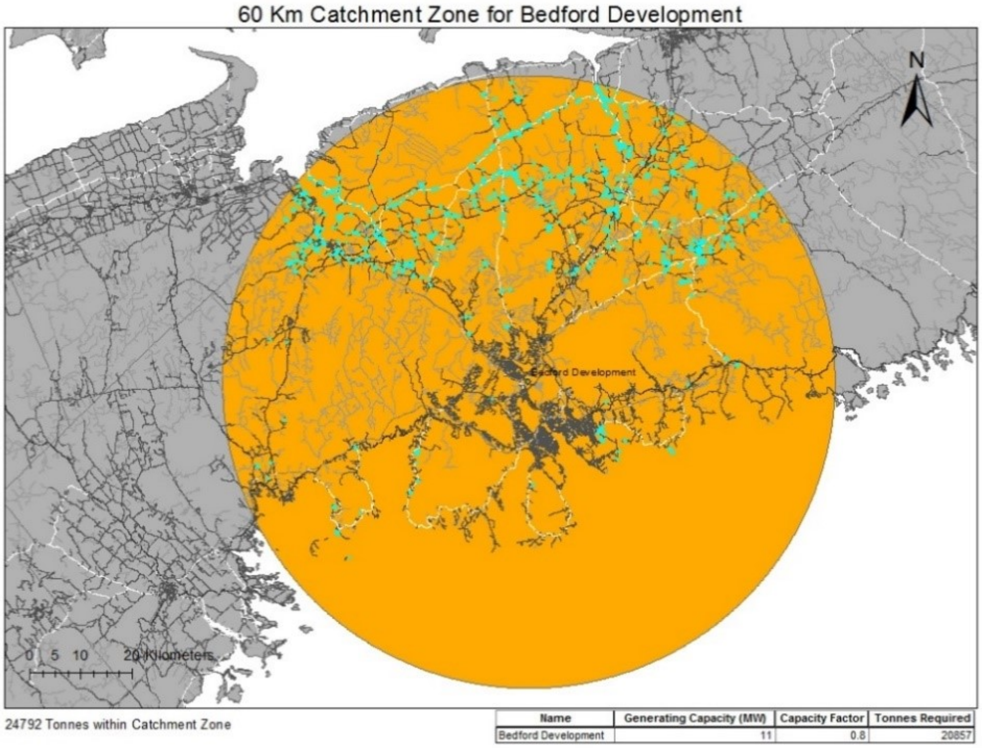
Facility			Catchment Zone and Tonnage			
Name	Generating Capacity (MW)	Required Tonnage	25 Km	40Km	50Km	60Km
Bedford	11	20857	1197	-	16998	24792
Bowater	3	5688	431	-	3887	7078
Kentville	6	11376	13174	-	28006	-
Minas Basin	10	18960	12505	21606	29632	-
Sydney	6	11376	7316	-	10946	12556

Figures 7.11 and 7.12 display the catchment zones for Minas Basin and Bedford Developments and the available fields, highlighted in blue. While individually each facility could support itself within the identified catchment zones, if Minas Basin, Kentville and Bedford were operating at the same time, the catchment zones would have to be extended for one or all of the sites due to overlapping catchment zones. However looking province wide the yearly demand is 68,260 tonnes for all five biomass facilities; well within the potential 215,740 tonnes produced annually.



Name	Generating Capacity (MW)	Capacity Factor	Tonnes Required
Minas Basin Development	10	0.8	18960

Figure 7.11: Minas Basin catchment zone.



24792 Tonnes within Catchment Zone

Name	Generating Capacity (MW)	Capacity Factor	Tonnes Required
Bedford Development	11	0.8	20857

Figure 7.12: Bedford catchment zone

CHAPTER 8 SRC WILLOW CASE STUDY

8.1 SRC Willow Case Study – Background

Dalhousie University, founded in 1818, comprises of over one hundred buildings across 32 ha in downtown Halifax, Nova Scotia, and over fifty buildings located at their Agricultural Campus. The Agricultural Campus services over one thousand Students and three hundred members of Faculty and Staff.

The Agricultural campus is comprised of three residential buildings, an administration building, Athletics Centre, library, engineering building, animal and aqua culture building, environmental and plant science building, student services and securities building, a poultry research centre, ruminant animal centre and a mink production facility as well as multiple ancillary buildings.

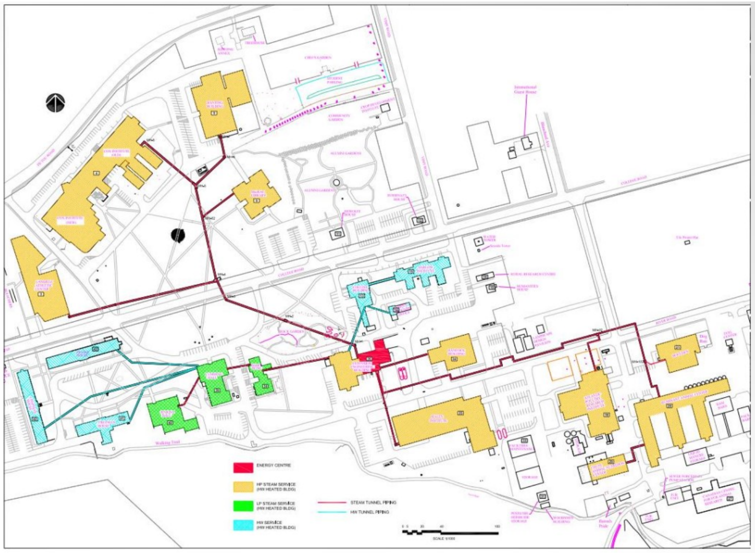


Figure 8.1: Dalhousie University Agricultural Campus schematic.

The Agricultural Campus operates a District Heating System, which services all large buildings on-campus (Figure 8.1). A new Combined Heat and Power Systems at a cost of $24.2 Million replaced the previous heating systems and allowed Dalhousie University to capitalize on the COMFIT program which ran from 2011 to 2015. Under the COMFIT program, the CHP project was granted under Directives two and four, which stipulates the utilization of wood waste and a maximum of 25% from 'other' wood biomass sources which could include agricultural energy crops like SRC willow.

8.1.1 Biomass System

The Agricultural Campus' biomass CHP system operating using am Organic Rankin Cycle has been designed with an operating capacity of 2.8 MW thermal energy and 0.96 MW electric. The system was designed with a specified fuel requirement of wood chips and a moisture content operating range of between 35% and 55% with desired feedstocks being 45% MC.

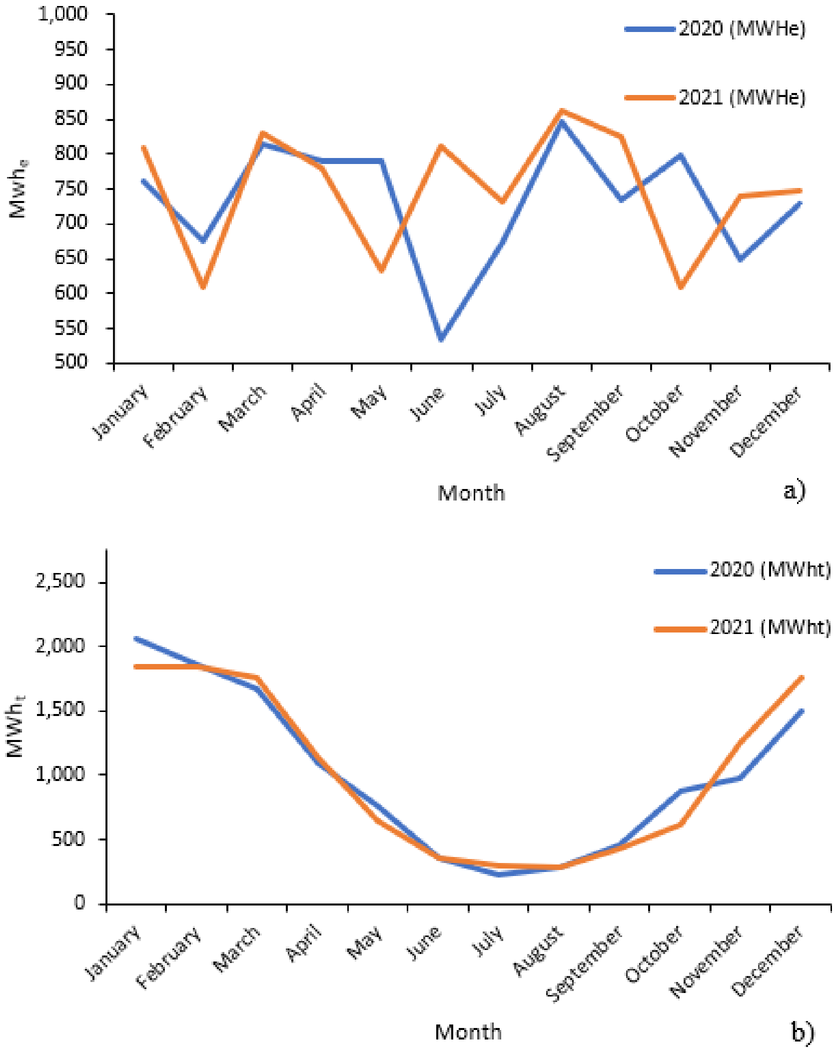


Figure 8.2: a) MWh heat production for 2020 and 2021. b) MWh energy production for 2020 and 2021.

Electricity production is variable trough-out the year, but the CHP operators aim to produce between 700 MWh_e and 850 MWH per month (Figure 8.2a), the fluctuation in output is often because of the variation in heat output. The CHP system has a higher heat output in the winter months at approximately 2 MWh_t (Figure 8.2b), reaching its lowest output in the summer when limited space heating is required.

8.1.2 Biomass Fuel Requirement

For fuel requirements (Table 8.1), Dalhousie University's Agricultural Campus currently has a fuel contract with a local lumber mill for 20,000 – 22,000 tonnes of wood chips at $54/tonne (Figure 8.3), with a MC range of between 45-50%. Dalhousie University has stated a maximum purchase price set between $75-80 per delivered tonne for purpose grown energy crops (SRC willow) and waste products waste products set between $40-60 per delivered tonne.

Table 8.1: Dalhousie University Agricultural Campus fuel requirements.

Fuel Supply	
Estimated Fuel Requirement	20,000 Tonnes per year
Calculated Fuel HHV	20.25 GJ/Tonne
System MC% Operating Design	45%
System tolerance MC% Range	33% - 55%
Bulk Density Storage Capacity	240 kg/m3
Bulk Density Material Handling	400kg/m3

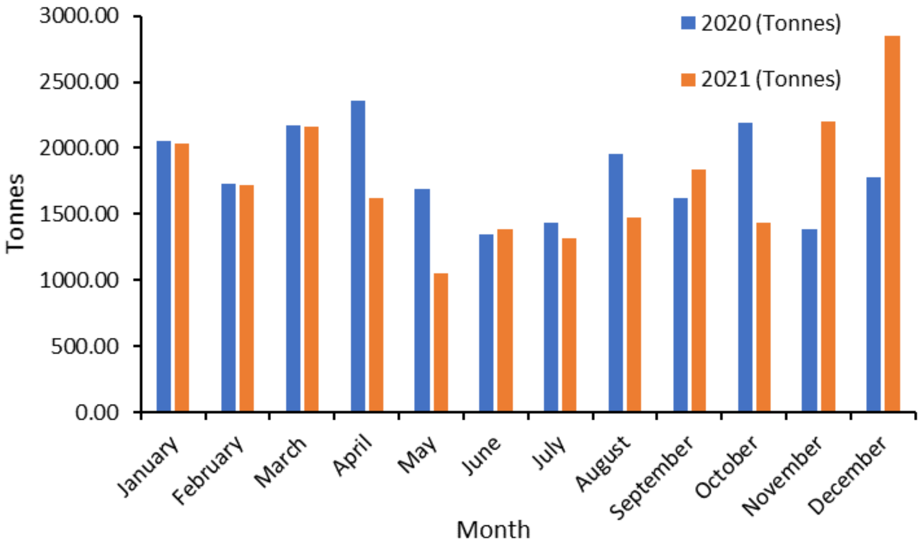


Figure 8.3: Dalhousie University Agricultural Campus CHP system biomass fuel usage.

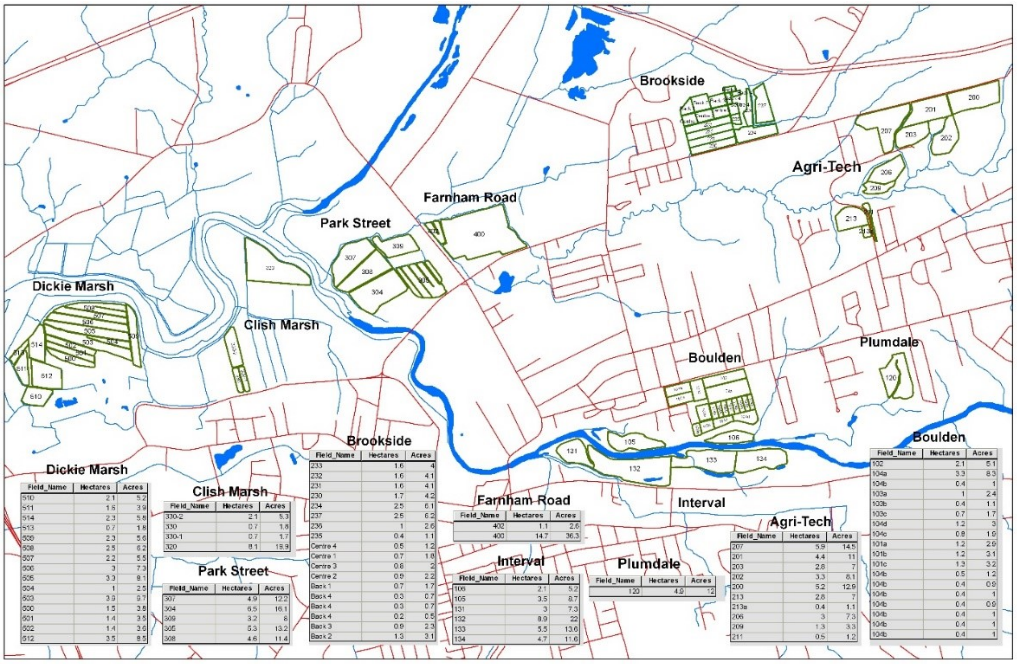
8.1.3 Biomass Fuel Handling System

Due to the confined space available on the Agricultural Campus, storage is confined to 180 tonnes of biomass at an average bulk density of 240 Kg/m3. With the system operating 24/7, deliveries are daily, Monday through Friday from suppliers with a maximum of three trucks per day. This provides a seventy-two-hour on-site supply of feedstock, with a maximum designed consumption rate of 2.5 tonnes per hour at peak burn times. Fuel storage and handling system allows for two separate fuel sources, with delivery via a standard dumping trailer. Two separate fuel rake systems are provided to allow for fuel blending towards a common fuel transfer conveyor belt. Additional fuel transfer drag chain sections are provided to transfer the blended fuel up to an elevated fuel clean-up and metering section. Fuel feedstocks have been specified as being <5" in diameter and at a moisture content range of between 35 % - 55 %, with a desired MC% of 45 %, The fuel feed system continuously feeds the desired fuel feedstock from storage via t-rod pushers onto the step grate combustor. The fuel feed rate is variable depending on the demand condition required and includes a system to meter the fuel consumed. The fuel feed system is protected from burn back of the fuel, by a water sprinkler system. The combustor is equipped with a moving grate burner and refractory lined furnace. Primary combustion air is fed from under the grate, while over-fire secondary combustion air is provided above the grate.

8.1.4 Availability of fuel

Dalhousie University is located near Truro in the County of Colchester, NS, with significant forestry land, available agricultural land, and a local wood processing facility nearby, JD Irving. The surrounding agricultural land is in good agricultural condition with 33 % being classified as class 2 land, 45 % as class 3 land, 13 % as class for and the remainder considered to be lower than class 4 making it typically unsuitable for agricultural production. Being central to Nova Scotia, the travel network to Dalhousie University considers lands in Annapolis, Kings, Hants, Halifax, Lunenburg, Pictou, Cumberland, Guysborough, Antigonish, Inverness, and Richmond counties to be with 200 km of the site.

8.2 Available Land Resources



Dickie Marsh

Field_Name	Hectares	Acres
510	2.1	5.2
511	1.6	3.9
514	2.3	5.8
513	0.7	1.8
509	2.3	5.6
508	2.5	6.2
507	2.2	5.5
506	3	7.3
505	3.3	8.1
504	1	2.5
503	3.9	9.7
500	1.5	3.8
501	1.4	3.5
502	1.4	3.6
512	3.5	8.5

Clish Marsh

Field_Name	Hectares	Acres
330-2	2.1	5.3
330	0.7	1.8
330-1	0.7	1.7
320	8.1	19.9

Park Street

Field_Name	Hectares	Acres
307	4.9	12.2
304	6.5	16.1
309	3.2	8
305	5.3	13.2
308	4.6	11.4

Brookside

Field_Name	Hectares	Acres
233	1.6	4
232	1.6	4.1
231	1.6	4.1
230	1.7	4.2
234	2.5	6.1
237	2.5	6.2
236	1	2.6
235	0.4	1.1
Centre 4	0.5	1.2
Centre 1	0.7	1.8
Centre 3	0.8	2
Centre 2	0.9	2.2
Back 1	0.7	1.7
Back 4	0.3	0.7
Back 4	0.3	0.7
Back 4	0.2	0.5
Back 3	0.9	2.3
Back 2	1.3	3.1

Farnham Road

Field_Name	Hectares	Acres
402	1.1	2.6
400	14.7	36.3

Interval

Field_Name	Hectares	Acres
106	2.1	5.2
105	3.5	8.7
131	3	7.3
132	8.9	22
133	5.5	13.6
134	4.7	11.6

Plumdale

Field_Name	Hectares	Acres
120	4.9	12

Agri-Tech

Field_Name	Hectares	Acres
207	5.9	14.5
201	4.4	11
203	2.8	7
202	3.3	8.1
200	5.2	12.9
213	2.8	7
213a	0.4	1.1
206	3	7.3
209	1.3	3.3
211	0.5	1.2

Boulden

Field_Name	Hectares	Acres
102	2.1	5.1
104a	3.3	8.3
104b	0.4	1
103a	1	2.4
103b	0.4	1.1
103c	0.7	1.7
104d	1.2	3
104c	0.8	1.9
101a	1.2	2.9
101b	1.2	3.1
101c	1.3	3.2
104b	0.5	1.2
104b	0.4	0.9
104b	0.4	1
104b	0.4	0.9
104b	0.4	1
104b	0.4	1
104b	0.4	1

Figure 8.4: Dalhousie University agricultural land [314].

Dalhousie University owns 182.8 ha of agricultural land (Figure 8.4 and Table 8.2) surrounding the Agricultural Campus, the land is currently utilized as pastureland for grazing their dairy herd, for the production of feed for their dairy herd and as crop research production land.

Table 8.1: Breakdown of Dalhousie University Agricultural Campus land resources by location.

Field Location	Ha Available	Road Distances to Biomass Facility (km)	Suitability for Production
Agri-tech park	29.6	3.5	Yes
Boulden	17.3	0.6	Yes
Brookside	19.5	2.4	Yes
Clish marsh	11.6	3.7	Yes
Dickie Marsh	31.9	4.5	Yes
Farnham Road	15.8	3.1	Yes
Interval	27.7	2.9	Yes
Park Street	24.5	3.1	Yes
Plumdale	4.9	2.4	Yes
Total	**182.8**		

Table 8.2 details the available agricultural and the calculated distance from each location to the installed biomass system. All the land currently owned by Dalhousie University is classified as Class 2 land and is highly suitable for agricultural production. Based upon the ALIP dataset, incorporating all available land types including long-term, rotational, active, and inactive transitional land, Table 8.3 demonstrates the availability of land that could be potentially utilized for production.

Table 8.2: Land availability for Dalhousie University.

Location	**25 km**	**50km**	**100km**	**150 km**	**200km**
Dalhousie University, Bible Hill (Ha)	-	5,0137	11,5845	18,2255	21,9318

7.2 Case Study Process

Figures 8.5 to 8.11 show the steps taken to identify the land availability surrounding Dalhousie University's Agricultural Campus and spatial maps identifying land parcels.

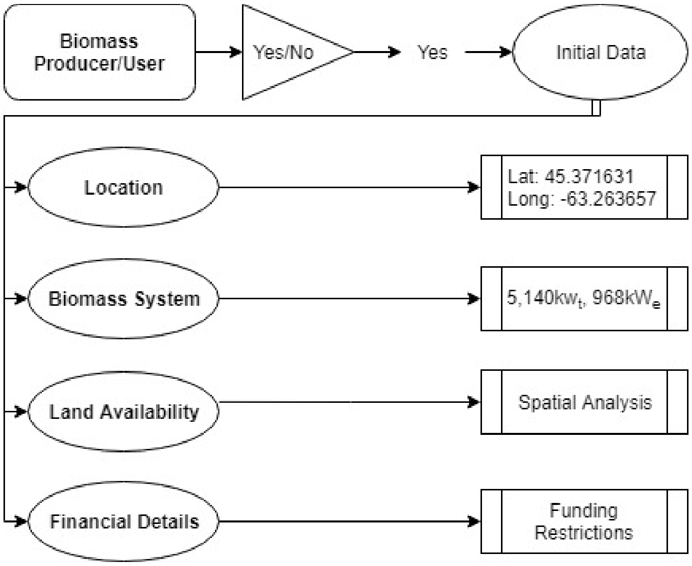


Figure 8.5: Dalhousie University system analysis.

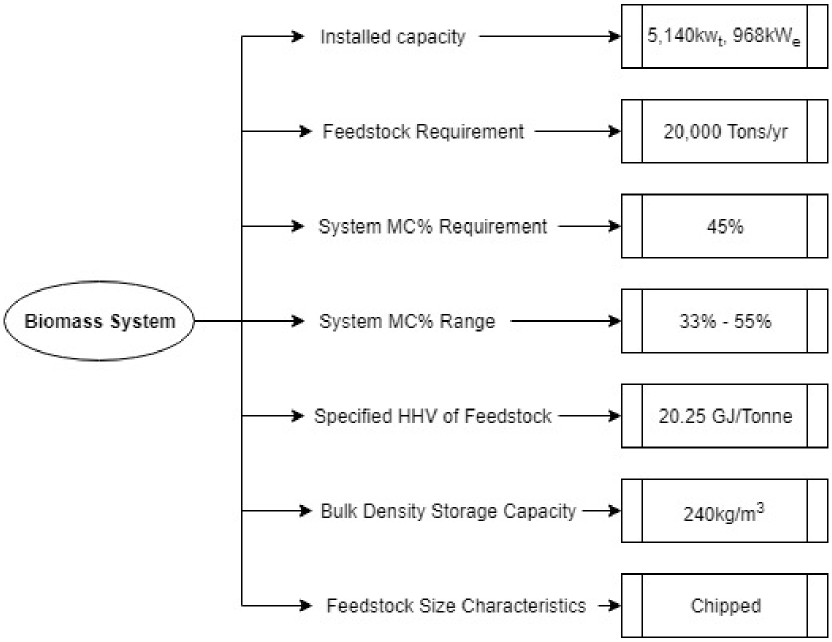


Figure 8.6: Dalhousie University biomass system analysis.

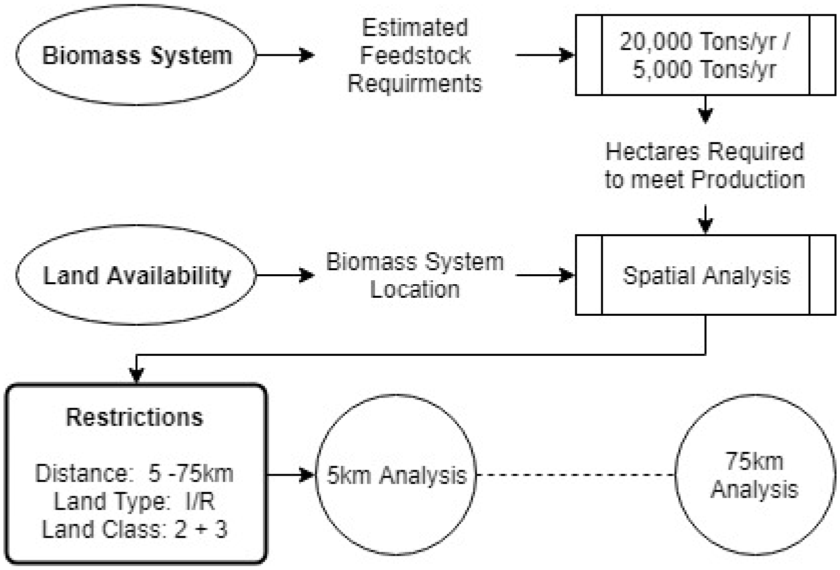


Figure 8.7: Dalhousie University biomass system and land availability analysis.

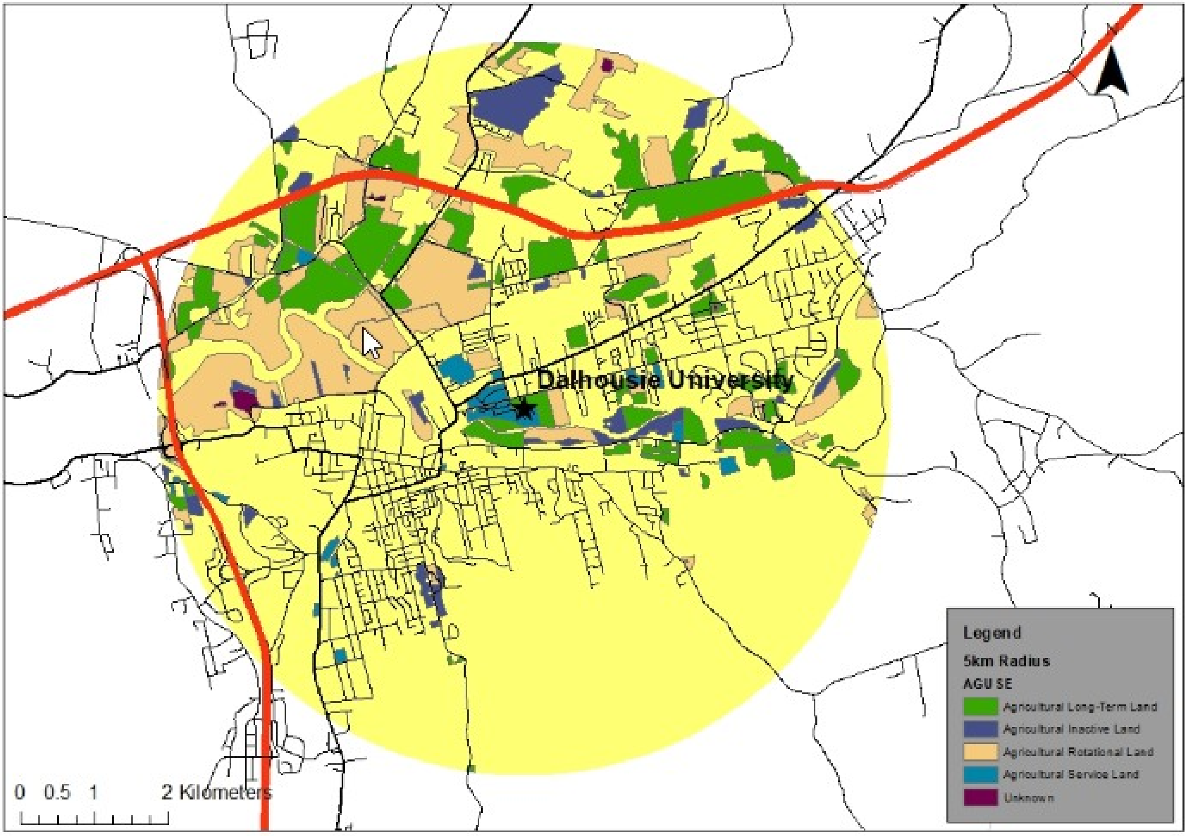


Figure 8.8: Land Availability 5km radius from location.

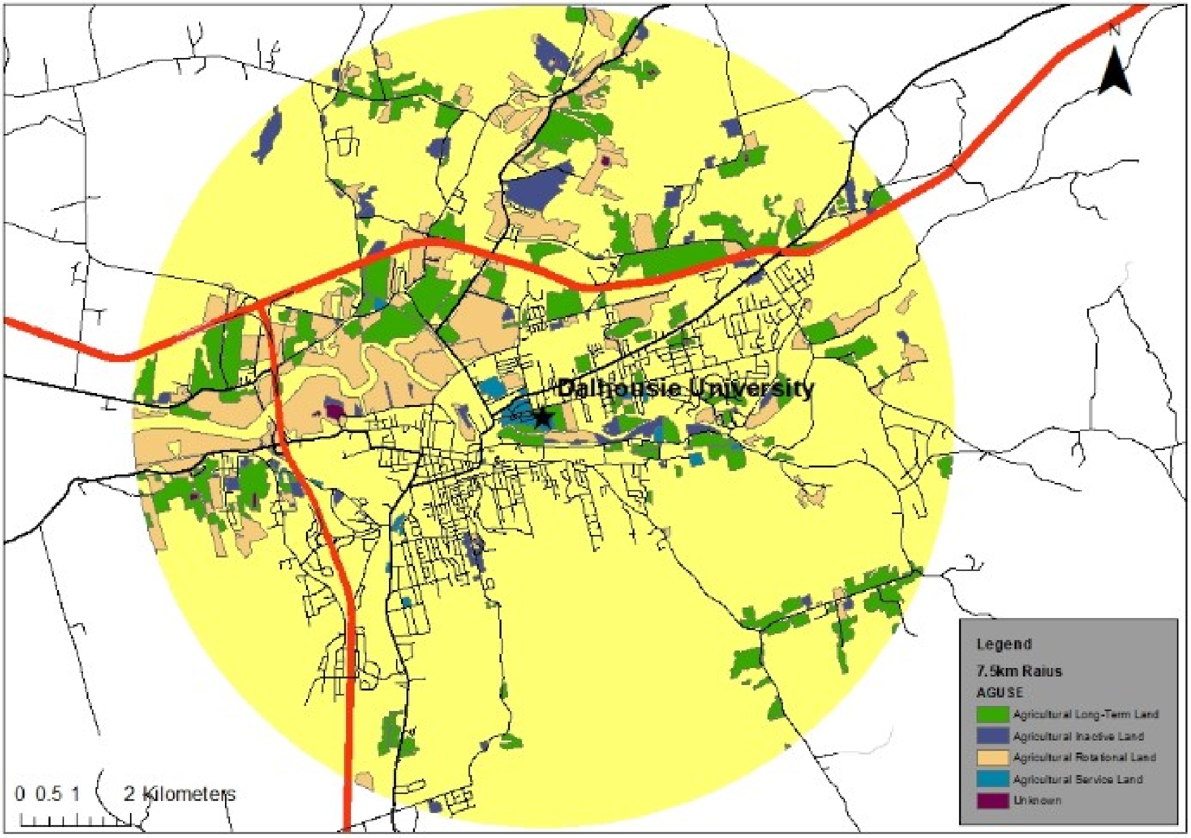


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Figure 8.9: Land Availability 7.5km radius from location.

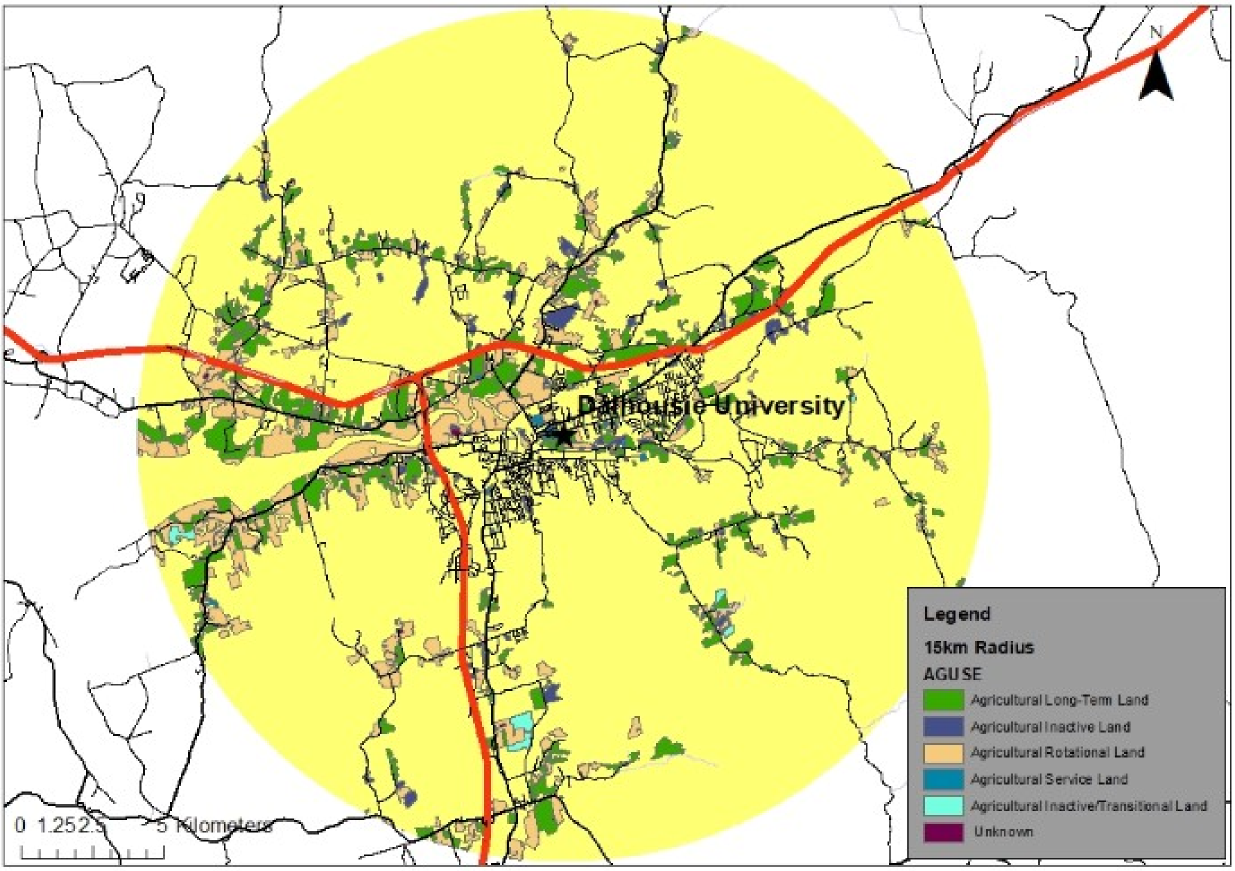


Figure 8.10: Land Availability 15km Radius from Location.

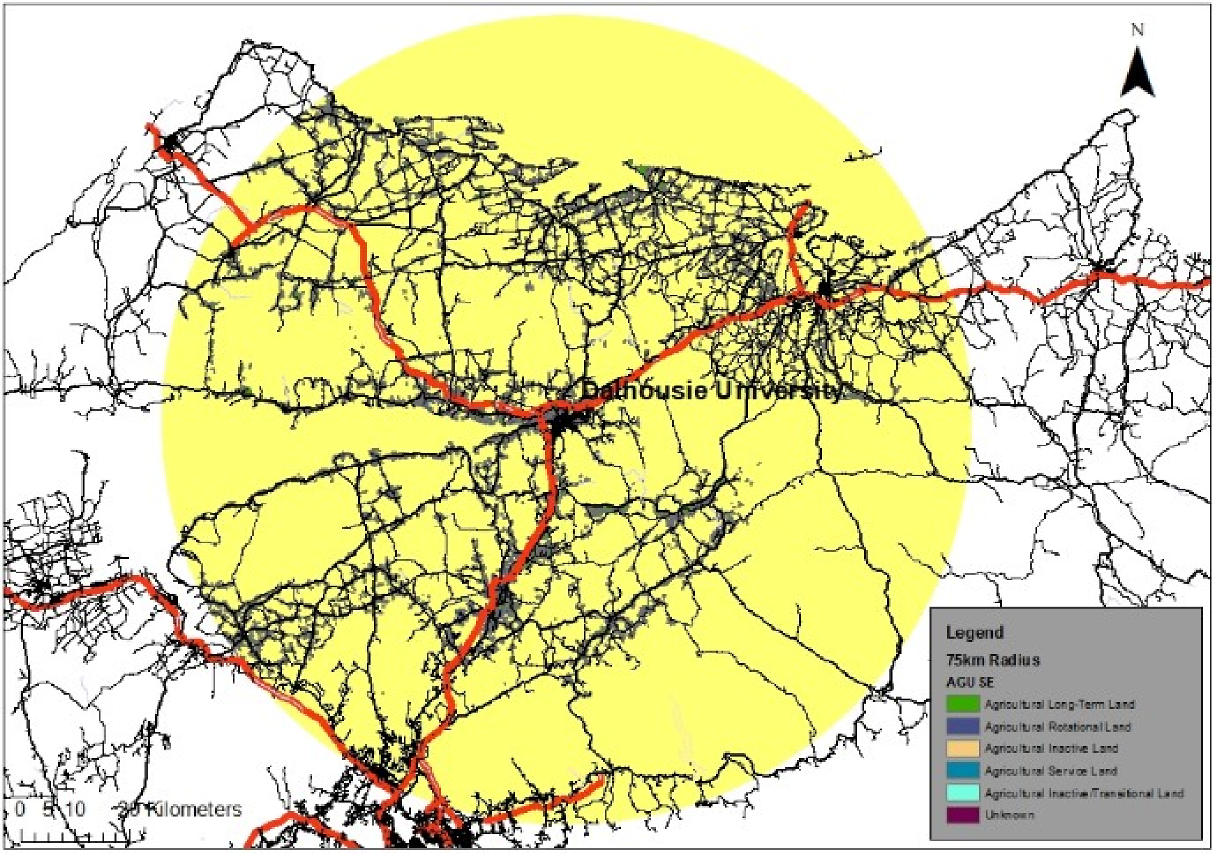


Figure 8.11: Agricultural Land 75km Radius from Location.

Tables 8.4 to 8.6 are the results of the spatial analysis, showing the available hectares between 5km and 75km radius out from Dalhousie University's Agricultural Campus and the corresponding tonnes available for use. For example, within 5 km of the Agricultural Campus there is 1,058 ha of agricultural rotational land inactive land across ninety-three parcels of land. The potential yield, based on 18 tonnes/ha/year would be 20,630 Tonnes on a three-year harvest cycle. Tables 8.7 and 8.8 show the availability of land and potential yields based on available percentages of land, the assumption being that only a percentage of land would be available within a catchment area.

Table 8.3: Model Output - Hectares available between 5 km and 75 km radius.

Land Type	Hectares										
	5km	7.5km	10km	12.5km	15km	17.5km	20km	22.5km	25km	50km	75km
Agricultural Long-Term Land	739	1526	2438	3273	3876	5078	6166	6918	7921	26023	38269
Agricultural Rotational Land	867	1526	2259	3271	3955	5059	6266	7320	8796	33817	47213
Agricultural Inactive Land	191	326	508	544	626	698	807	961	1142	6660	9662
Agricultural Inactive /Transitional Land	0	0	95	99	136	150	179	233	251	523	901
Agricultural Service land	80	81	81	82	92	97	97	97	97	112	132
Unknown	13	19	31	37	45	62	72	79	92	474	621

Table 8.4: Model Output - Land parcels available between 5 km and 75 km radius.

Land Type	Land Parcel Count										
	5km	7.5km	10km	12.5km	15km	17.5km	20km	22.5km	25km	50km	75km
Agricultural Long-Term Land	67	141	223	292	348	420	529	599	698	2414	3526
Agricultural Rotational Land	56	111	194	264	330	409	538	649	745	3240	4843
Agricultural Inactive Land	37	65	102	117	139	158	200	237	273	1435	2135
Agricultural Inactive /Transitional Land	0	0	5	7	9	11	21	26	29	87	160
Agricultural Service land	22	23	23	26	28	31	31	31	31	46	54
Unknown	5	11	18	23	28	33	39	47	56	376	550

Table 8.5: Model Output - Estimated tonnage per total available land.

Land Type	Estimated Tonnage per Year per Total Available Land										
	5km	7.5km	10km	12.5km	15km	17.5km	20km	22.5km	25km	50km	75km
Agricultural Long-Term Land	14410.5	29757	47541	63823.5	75582	99021	120237	134901	154459.5	507448.5	746245.5
Agricultural Rotational Land	16906.5	29757	44050.5	63784.5	77122.5	98650.5	122187	142740	171522	659431.5	920653.5
Agricultural Inactive Land	3724.5	6357	9906	10608	12207	13611	15736.5	18739.5	22269	129870	188409
Agricultural Inactive /Transitional Land	0	0	1852.5	1930.5	2652	2925	3490.5	4543.5	4894.5	10198.5	17569.5
Agricultural Service land	1560	1579.5	1579.5	1599	1794	1891.5	1891.5	1891.5	1891.5	2184	2574
Unknown	253.5	370.5	604.5	721.5	877.5	1209	1404	1540.5	1794	9243	12109.5

Table 8.6: Model Output - Hectares available with 5 - 20% land availability

Land Type	Available Percentage	Hectares										
		5km	7.5km	10km	12.5km	15km	17.5km	20km	22.5km	25km	50km	75km
Agricultural Rotational Land	5	43.35	76.3	112.95	163.55	197.75	252.95	313.3	366	439.8	1690.85	2360.65
Agricultural Inactive Land		9.55	16.3	25.4	27.2	31.3	34.9	40.35	48.05	57.1	333	483.1
Agricultural Rotational Land	7.5	65.025	114.45	169.425	245.325	296.625	379.425	469.95	549	659.7	2536.275	3540.975
Agricultural Inactive Land		14.325	24.45	38.1	40.8	46.95	52.35	60.525	72.075	85.65	499.5	724.65
Agricultural Rotational Land	10	86.7	152.6	225.9	327.1	395.5	505.9	626.6	732	879.6	3381.7	4721.3
Agricultural Inactive Land		19.1	32.6	50.8	54.4	62.6	69.8	80.7	96.1	114.2	666	966.2
Agricultural Rotational Land	12.5	108.375	190.75	282.375	408.875	494.375	632.375	783.25	915	1099.5	4227.125	5901.625
Agricultural Inactive Land		23.875	40.75	63.5	68	78.25	87.25	100.875	120.125	142.75	832.5	1207.75
Agricultural Rotational Land	15	130.05	228.9	338.85	490.65	593.25	758.85	939.9	1098	1319.4	5072.55	7081.95
Agricultural Inactive Land		28.65	48.9	76.2	81.6	93.9	104.7	121.05	144.15	171.3	999	1449.3
Agricultural Rotational Land	17.5	151.725	267.05	395.325	572.425	692.125	885.325	1096.55	1281	1539.3	5917.975	8262.275
Agricultural Inactive Land		33.425	57.05	88.9	95.2	109.55	122.15	141.225	168.175	199.85	1165.5	1690.85
Agricultural Rotational Land	20	173.4	305.2	451.8	654.2	791	1011.8	1253.2	1464	1759.2	6763.4	9442.6
Agricultural Inactive Land		38.2	65.2	101.6	108.8	125.2	139.6	161.4	192.2	228.4	1332	1932.4

Table 8.7: Model Output - Estimated Tonnage per year per Percentage of Available Land.

Land Type	Available Percentage	Estimated Tonnage per Year per Percentage of Available Land										
		5km	7.5km	10km	12.5km	15km	17.5km	20km	22.5km	25km	50km	75km
Agricultural Rotational Land	5	845	1488	2203	3189	3856	4933	6109	7137	8576	32972	46033
Agricultural Inactive Land		186	318	495	530	610	681	787	937	1113	6494	9420
Agricultural Rotational Land	7.5	1268	2232	3304	4784	5784	7399	9164	10706	12864	49457	69049
Agricultural Inactive Land		279	477	743	796	916	1021	1180	1405	1670	9740	14131
Agricultural Rotational Land	10	1691	2976	4405	6378	7712	9865	12219	14274	17152	65943	92065
Agricultural Inactive Land		372	636	991	1061	1221	1361	1574	1874	2227	12987	18841
Agricultural Rotational Land	12.5	2113	3720	5506	7973	9640	12331	15273	17843	21440	82429	115082
Agricultural Inactive Land		466	795	1238	1326	1526	1701	1967	2342	2784	16234	23551
Agricultural Rotational Land	15	2536	4464	6608	9568	11568	14798	18328	21411	25728	98915	138098
Agricultural Inactive Land		559	954	1486	1591	1831	2042	2360	2811	3340	19481	28261
Agricultural Rotational Land	17.5	2959	5207	7709	11162	13496	17264	21383	24980	30016	115401	161114
Agricultural Inactive Land		652	1112	1734	1856	2136	2382	2754	3279	3897	22727	32972
Agricultural Rotational Land	20	3381	5951	8810	12757	15425	19730	24437	28548	34304	131886	184131
Agricultural Inactive Land		745	1271	1981	2122	2441	2722	3147	3748	4454	25974	37682

8.2.1 Spatial Analysis Results

Based on the spatial analysis there is available land from production, with 371 ha of land (20% of available land) being available within 7.5 km of Dalhousie University's Agricultural Campus, potentially yielding 7,222 tonnes of biomass in fields producing 18 tonnes/ha/year. This would be sufficient for supplying the Agricultural Campus with 25% of their required biomass during October – December each year.

8.3 Financial Analysis Results

Based upon available land surrounding Dalhousie University's Agricultural Campus, these results identify whether it would be financially viable to produce SRC willow to meet 25% of the CHP system's demand.

8.3.1 Production by the Agricultural Campus – Scenario One

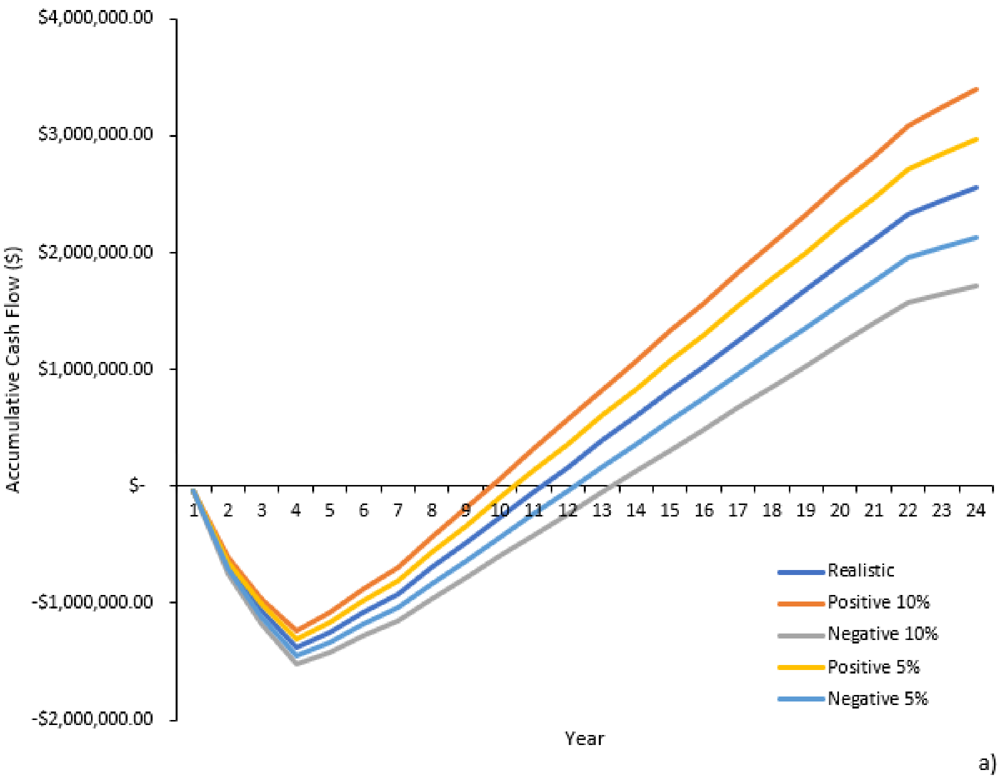
This scenario has been put forward due to the nature of Dalhousie University's Agricultural Campus' current land inventory, agricultural expertise, existing equipment, existing labour pool and existing infrastructure.

Dalhousie University operates several agricultural units including, Dairy, Poultry and Mink and produces feedstock on owned land surrounding the facility totalling 182 ha. Given the pre-existing infrastructure and expertise, this utilizes the financial model making the following operational assumptions:

- Dalhousie University's Agricultural Campus farm staff manages all aspects of operation.
- Dalhousie University purchases planting and harvesting equipment at $300,000 combined for a planter (Semi-automated 2 row step-planter) and a cut and chip harvester. A cut-and-chip harvesting system is the recommended option for Dalhousie University's Agricultural CHP System allowing for a direct harvest to combustion system delivery process and ensures that the moisture content is suitable for combustion (approximately 50%). In addition, harvesting as rods, would require an additional chipping process, increasing production costs.
- Farm Gate Price: $54 – This reflects the current cost of waste wood purchased for the CHP system.
- Land Availability: 182 ha of land of land currently owned by Dalhousie University and 138 leased at a cost of $300/ha.

- Plowing is set at three hours per hectare and disking and tilling at two hours per hectare using a 100-horsepower tractor.
- Planting Density – 15,000 cuttings per hectare as based on literature and European planting guides.
- Labour Rate - $25 per hour and is based on the current Dalhousie University's Agricultural Campus farm employee hourly rate.
- A fuel price of $1.69/l has been used, this reflects the currently price of agricultural diesel found in Colchester County, NS.

Financial analysis is based on production of 320 ha to achieve a total yield of 5,248 tonnes, to supply a biomass feedstock between October (start of harvest) and the end of December, before fields become inaccessible due to a change in weather conditions. Analysis is based on three separate plantings taking place on years two, three and four. Year one is used for land preparation for the first planting occurring on year two, followed by land preparation on years two and three.



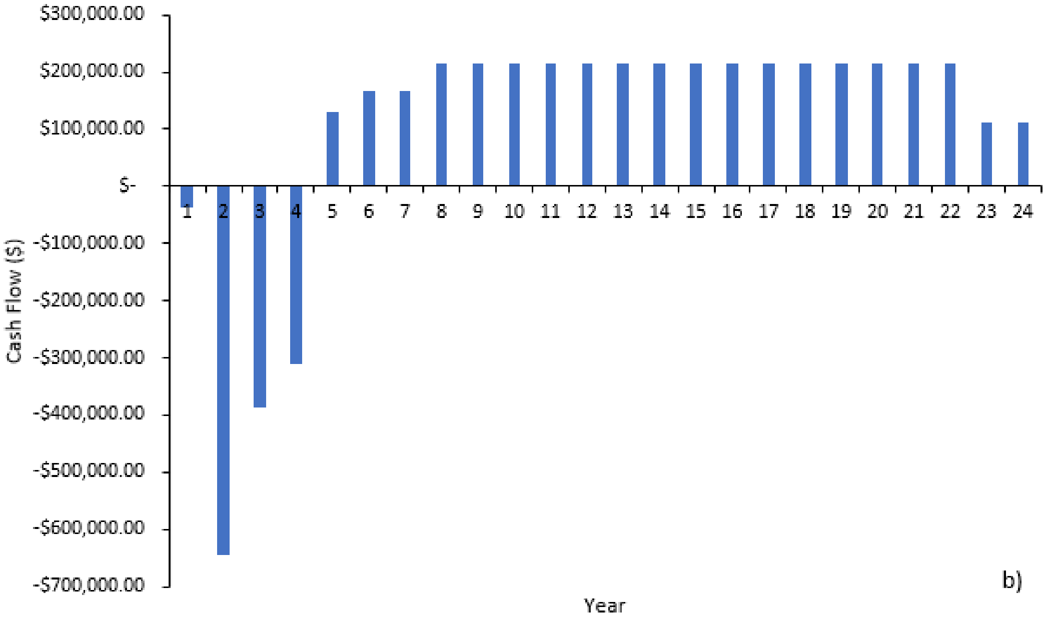


Figure 8.12: a) Accumulative cash flow, and b) Cash flow of SRC willow production system.

Under a realistic assumption to produce 5,248 tonnes of biomass per year, using with staggered field preparation and establishment to allow for continuous year-on-year harvest, year two of the SRC willow production system would incur the highest costs (Figure 8.12b) with the purchase of a planter and a harvesting system, this scenario assumes full purchase at the point of year two and not purchased and paid for over several years. This option was chosen due to reduce interest cost associated with purchasing over time.

From year eight through to year twenty-one, the costs remain static, followed by an increase in years twenty-two and twenty-three due to the removal of the plantations. Based upon the estimated purchase price of local biomass per delivered tonne ($54/tonnes), producing SRC willow is favorable compared to the purchasing of biomass from external sources over the harvest period (October to December), with the total production cost (operating under a realistic case) over twenty-three years is estimated to be $2,945,082, this compares to purchasing waste wood chips from a local lumber mill at $5,207,004 based on the quantity of biomass purchased by Dalhousie University Agricultural Campus between October and December 2020.

The accumulative cash flow indicated that in year eleven under a realistic case Dalhousie University's Agricultural Campus would begin to make a profit (Figure 8.12a), this translates into a saving from buying purchased biomass from the local lumber mill. By year thirteen, assuming a net revenue of $12.15/tonne of biomass (Table 8.9), they would be saving $41.85/tonne over the harvest period (October – December), this however drops in year twenty-three to a saving of $28.92/tonne assuming the price of purchased biomass was maintained at $54/tonne.

Table 8.8: Production cost and revenue based on 18 tonnes/ha/year production.

	Year 4	Year 7	Year 10	Year 13	Year 23
Production Cost per ha	$ -	$ 814.88	$ 639.29	$ 544.75	$ 439.12
Gross Revenue per ha	$ -	$ 472.11	$ 622.08	$ 702.83	$ 819.86
Net Revenue per ha	$ -	-$ 342.77	-$ 17.21	$ 158.08	$ 380.74
Cost per Tonne	$ 351.04	$ 93.21	$ 55.49	$ 41.85	$ 28.92
Sale Price per Tonne	$ 54.00	$ 54.00	$ 54.00	$ 54.00	$ 54.00
Net Revenue per Tonne	-$ 297.04	-$ 39.21	-$ 1.49	$ 12.15	$ 25.08

Assessing the internal rate of return, under a 5% positive case (5% reduction in costs and 5% increase in profit), an IRR of 2% could be achieved in year ten (Table 8.10), the IRR increase under all cases from year thirteen onwards.

Table 8.9: IRR based on 18 tonnes/ha/year production.

	Year 10	Year 13	Year 23
IRR Realistic	-1%	5%	11%
IRR Positive (5%)	2%	7%	12%
IRR Positive (10%)	4%	10%	14%
IRR Negarive (-5%)	-3%	3%	9%
IRR Negative (-10%)	-5%	1%	7%

8.3.1.1 Sensitivity Analysis

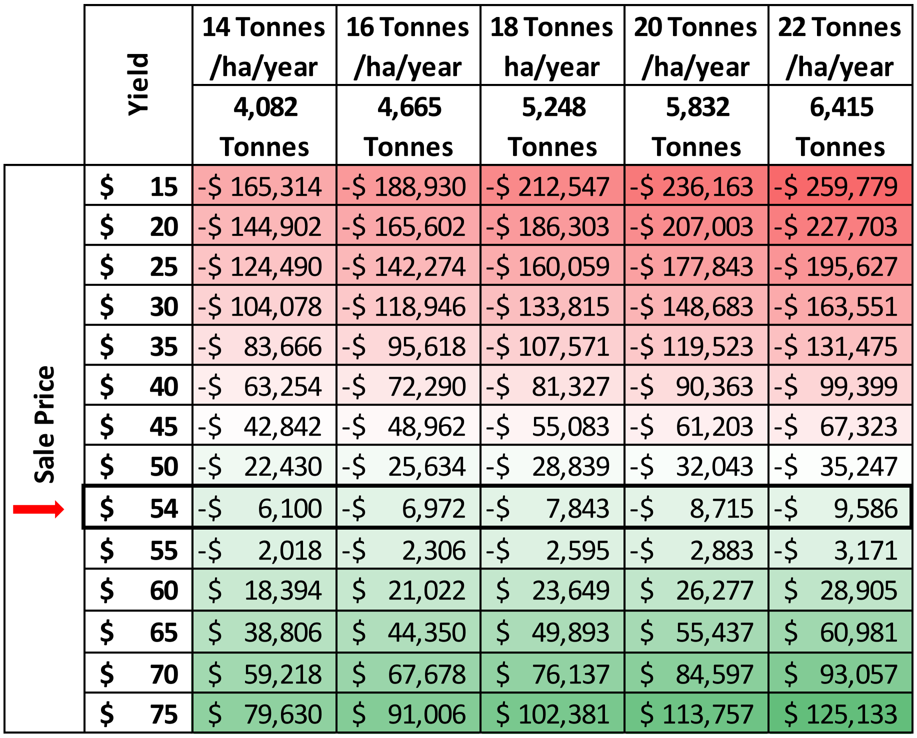
A sensitivity analysis of production cost vs yield on year ten of production (Table 8.11), shows that with increasing yield the total cost of production goes up, this is a function of increased time to harvest the biomass and increased transportation costs from the field to the CHP system. As of year ten the production cost is $55.50 per tonne of SRC willow harvested, with a total of $291,308 for the total harvest of 5,248 tonnes assuming a yield of 18 tonnes/ha/year, increasing the yield to 22 tonnes/ha/year sees the cost increase to $356,044.

Table 8.10: Sensitivity analysis of production costs vs yield for year ten.

	Yield	14 Tonnes /ha/year	16 Tonnes /ha/year	18 Tonnes ha/year	20 Tonnes /ha/year	22 Tonnes /ha/year
		4,082 Tonnes	4,665 Tonnes	5,248 Tonnes	5,832 Tonnes	6,415 Tonnes
Production Cost	**$ -**	$ -	$ -	$ -	$ -	$ -
	$ 5	$ 20,412	$ 23,328	$ 26,244	$ 29,160	$ 32,076
	$ 10	$ 40,824	$ 46,656	$ 52,488	$ 58,320	$ 64,152
	$ 15	$ 61,236	$ 69,984	$ 78,732	$ 87,480	$ 96,228
	$ 20	$ 81,648	$ 93,312	$ 104,976	$ 116,640	$ 128,304
	$ 25	$ 102,060	$ 116,640	$ 131,220	$ 145,800	$ 160,380
	$ 30	$ 122,472	$ 139,968	$ 157,464	$ 174,960	$ 192,456
	$ 35	$ 142,884	$ 163,296	$ 183,708	$ 204,120	$ 224,532
	$ 40	$ 163,296	$ 186,624	$ 209,952	$ 233,280	$ 256,608
	$ 45	$ 183,708	$ 209,952	$ 236,196	$ 262,440	$ 288,684
	$ 50	$ 204,120	$ 233,280	$ 262,440	$ 291,600	$ 320,760
→	**$55.50**	$ 226,573	$ 258,941	$ 291,308	$ 323,676	$ 356,044
	$ 60	$ 244,944	$ 279,936	$ 314,928	$ 349,920	$ 384,912
	$ 65	$ 265,356	$ 303,264	$ 341,172	$ 379,080	$ 416,988
	$ 70	$ 285,768	$ 326,592	$ 367,416	$ 408,240	$ 449,064
	$ 75	$ 306,180	$ 349,920	$ 393,660	$ 437,400	$ 481,140

A sensitivity analysis of revenue generated based upon sale price/tonne of SRC willow and yield based on year ten of production (Table 8.12) shows that at $54/tonne a profit cannot be made on any of the potential yields, 14 to 22 tonnes/ha/year. Sale price would need to increase to between $55 and $60 tonnes. This is in line with the expected projection of profitability being seen in years eleven to twelve. However, an increase in the sale price to at least $60/tonne would see profitability in year ten achieved.

Table 8.11: Sensitivity analysis of sale price vs yield on revenue for year ten.



	Yield	14 Tonnes /ha/year	16 Tonnes /ha/year	18 Tonnes ha/year	20 Tonnes /ha/year	22 Tonnes /ha/year
		4,082 Tonnes	4,665 Tonnes	5,248 Tonnes	5,832 Tonnes	6,415 Tonnes
Sale Price	$ 15	-$ 165,314	-$ 188,930	-$ 212,547	-$ 236,163	-$ 259,779
	$ 20	-$ 144,902	-$ 165,602	-$ 186,303	-$ 207,003	-$ 227,703
	$ 25	-$ 124,490	-$ 142,274	-$ 160,059	-$ 177,843	-$ 195,627
	$ 30	-$ 104,078	-$ 118,946	-$ 133,815	-$ 148,683	-$ 163,551
	$ 35	-$ 83,666	-$ 95,618	-$ 107,571	-$ 119,523	-$ 131,475
	$ 40	-$ 63,254	-$ 72,290	-$ 81,327	-$ 90,363	-$ 99,399
	$ 45	-$ 42,842	-$ 48,962	-$ 55,083	-$ 61,203	-$ 67,323
	$ 50	-$ 22,430	-$ 25,634	-$ 28,839	-$ 32,043	-$ 35,247
→	**$ 54**	-$ 6,100	-$ 6,972	-$ 7,843	-$ 8,715	-$ 9,586
	$ 55	-$ 2,018	-$ 2,306	-$ 2,595	-$ 2,883	-$ 3,171
	$ 60	$ 18,394	$ 21,022	$ 23,649	$ 26,277	$ 28,905
	$ 65	$ 38,806	$ 44,350	$ 49,893	$ 55,437	$ 60,981
	$ 70	$ 59,218	$ 67,678	$ 76,137	$ 84,597	$ 93,057
	$ 75	$ 79,630	$ 91,006	$ 102,381	$ 113,757	$ 125,133

The scenario presented is based upon a discount rate of 5%, using the net present value (NPV) for years ten (Table 8.13), thirteen (Table 8.14) and twenty-three (Table 8.15), a positive NPV can be seen in year ten if there was a 10% decrease in costs and a 10% increase in revenue) and the discount rate was 3 or 4%, all other discount rates and variations in costs and revenue show a negative value.

Table 8.12: Analysis of net present value based on different discount rates for year ten.

10 year					
Discount Rate	**NPV Realistic**	**NPV Positive (5%)**	**NPV Positive (10%)**	**NPV Negative (-5%)**	**NPV Negative (-10%)**
3%	-$ 239,132.31	-$ 80,246.41	$ 78,639.48	-$ 398,018.20	-$ 556,904.09
4%	-$ 289,849.16	-$ 138,106.16	$ 13,636.83	-$ 441,592.15	-$ 593,335.14
5%	-$ 335,431.06	-$ 190,320.11	-$ 45,209.15	-$ 480,542.02	-$ 625,652.98
6%	-$ 376,381.14	-$ 237,436.22	-$ 98,491.30	-$ 515,326.06	-$ 654,270.98
7%	-$ 413,149.70	-$ 279,945.18	-$ 146,740.65	-$ 546,354.22	-$ 679,558.74
8%	-$ 446,140.22	-$ 318,286.82	-$ 190,433.42	-$ 573,993.62	-$ 701,847.03
9%	-$ 475,714.65	-$ 352,855.89	-$ 229,997.14	-$ 598,573.41	-$ 721,432.16
10%	-$ 502,197.98	-$ 384,007.01	-$ 265,816.05	-$ 620,388.94	-$ 738,579.91

Moving to year thirteen, the NPV using different discount rates show that profitability is possible under realistic conditions up to a discount rate of 5% and would also be positive under a 5 % increase in cost and a 5 % decrease in revenue if the discount rate dropped to 2 %.

Table 8.13: Analysis of net present value based on different discount rates for year thirteen.

13 Year					
Discount Rate	**NPV Realistic**	**NPV Positive (5%)**	**NPV Positive (10%)**	**NPV Negative (-5%)**	**NPV Negative (-10%)**
3%	$ 216,518	$ 412,277.16	$ 608,037	$ 20,758.18	-$ 175,001
4%	$ 116,010	$ 300,596.64	$ 485,184	-$ 68,577.63	-$ 253,165
5%	$ 26,500	$ 200,900.17	$ 375,300	-$ 147,900.19	-$ 322,300
6%	-$ 53,253	$ 111,840.76	$ 276,935	-$ 218,347.13	-$ 383,441
7%	-$ 124,340	$ 32,235.94	$ 188,812	-$ 280,916.60	-$ 437,493
8%	-$ 187,720	-$ 38,953.96	$ 109,812	-$ 336,485.73	-$ 485,252
9%	-$ 244,235	-$ 102,644.49	$ 38,947	-$ 385,826.49	-$ 527,417
10%	-$ 294,631	-$ 159,643.11	-$ 24,655	-$ 429,619.27	-$ 564,607

At twenty-three years, the NPV is positive in all cases except 9-10 % under a 5 % increase in cost and a 5 % decrease in profits, and changes slightly to 8 – 10 % where costs increase by 10 % and revenue decreases by 10 %.

Table 8.14: Analysis of NPV based on different discount rates for year twenty-three.

23 Year					
Discount Rate	**NPV Realistic**	**NPV Positive (5%)**	**NPV Positive (10%)**	**NPV Negative (-5%)**	**NPV Negative (-10%)**
3%	$ 1,365,726.64	$ 1,668,663.35	$ 1,971,600.07	$ 1,062,789.93	$ 759,853.21
4%	$ 1,083,422.93	$ 1,357,706.18	$ 1,631,989.42	$ 809,139.69	$ 534,856.45
5%	$ 842,750.76	$ 1,092,405.14	$ 1,342,059.52	$ 593,096.38	$ 343,442.00
6%	$ 637,002.81	$ 865,388.83	$ 1,093,774.85	$ 408,616.79	$ 180,230.78
7%	$ 460,650.62	$ 670,585.57	$ 880,520.52	$ 250,715.66	$ 40,780.71
8%	$ 309,122.17	$ 502,977.44	$ 696,832.71	$ 115,266.89	-$ 78,588.38
9%	$ 178,624.01	$ 358,403.61	$ 538,183.21	-$ 1,155.58	-$ 180,935.18
10%	$ 65,998.49	$ 233,402.65	$ 400,806.81	-$ 101,405.67	-$ 268,809.83

Based on the results, it indicated the SRC willow production for 25 % of Dalhousie University's Agricultural Campus would make financial sense to produce SRC willow, with a projection of year eleven being the point of break-even and profits from years twelve to twenty-three.

8.3.2 Production by the Agricultural Campus – Scenario Two

This scenario is based upon Dalhousie University's Agricultural Land leasing land and not using any available land. Currently existing land is used for crop production for animal feed, bedding, grazing and for research purposes. A value of $300/ha/year is used for the field rental cost. This reflects current average field rental prices around the Colchester County, NS area. A fuel price of $1.69/L has been used, this reflects the currently price of agricultural diesel found in Colchester County, NS.

Potential yield/ha/year has been adjusted to 14 tonnes/ha/year, this is based on recent research conducted by Lafleur *et al*. (2017) that looked at the performance of five SRC willow cultivars across a large climate gradient. Two SRC willow plantation sites used by Lafleur, Lalonde and Labrecque (2017) are on a similar latitude to Dalhousie University's Agricultural Campus but 770-800 km West, one is based in Beloeil, QC (lat: 45.60847, long -73.19950), and the other in St Roch, QC (lat: 45.8856, long: -73.59495), similarities also include heating degree days (2,000 – 2,300 HDD) and annual rainfall (1,000mm/year, Beloeil and 1,200mm/year Truro, NS). Lafleur, Lalonde and Labrecque (2017) assessed the SRC willow Cultivars SV1, S5027, SX61, SX64 and SX67, finding higher yields in Beloeil (average of 12 ODT/ha/year) than St Roch (average of 6 ODT/ha/year) the variation was attributed to field conditions, with St Roch being on compacted soil, but similar soil type and nutrient values [241].

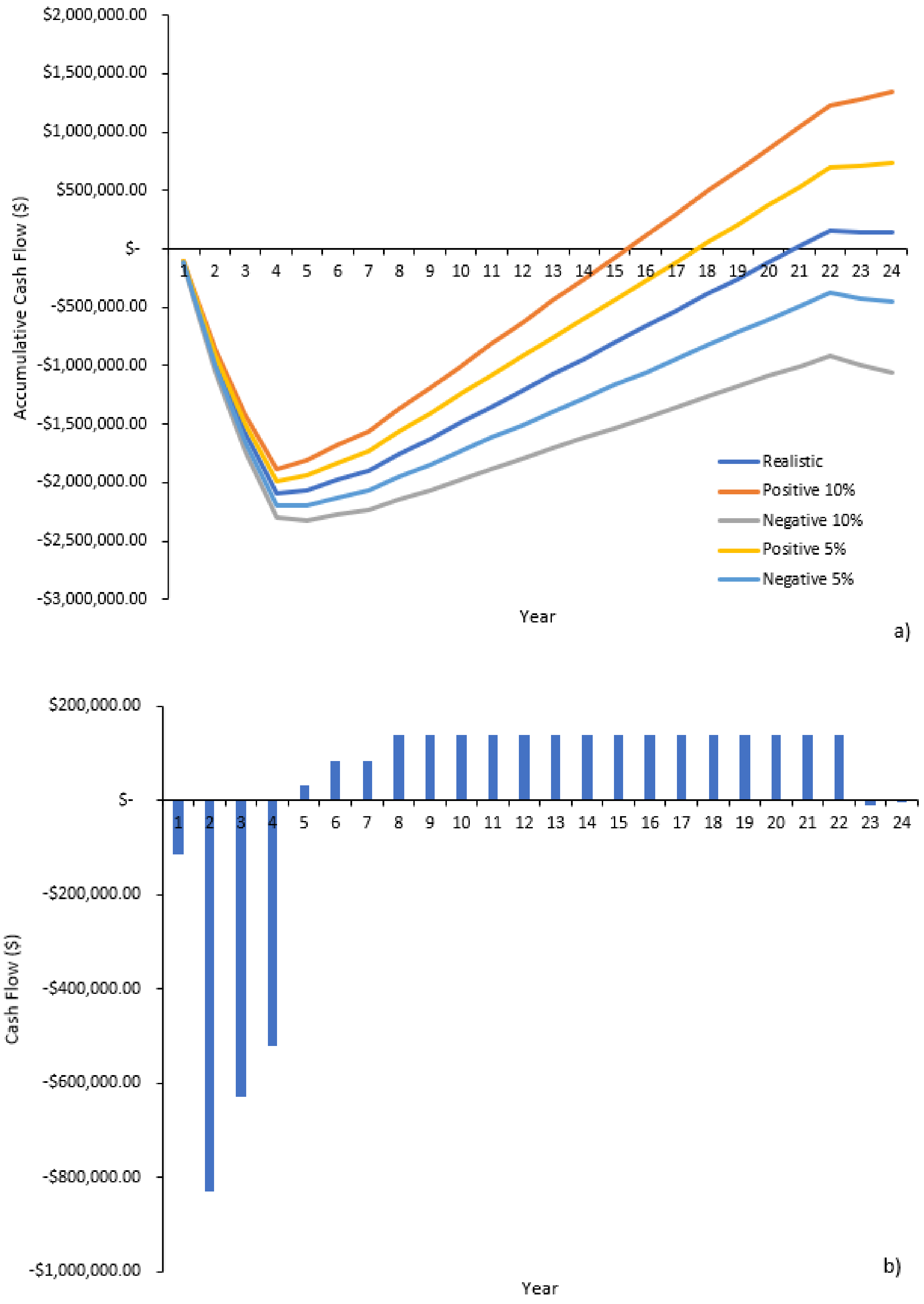


Figure 8.13: a) Accumulative Cash Flow, and b) Cash Flow of SRC willow Production System for Scenario two

With an increase in land rental costs ($300/ha) and a reduced yield (14 tonnes/ha/year), reflecting SRC production grown at a similar latitude, under a realistic case scenario, profitability will not be achieved by year twenty-one of the project (Figure 8.13a). Even under a 5% positive case, (assuming a 5% increase in revenue and a 5% reduction in costs), profitability would not be achieved until year seventeen.

Under a realistic assumption to produce 5,248 tonnes of biomass per year, using with staggered field preparation and establishment to allow for continuous year-on-year harvest, year two of the SRC willow production system would again incur the highest costs (Figure 8.13b) with the purchase of a planter and a harvesting system, this scenario assumes full purchase at the point of year two and not purchased and paid for over several years.

From year eight through to year twenty-one, the costs remain static, followed by an increase in years twenty-two and twenty-three due to the removal of the plantations. Based upon the estimated purchase price of local biomass per delivered tonne ($54/tonnes), producing SRC willow is not favorable compared to the purchasing of biomass from external sources over the harvest period (October to December), where the total production cost (operating under a realistic case) over twenty-three years is estimated to be $5,916,139, this compares to purchasing waste wood chips from a local lumber mill at $5,207,004 based on the quantity of biomass purchased by Dalhousie University Agricultural Campus between October and December 2020. Profits are not seen until year twenty-three where a net revenue (Table 8.16) could be achieved of $1.27, assuming costs and purchase price of biomass stays the same ($54/tonne).

Table 8.15: Production cost and revenue based on 14 tonnes/ha/year production and $300/ha land lease cost

	Year 4	Year 7	Year 10	Year 13	Year 23
Production Cost per ha	$ -	$ 1,382.99	$ 1,148.28	$ 1,021.91	$ 882.11
Gross Revenue per ha	$ -	$ 520.20	$ 685.44	$ 774.42	$ 903.37
Net Revenue per ha	$ -	-$ 862.79	-$ 462.84	-$ 247.49	$ 21.25
Cost per Tonne	$ 499.96	$ 143.56	$ 90.46	$ 71.26	$ 52.73
Sale Price per Tonne	$ 54.00	$ 54.00	$ 54.00	$ 54.00	$ 54.00
Net Revenue per Tonne	-$ 445.96	-$ 89.56	-$ 36.46	-$ 17.26	$ 1.27

Assessing the internal rate of return, only year twenty-three shows a positive IRR under realistic, positive 5 % and positive 10 % Scenarios, making the project unviable (Table 8.17).

Table 8.16: IRR based on 14 tonnes/ha/year production

	Year 10	Year 13	Year 23
IRR Realistic	-16%	-7%	1%
IRR Positive (5%)	-12%	-5%	3%
IRR Positive (10%)	-9%	-2%	5%
IRR Negarive (-5%)	-19%	-10%	-2%
IRR Negative (-10%)	-23%	-14%	-5%

8.3.2.1 Sensitivity Analysis – Scenario Two

Based on the sales price and considering year ten production costs and sale price (currently set at $54/Tonne), at 14 tonnes/ha, there is a loss of $250,694 in revenue (Table 7.18), with a decrease in revenue shown with an increase in production due to the increased time associated with harvesting. A positive revenue scenario would not be seen until the sale price reaches $100/tonne of chipped material. In any instance here, it is not feasible that the cost per tonnes of bought wood waste, currently at $54/tonne would increase to a level that would make SRC willow production favourable.

Table 8.17: Sensitivity analysis of sale price vs yield on revenue for year ten based on 14 tonnes/ha/year

	Yield	10 Tonnes /ha/year	12 Tonnes /ha/year	14 Tonnes ha/year	16 Tonnes ha/year	18 Tonnes /ha/year	20 Tonnes /ha/year
		4,110 Tonnes	4,932 Tonnes	5,754 Tonnes	6,576 Tonnes	7,398 Tonnes	8,220 Tonnes
Sale Price	$ 45	-$ 220,167	-$ 264,201	-$ 308,234	-$ 352,268	-$ 396,301	-$ 440,335
	$ 50	-$ 199,617	-$ 239,541	-$ 279,464	-$ 319,388	-$ 359,311	-$ 399,235
→	$ 54	-$ 179,067	-$ 214,881	-$ 250,694	-$ 286,508	-$ 322,321	-$ 358,135
	$ 60	-$ 158,517	-$ 190,221	-$ 221,924	-$ 253,628	-$ 285,331	-$ 317,035
	$ 65	-$ 137,967	-$ 165,561	-$ 193,154	-$ 220,748	-$ 248,341	-$ 275,935
	$ 70	-$ 117,417	-$ 140,901	-$ 164,384	-$ 187,868	-$ 211,351	-$ 234,835
	$ 75	-$ 96,867	-$ 116,241	-$ 135,614	-$ 154,988	-$ 174,361	-$ 193,735
	$ 80	-$ 76,317	-$ 91,581	-$ 106,844	-$ 122,108	-$ 137,371	-$ 152,635
	$ 85	-$ 55,767	-$ 66,921	-$ 78,074	-$ 89,228	-$ 100,381	-$ 111,535
	$ 90	-$ 35,217	-$ 42,261	-$ 49,304	-$ 56,348	-$ 63,391	-$ 70,435
	$ 95	-$ 14,667	-$ 17,601	-$ 20,534	-$ 23,468	-$ 26,401	-$ 29,335
	$ 100	$ 5,883	$ 7,059	$ 8,236	$ 9,412	$ 10,589	$ 11,765
	$ 105	$ 26,433	$ 31,719	$ 37,006	$ 42,292	$ 47,579	$ 52,865
	$ 110	$ 46,983	$ 56,379	$ 65,776	$ 75,172	$ 84,569	$ 93,965
	$ 115	$ 67,533	$ 81,039	$ 94,546	$ 108,052	$ 121,559	$ 135,065
	$ 120	$ 88,083	$ 105,699	$ 123,316	$ 140,932	$ 158,549	$ 176,165
	$ 125	$ 108,633	$ 130,359	$ 152,086	$ 173,812	$ 195,539	$ 217,265
	$ 130	$ 129,183	$ 155,019	$ 180,856	$ 206,692	$ 232,529	$ 258,365
	$ 135	$ 149,733	$ 179,679	$ 209,626	$ 239,572	$ 269,519	$ 299,465
	$ 140	$ 170,283	$ 204,339	$ 238,396	$ 272,452	$ 306,509	$ 340,565

Variations in the discount rate show that for years ten (Table 8.19) and thirteen (Table 8.20) and under any NPV scenario, negative NPV is demonstrated. Only in year twenty-three (Table 8.21), with a discount rate of 3 % and 4 % under a 10 % positive NPV (10% reduction in costs and 10 % increase in sale price) or the 5 % positive NPV (5 % reduction in costs and 5 % increase in sale price) would a positive value be achieved. Under any of these scenarios, this would indicate that it would not be financially viable to produce SRC willow using lease land at $300/ha and where expected annual growth yields are fourteen tonnes/ha/year.

Table 8.18: Analysis of net present value based on different discount rates for year ten based on 14 tonnes/ha/year.

10 year					
Discount Rate	**NPV Realistic**	**NPV Positive (5%)**	**NPV Positive (10%)**	**NPV Negative (-5%)**	**NPV Negative (-10%)**
3%	-$ 1,395,061.35	-$ 1,163,413.99	-$ 931,766.62	-$ 1,626,708.72	-$ 1,858,356.08
4%	-$ 1,404,149.80	-$ 1,182,712.56	-$ 961,275.31	-$ 1,625,587.05	-$ 1,847,024.30
5%	-$ 1,410,777.34	-$ 1,198,827.47	-$ 986,877.59	-$ 1,622,727.22	-$ 1,834,677.10
6%	-$ 1,415,225.40	-$ 1,212,103.23	-$ 1,008,981.05	-$ 1,618,347.58	-$ 1,821,469.76
7%	-$ 1,417,744.16	-$ 1,222,846.79	-$ 1,027,949.42	-$ 1,612,641.53	-$ 1,807,538.90
8%	-$ 1,418,556.16	-$ 1,231,331.87	-$ 1,044,107.57	-$ 1,605,780.45	-$ 1,793,004.74
9%	-$ 1,417,859.54	-$ 1,237,802.77	-$ 1,057,746.00	-$ 1,597,916.31	-$ 1,777,973.09
10%	-$ 1,415,830.82	-$ 1,242,477.73	-$ 1,069,124.65	-$ 1,589,183.90	-$ 1,762,536.99

Table 8.19: Analysis of net present value based on different discount rates for year thirteen based on 14 tonnes/ha/year.

13 Year					
Discount Rate	**NPV Realistic**	**NPV Positive (5%)**	**NPV Positive (10%)**	**NPV Negative (-5%)**	**NPV Negative (-10%)**
3%	-$ 1,106,381	-$ 823,435.50	-$ 540,490	-$ 1,389,326.56	-$ 1,672,272
4%	-$ 1,147,016	-$ 879,885.80	-$ 612,756	-$ 1,414,145.23	-$ 1,681,275
5%	-$ 1,181,474	-$ 928,777.20	-$ 676,080	-$ 1,434,170.83	-$ 1,686,868
6%	-$ 1,210,506	-$ 971,005.76	-$ 731,505	-$ 1,450,006.82	-$ 1,689,507
7%	-$ 1,234,768	-$ 1,007,355.97	-$ 779,944	-$ 1,462,180.02	-$ 1,689,592
8%	-$ 1,254,833	-$ 1,038,515.62	-$ 822,198	-$ 1,471,150.94	-$ 1,687,469
9%	-$ 1,271,206	-$ 1,065,088.54	-$ 858,972	-$ 1,477,322.57	-$ 1,683,440
10%	-$ 1,284,327	-$ 1,087,605.52	-$ 890,884	-$ 1,481,047.94	-$ 1,677,769

Table 8.20: Analysis of net present value based on different discount rates for year twenty-three based on 14 tonnes/ha/year.

23 Year					
Discount Rate	**NPV Realistic**	**NPV Positive (5%)**	**NPV Positive (10%)**	**NPV Negative (-5%)**	**NPV Negative (-10%)**
3%	-$ 459,314.02	-$ 27,315.51	$ 404,682.99	-$ 891,312.52	-$ 1,323,311.02
4%	-$ 599,316.97	-$ 207,443.05	$ 184,430.88	-$ 991,190.89	-$ 1,383,064.82
5%	-$ 716,931.45	-$ 359,573.41	-$ 2,215.37	-$ 1,074,289.49	-$ 1,431,647.53
6%	-$ 815,701.93	-$ 488,175.14	-$ 160,648.35	-$ 1,143,228.71	-$ 1,470,755.50
7%	-$ 898,572.23	-$ 596,947.96	-$ 295,323.70	-$ 1,200,196.49	-$ 1,501,820.75
8%	-$ 967,994.25	-$ 688,964.41	-$ 409,934.56	-$ 1,247,024.09	-$ 1,526,053.94
9%	-$ 1,026,015.85	-$ 766,783.71	-$ 507,551.58	-$ 1,285,247.98	-$ 1,544,480.12
10%	-$ 1,074,352.06	-$ 832,543.84	-$ 590,735.63	-$ 1,316,160.27	-$ 1,557,968.48

Based on the results, it indicates that SRC willow production for 25% of Dalhousie University's Agricultural Campus paying $300/ha land costs and a yield of 14 tonnes/ha/year would not make financial sense to produce SRC willow.

8.4 SRC willow Production in Nova Scotia

The case study of Dalhousie University's Agricultural Campus demonstrates that there is viability under certain conditions, specifically low land lease costs, however this cannot be extended to Nova Scotia as a whole, due to the Agricultural Campus being in a unique position of having an existing an existing CHP system, having a proportion of available land that could be utilized and an objective of cost reduction, not necessarily profitability. The driver for individual producers, agri-businesses or other institutions interested in growing SRC willow, or any other long-term agricultural energy crop relies predominantly on the profitability of the enterprise. The profitability of production will be influenced by the cost of establishment and in having a suitable long-term market for the product over the lifespan of the plantation, which will be at a minimum of twenty-three years. Dalhousie University's Agricultural Campus could produce their own SRC willow, based on the first scenario, assuming an average yield of 18 tonnes/ha/year, current fuel prices ($1.69/L) and assuming they use a large proportion, if not all of their existing 182 ha of land at no cost and $300 /ha for the remaining 138 ha.

Dalhousie University is also in the privileged position that they could develop a research program focusing on the different aspects of SRC willow production, from evaluation of varieties, evaluation of planting and harvesting equipment, a full life-cycle analysis of SRC willow production in Eastern Canada incorporating carbon sequestration assessment. Given this position, it could be feasible, provided research funding was available for infrastructure purchases, that they purchase planting and harvesting equipment. This approach has precedence within Dalhousie

University, with there already being pre-existing biomass processing equipment (briquetting and pelletizing equipment) as part of a research program.

Dalhousie University are also in the position of having COMFIT agreement in place. By having a COMFIT agreement, Dalhousie University are guaranteed an income for 25 years for each MWh they produce; this was one of the key deciding factors in replacing the existing biomass system with a CHP system. The generated revenue from COMFIT will improve the return-on-investment and offset the running costs of the system over the long-term. While the cost of SRC willow planters and harvesters are cost prohibitive for small-scale producers, Dalhousie University could be in the position of investing in the equipment, incorporating the cost into the total infrastructure cost of the CHP system.

While it is feasible that Dalhousie University could purchase a planter and offset the cost, the issue of the limited use of a planter once establishment has been used, still exists. While the University in theory could expand upon production or ‘lease-out’ the equipment to other universities or institutions for establishing plantations, there are a limited number of institutions within Eastern Canada that would be likely candidates for utilizing a planter (and subsequently a harvester). Though it may be suggested that the University lease out any purchased equipment for commercial use to local farmers or landowners to produce their own SRC willow, for the purposes of generating addition revenue and aiding in stimulating SRC willow production through making equipment available, this would not be a viable option due to the university (and any other educational institution) being prohibited from competing with private enterprises and industry.

Although with the availability of the COMFIT agreement, having the option of pursuing research funding as a means to produce SRC willow and Dalhousie University having project goals including ‘promoting and supporting existing and new sustainable biomass supply’ SRC willow is demonstrably more expensive up to years thirteen in the first scenario than utilizing biomass from the near-by lumber-mill; there are other non-economic benefits to production. The production and utilization of SRC willow would be a positive message to the community in further showing the University’s green credentials, demonstrating their commitment to sustainability, and demonstrating to the agricultural community and bioenergy that SRC willow is a viable option within Nova Scotia and Eastern Canada.

However, while production is possible, it could also be considered impractical as this would result in increased costs for other farming practices including crop production for feed and bedding for their dairy and sheep herds, and it removes current grazing land which would mean additional land would need to be found at cost, likely $300 /ha. There is also an issue of reliability of delivery, currently the waste biomass come from the local lumbermill located approximately 6 km from the Agricultural Campus, delivering three tractor-trailer loads per day, with approximately 30 – 40 tonnes per load.

Under the second scenario, assuming fully leasing land at $300/ha, the current average cost of agricultural land in Colchester County NS, and basing production of the production data from Lafleur, Lalonde and Labrecque (2017), it would not make economical sense unless the price of waste woodchips increased significantly, towards $100/tonne.

As highlighted, there are no commercial SRC willow plantations in Eastern Canada, with Nova Scotia, PEI, New Brunswick and Quebec having small-scale trials evaluating varieties, production techniques and yields or as a means for habitat restoration or riverbank stabilization. The University, as such, could be viewed not only as a demonstration for commercial SRC willow production but as a potential ‘Anchor’ customer for agricultural biomass, should the university decide to utilize more than their current limit of 5,000 tonnes of ‘alternative/research’ biomass.

When considering Dalhousie university as solely a producer without the means to financially support SRC willow production through research, COMFIT or as a large-scale institution, but taking Dalhousie university as an enterprise looking to produce SRC willow for sale, there is currently no developed market for selling SRC willow, nor would it be financially viable based upon the cost of purchasing a planter or harvester.

The production of SRC willow (or poplar) within Nova Scotia and Easter Canada in general, suffers from the problem of a lack of drive within the sector to produce the SRC willow because there is currently no market, a lack of incentives for production and a clear lack of information available to farmers and landowners about the costs and implications of SRC willow production, similar to reasons found by some European countries [71, 73, 102]. Therefore, the issue becomes that without producers there is no markets, yet without the market there will be no producers. With regards to markets, as indicated, there are limited large-scale biomass systems within Nova Scotia and those systems will be looking to reduce overhead costs by sourcing inexpensive biomass feedstocks which is currently forestry based or by-products from lumber mills.

One option for Nova Scotia that would have the potential of developing a supply of SRC willow and having the ability to help stimulate the market would be through large-scale production of SRC willow by one or two commercial companies, similar to the European/Swedish example of one commercial company controlling all aspects of the supply chain [315].

As Sweden has demonstrated, having a small number of large commercial producers of SRC willow allows SRC willow to become economically viable due to economies-of-scale, similar to that of the forestry industry within Nova Scotia, where there are a small number of large companies involved in forestry biomass, and a strong support for small woodlot owners through the Federation of Nova Scotia Woodland Owners who provide education, advocacy and forest management [316]. The issue, as stated is, 'would a company be willing to invest in Nova Scotia for the purposes of producing SRC willow?' The question in part can be answered though the 2011-2015 COMFIT program, and the application for a biomass power Station in Hantsport (Minas Basin). The feedstock proposed for the CHP system was miscanthus, produced on a large-scale, with production and management being controlled by one company.

In 2012, an Ontario based company [317], aimed to promote miscanthus to the agricultural community, offering a 20 year lease-term to farmers for their land at a base rate of $86 per hectare for the first three years with the base rate Consumer Price Index adjusted for years four to twenty. In addition to the base rate, the company offered various premiums depending upon distance from the field to the prospective site of the CHP systems and a premium based upon land quality/characteristics. Additionally, the company sought to employ local farmers as contractors for various aspects of the production and processing, providing further benefit to the local economy [317].

The enterprise did not take off due to a number of reasons, however there is no indication of which was the catalyst; 1) the failure of the CHP to achieve COMFIT status, 2) the investors opting for a different renewable technology (wind turbines) to invest in; 3) the lack of uptake from farmers willing to lease land for an unproven crop, and, 4) the risk to landowners in committing land long-term to an unproven, within Eastern Canada, crop. Trials by Natural Resource Canada indicated relatively poor performance of miscanthus at the establishment phase, which may have influenced farmers in their decisions on whether to take lease land for miscanthus production.

Focusing on grass-based biomass (switchgrass, timothy hay, and *Arundo donax* [318] [319], research has indicated that they are viable within Nova Scotia and currently grown in some instances. The benefit of these crops are the general low production and harvesting costs due to using common agricultural harvesting equipment, however, according to research by Bailey [210] in a 2012 publication note, farmers had indicated that they must get at least $100 /tonne or better than the market value of hay for feed. To-date there has been no established market for switchgrass within Eastern Canada despite improvements and developments in grass-based biomass systems, nor is there any current indication of a market price for the crop.

Evidence, previously highlighted, indicates that a primary factor that inhibits the cost of establishment is the cost for planting and harvesting systems; it is currently not feasible for an individual landowner/farmer to purchase the equipment and currently there is no scope for leasing equipment. In addition to the challenged faced by the economics and a lack of developed market, on average farmland holding within Nova Scotia is currently 105 ha, which is not a feasible production area for large-scale production on an individual basis, as shown here, with Dalhousie University's Agricultural Campus, their total land capacity of 182 ha would only produce approximately 10,500 tonnes assuming a yield of 18 tonnes/ha/year.

Within the EU there is a small market for SRC willow, predominantly in countries in Northern Europe where they are the main producers and consumers [315], however, over the past several years there have been various financial incentives either directly related to biomass production and utilization or indirectly through various farm schemes focused around set-aside, land management or environmental concerns, which has in the past made the production of SRC willow and other energy crops more economically viable.

Within Nova Scotia and across Canada, there is no equivalent to the European Common Agricultural Policy and farm subsidies, with the EU providing €278 EUR billion in direct subsidies out of a total EU Agricultural Budget of €363 billion [259, 260] or the American farm subsidy program where on average $20 billion is provided in subsidies to farm owners and farmland owners [322].

Within Canada, farmers are not provided long-term year-on-year subsidies, however there are variable funding programs and government support aimed at developing to agriculture and agri-food for biofuel production including a $1.5 billion program aimed at developing the biofuel industry which includes support for establishing biomass supply chains [196], but no direct year-on-year subsidy programs focused around production or land management.

Instead, for a number of agricultural commodities, Canada operates a supply management system [323], to ensure consistency in supply and an acceptable retail price for the selected farm products. Given the current and historic systems supporting Canadian agriculture, it is unlikely that the Canadian federal or provincial governments would be likely to adopt farm subsidy payments or subsidies to produce energy crops including SRC willow, nor would public support be likely.

Given the thriving agricultural sector in Nova Scotia, it is unlikely that programs and funding will be made available for the production of energy crops for direct combustion purposes when there is a large focus on biofuels as evident by the recent federally funded Clean Fuels Fund [196].

If a scheme were to be developed it is more likely to come from a dedicated feed-in-tariff program like the previous Nova Scotia COMFIT program or the NS Solar Program for community groups and homeowners [324] for biomass utilization in direct-heating schemes, electricity generation or CHP systems, similar to the now closed UK Renewable Heat Incentive Program [129] which focused on non-domestic financial credits for heat generation over a 20 year period. While these programs did not promote the production of agricultural biomass, they did increase the uptake of heat systems, expanding the market for biomass [325].

While this may be a potential option in the future, any policy would have to stipulate the use of agricultural biomass for production. This option has precedence, with the UK having developed a biomass energy generating sector, both domestically and large-scale, which required the use of UK grown agricultural biomass, wastes, residues and forestry biomass for energy generation where available UK biomass was available [59]. The requirement for agricultural biomass use in any future biomass bases feed-in-tariff program within Nova Scotia could be put forward and enforced or incentivised as with the case within the UK.

Another option the Nova Scotia Government could explore to aid in the development of SRC willow, is to offer funding for the purchase of planting and harvesting equipment, similar to that of the UK Government's 2005 – 2008 Bioenergy Infrastructure Scheme. Having the Nova Scotia Government providing funding for such equipment could potentially be more viable than the UK's attempt, where funding was removed for harvesting equipment. However, currently within Nova Scotia, the widespread production of SRC willow is unlikely due to the high cost associated with establishment as shown through analysis here, the lack of incentives towards production for agricultural energy crops for combustion and the economic attractiveness of other renewable energy technologies, which, in Nova Scotia, includes new proposed projects of wind and solar technologies totalling 350 MW [326] in 2022.

CHAPTER 9 CONCLUSION

SRC willow has had limited success as a bioenergy crop, specifically in northern European countries, which can be used as a model for Nova Scotia. Production of SRC willow has been promoted in Europe through changes in policy relating to the provision of establishment subsidies, market development programs and grower education/knowledge. Production has further been promoted due to the significant push towards biofuel production, which utilizes grasses, corn/maize, sugar beets, soybeans and oilseed rape; crops that utilize commonly used farming equipment, require common and well-known agricultural practices and have clear market opportunities.

In Canada, and in particular Eastern Canada and Nova Scotia, SRC willow has not been fully evaluated, with limited trials focused on identifying appropriate cultivars, and it is not currently utilized as an energy crop for combustion or for any other bioeconomy related product. Moving the industry forward in Nova Scotia, even in a limited capacity, there is a clear need for land capacity to be evaluated and to assess the economic viability of production.

This research demonstrated that there is sufficient land available for SRC willow production, however certain areas of Nova Scotia are more viable than others in terms of production capacities on inactive land, especially Cumberland, Colchester and Pictou Counties. Cumberland County is the most promising for SRC willow due to close field to field proximity and volume of available marginal or inactive land and the eastern and southern regions having the least available capacity. With regards to production, there is a lack of knowledge within the province surrounding the crop but there is no real barrier in terms of the planting and harvesting processes; however, due to the lack of production in Canada and the US there is a barrier with regards to available technology for planting and harvesting; a potentially cost prohibitive investment for the individual grower. To demonstrate the viability of using SRC willow as an energy crop for combustion, this research conducted a case study of Dalhousie University's Agricultural Campus, developing an economic model to determine the economic viability of SRC willow production.

This research determined that Dalhousie University's Agricultural Campus could produce and use SRC willow for their own use, under yields of 14 tonnes/ha/year with a sale price of $55-60/tonne for ten years of production, however with high land rental costs profitability cannot be achieved. It is worth noting that the outcome of Dalhousie University's Agricultural Campus being able to grow and utilize SRC willow for use in their CHP system, assuming there are no significant land costs associated with production, does not necessarily make it applicable to other biomass/CHP systems or to individual producers or agri-businesses.

In Dalhousie University's Agricultural Campus' case, the goal was a reduction in operating costs, producing a suitable biomass at a lower cost than they are currently purchasing woodchips. For producers looking to grow and sell SRC willow, the sale price per tonne must be equal to or lower than existing forestry biomass products, including wood chips, while still making a profit. This is a difficult proposition given the very well-established forestry industry in Nova Scotia and the availability of waste woodchips from lumber mills. Achieving SRC willow production, under current conditions, has to be through either through a guaranteed market for, or user of, the product, or there needs to be production incentives like those previously offered in Europe to help offset expensive capital costs. A decision to develop production incentives is largely political, but currently unlikely in Nova Scotia or across Canada when there is not a significant push for biofuel production

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9.1 Contribution

Limited evaluation of the viability of SRC willow has been conducted in Canada using a method to assess multiple plantations on a field-by-field basis. The novelty of this research is a comprehensive evaluation of the potential of SRC willow in Nova Scotia through identifying the land availability and suitability, estimating potential yields, applying it to prospective biomass energy generating systems, and identifying capture zones around the prospective biomass facilities. Particularly this research applied a spatial analysis and economic model to a specific case study, Dalhousie University's, Agricultural Campus, where a combined heat and power system (CHP) has been installed.

This research evaluated to what range extent SRC willow could be grown from the facility, what the associated costs would be to produce and utilize SRC willow compared to their current biomass supply and to determine at what point it would or would not make economic sense to do so. This research is of importance to Nova Scotia and the Canadian biomass industry in general as it provides an indication of the potential that Nova Scotia has for SRC willow production.

9.2 Future Direction and Research

Further work can consider applying the spatial and economic analysis model developed in this research to other agricultural biomass systems. For example, switchgrass, and other grasses are currently grown in Nova Scotia, they are a known agricultural crop, with some farmers being familiar with production methods and the equipment for planting and harvesting are already here [319].

This research found that given the limited markets, high costs of establishment and without incentives and policy support, production of SRC willow for energy generation was not economical. Future research needs to put on an integrated utilization of SRC to collaboratively produce biochemicals, biomaterials and bioenergy. This is a good practice for carbon sequestration and storage in both the crop and the soil, and for production of an array of products from biomass instead of from petroleum. Incorporating carbon sequestration and offsetting has significant potential as the federal government are working on developing a carbon offset program, with several protocols including improved forest management, livestock feed management and enhanced soil organic carbon [218]. The purpose will provide credits for set quantities of CO_2 sequestration; this will likely be achieved through the building of soil carbon on agricultural land.

There is continuous scope to develop tools and methods for assessing agricultural biomass production. These tools should be accessible and usable to farmers and be able to help inform policy makers in further developing a bioeconomy.

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