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# Life Cycle Assessment of Carbon Dioxide Emissions from Shelterbelt Seedling Production and Transportation in Saskatchewan, Canada

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**Abstract:** Shelterbelts on Saskatchewan (SK) farms are rows of tree and shrub species established around farmyards and livestock enclosures and within crop fields to serve various roles, including protection against wind and water damage to crops and farm infrastructure, soil erosion and moisture loss. Shelterbelts also can contribute to environmental benefits, most important of which is mitigation of greenhouse gas (GHG) emissions, which has been identified as an important climate change mitigation strategy. In the overall strategy of mitigation of GHGs, there is a need for quantifying emissions of these gases in various mitigation operations, including plating of shelterbelts on farms. In order for a farm to plant a shelterbelt, a seedling has to be produced. This information is not currently available and therefore, was selected as the focus of the study. This research developed a life-cycle assessment of production and transportation of shelterbelt seedlings. It provides details on the processes and emissions of the production and transportation stages in the generation of tree seedlings used to establish a one kilometer long farm shelterbelt. The production and transportation stages for 1,000 shrub shelterbelt seedlings was estimated to generate 2,200 kg of carbon dioxide emissions regardless of species. During these stages of the shelterbelt life-cycle, the primary sources of GHG emissions were energy use for heating and for lighting during seedling growth while transportation of seedlings from the point of production to point of use represented a significantly smaller proportion of overall emissions.

**Keywords:** Carbon Dioxide Emissions, Life Cycle Assessment, Shelterbelt, Seedling Production, Seedlings Transportation

## 1. Introduction

### *1.1. Background*

Shelterbelts are planted rows of tree and shrub species in agricultural landscapes including tree rows established within crop fields, surrounding farmyards and infrastructure, alongside livestock enclosures for protection, and as riparian buffers near bodies of water [17, 24]. The establishment of shelterbelts represented an important agricultural management practice in the beginning of the 20$^{th}$ century in the Canadian prairies, primarily to protect against soil erosion in periods of drought [7].

With increasing concerns about climate change and greenhouse gas (GHG) emission reductions, the role of shelterbelts in climate mitigation has started to be recognized [19, 22]. The carbon (C) sequestration potential of six shelterbelt species: white spruce (*Picea glauca*), green ash (*Fraxinus pennsylvanica*), hybrid poplar (*Populus spp.*), Manitoba maple (*Acer negundo*), Scots pine (*Pinus *sylvestris*), and caragana (*Caragana arborescens*)[1] has been reported by [7]. Although studies on carbon sequestration potential of these six species have been reported by [4, 5, 6, 8, 31], they have not been based on a total lifetime carbon sequestration. Some recent studies [15] have also estimated carbon stocks in shelterbelts, while others have shown their importance for climate mitigation [22, 9]. In none of these studies GHG emissions from the production of shelterbelt seedlings were included. None of these studies have used LCA for estimating the total carbon sequestration potential of shelterbelts. Further review of the existing studies found no study on this topic and therefore, this area appears to be an ignored area of research. This study is the first reported application of LCA of shelterbelt seedling or even any other type of analysis reporting GHG emissions from shelterbelt seedling production.

This study addresses the above gap by undertaking an analysis of shelterbelt seedlings since it is a component of total lifetime carbon sequestration of a shelterbelt. It involves the very first phase of shelterbelts – production and transportation of seedlings. This study also provides information on net mitigation of carbon dioxide ($CO_2$) from seedling production in the province of Saskatchewan (SK)[2]. Production and transportation of seedlings may also generate other greenhouse gases (methane and nitrous oxide) but in relatively very small quantities. For this reason, in this study the focus was only on $CO_2$ emissions.

### *1.2. Objectives and Scope of Study*

The major objective of this study was to fill the void in the existing literature on shelterbelt seedlings. Specifically, the net $CO_2$ emissions resulting from growing of shelterbelt seedlings and their transportation to farms before being planted as shelterbelts is investigated. These results are based on data from actual production processes used in a Saskatchewan-based tree nursery, which reflect general conditions and practices in other tree nurseries in Canada.

## 2. Materials and Methods

### *2.1. Life Cycle Assessment (LCA)*

The International Organization for Standardization (ISO) provides a description for LCA as "the compilation and evaluation of inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" [16]. LCAs are a key tool used to advise the development of goods and services and provide incentive for developers to innovate sustainability [32]. They are often applied to monitor the GHG produced during the various phases of the product or service [23].

There are four main phases in an LCA application, including: (1) Goal and Scope Definition; (2) Life Cycle Inventory Analysis (LCI); (3) Life Cycle Impact Assessment (LCIA); and (4) Interpretation [12]. Goal and scope definition includes identifying the functional unit and system boundary of the study, reasons for completing the study, intended use of results, as well as the primary audience [16]. The LCI is the compilation of the inputs and outputs, or resources and emissions, relative to the good or service. The LCIA is completed to quantify the environmental impacts of the good or service [16]. The interpretation phase includes the evaluation of the results [16].

There are two main types of LCAs – Attributional Life Cycle Assessment (ALCA) and Consequential Life Cycle Assessment (CLCA). The main distinction is that ALCAs focus on tracking and prediction of emissions from "cradle to grave" and are a more broadly used to make comparisons, [23, 12]. In contrast, CLCA is a tool used for decision-making, where assessment is based on total emissions by the various inputs and uses [23] and Finnveden et al. [12]). In this study, the ALCA is applied as the research does not directly focus on making decisions regarding changing the various inputs and/or processes of the phases of shelterbelts.

This study adopted the SimaPro LCA tool [30], which is a LCA software program commonly used for similar types of situations. The SimaPro software has a number of databases which it draws from, accessing information from a large library of products and services and their respective emissions. In this study, Ecoinvent database was used for data retrieval [30, 11]. The Ecoinvent is the world's most consistent and transparent life cycle database, with more than 2,200 new and 2,500 updated datasets, including more than 240 new products in many areas, such as energy supply, agriculture, transport, biofuels and biomaterials, bulk and specialty construction material, wood, and waste material [30]. *LCI Selected Results* is a tool within SimaPro which provides the sum of environmental indicators generated by the process under investigation.

### *2.2. Application of LCA to Shelterbelts*

#### *2.2.1. Goal, Scope and Functional Unit*

To estimate $CO_2$ emissions attributable to the production and transportation of shelterbelt seedlings, we assumed the establishment of a one-kilometer (one-km) long shelterbelt, an appropriate length for the study landscape. This one-km shelterbelt will require 1,000 shrub seedlings [3] [2, 3]. However, there was no meaningful difference in processes and practices for the production of different species of seedlings. Data for the seedling production were based on production from a specific tree nursery and greenhouse operating in southeastern SK. Seedlings need to be transported from the nursey to the farm gate to be available

1 In this study, these six species were classified into three categories: Coniferous (to include white spruce and scots pine), deciduous (to include green ash, Manitoba maple, and green ash), and shrubs (caragana).

2 All the estimates in terms of C were converted into $CO_2$ equivalent.

3 The number of seedlings in a one-km long shelterbelt depend on the planting distance. For a coniferous shelterbelt the planning distance is 3.61 meters, whereas that for a deciduous tree at 2.5 m. A shelterbelt with exclusive coniferous trees would require only 277 seedlings, whereas that of deciduous trees would need 400 seedlings.

for farm level planting. The approach used was from cradle-to-date and is shown in Figure 1. Based on the assumed functional unit of 1,000 seedlings, the LCA was developed to represent activities and emissions for two phases relevant to the establishment of a farm shelterbelt: (1) All the operations required at the tree nursery to prepare seedlings for use; and (2) All operations required to transport the shelterbelt seedlings from the tree nursery to a central distribution point (Saskatoon, SK).

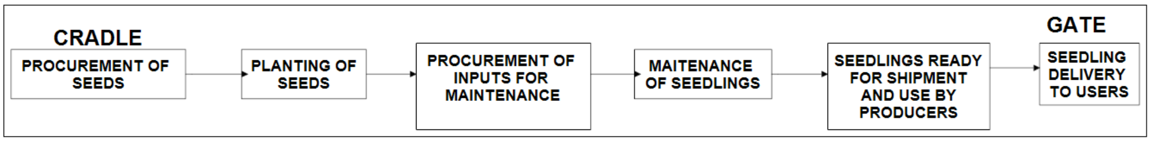


***Figure 1.*** *A schematic of seedling production.*

### *2.2.2. Data Collection*

As noted above, all data related to production method(s) and detailed activities for seedling production were obtained from an operational tree nursery, Shand Greenhouse, located in Estevan, SK. This facility was built in 1991 and is located beside the SaskPower Shand Power Station [28], a coal-fired electricity generation facility which provides a portion of its waste heat to the greenhouse. It is a major seedling producing nursery for the province of SK. Data collected were based on recorded information by the management of Shand Greenhouse / nursery (Bruce Hesselink and Shelley Heidinger) via phone interviews and email correspondence.

The Shand Greenhouse produces roughly 500,000 plant seedlings annually [28]. Data collected included: procurement of seed as a starting point, and quantity and quality of various inputs needed for the growth of seedlings after their planting. These inputs included fertilizer, containers for seedlings, machinery operations, plastic material, heating of the facility, and transportation vehicles used for sending the seedling to their final destination – producers in various parts of SK[4]. The nursery did not have details on greenhouse heating costs, as the primary heat source was waste heat released from the neighboring coal-fired power generation station. The emissions associated with greenhouse heating were estimated using proxy data for comparable (in terms of size of operations) greenhouse operations in SK.

## 3. Methodology

All the seedling production data were entered into SimaPro, through the analysis of *LCI Selected Results* to determine relative emissions. Details on this program are provided in [30]. However, in order to complete the LCA analysis for shelterbelt trees, the following assumptions were made:

1) Any inputs not reported by the Shand greenhouse due to their use in very small quantities (or those less frequently used, such as plastic pots) were omitted from this study.
2) It was assumed that data representing greenhouse heating requirements, which were based on a review of similar costs in comparable SK greenhouses, are a reasonable proxy to potential heating cost at the Shand Greenhouse.
3) As the specific source location of seeds to propagate the tree seedlings was not identified (due to large number of sources used in the past), it was assumed that the seeds were obtained from the stockpile of seeds on the nursery site. However, further details on procurement of seeds were not available and since attributable C emissions are relatively small, it was assumed that it would not affect the overall results of the LCA.
4) Based on data provide by Shand Greenhouse, all tree variety seedlings (i.e., conifers and deciduous) were treated in a similar manner requiring the same inputs and processes during the production phase, making it very difficult to distinguish by seedling varieties. This may have resulted in minor over or underestimation of net C sequestration for each variety.

### *3.1. Land and On-Site Infrastructure Need for the Nursery*

Based on [13], the amount of land required to produce 1,000 seedlings was 0.33 hectare. This value was entered into SimaPro as a land use change to annual crop. The building infrastructure at Shand Greenhouse consisted of a headerhouse, two outdoor shade houses, two storage buildings, a greenhouse, as well as one storage Quonset available off-site (Table 1). The off-site Quonset was not included in the LCA, as its use was not related to seedling production.

The on-site infrastructure costs were included in the SimaPro model using an input value from the Ecoinvent database for the operation of a greenhouse of a specified area. This function allows for the percentage of environmental costs from the construction of the building, including production of building materials. Since these assets have a life of more than one year, an annual apportionment cost was used to reflect one year of production.

There are concrete floors throughout the greenhouse and the headerhouse. The header house (area) and offices have metal studs with metal exterior with gyproc interior walls and insulated interior. The two storage buildings are set on pavement with concrete footing and a metal building (studs, siding and roof) [13]. The life expectancy of a steel and concrete building has been reported to be 60 years [27, 20]. Therefore, the environmental emissions for the construction

4 More details on these inputs are provided in Section 3.1.1.

of infrastructure (including concrete production) at the Shand greenhouse was based on 1/60 of the total emissions (equivalent to one year of production) estimated by [29].

***Table 1.*** *Inventory of buildings required for production of 500,000 shelterbelt seedlings at the Shand Greenhouse, Estevan, SK.*

| Buildings | Area ($m^2$) |
|---|---|
| Headerhouse | 490 |
| Outdoor shade houses (2) | 2,328 |
| Storage buildings (2) | 223 |
| Greenhouse | 1,486.5 |

### *3.2. Production Inputs*

To complete the LCA for shelterbelt seedling production and transportation of seedlings to the farm required a range of data to parameterize the model. The following inputs were used in the LCA analysis for shelterbelt seedlings.

*Seedling Propagation.* There are various strategies and practices followed for the propagation of different tree species. Coniferous trees (e.g., spruce and pine) require seed stratification, a process to interrupt seed dormancy and promote germination. Coniferous seeds are sown in December and the seedlings are moved outdoors in May, with the seedlings harvested in October or November [5]. Manitoba maple is sown in the spring months and harvested in the fall, with the majority of seedling growth occurring outdoors. Green ash seedlings are stratified in March, sown in May, moved outdoors in August, and finally packed in October. Hybrid poplar is grown from cuttings collected during the winter months, planted in May, and grown for one outdoor season prior to harvest, which happens in late October. Caragana is sown in May without seed stratification, moved outside in August and packaged in October [14]).

*Equipment and Fuel*: Shand Greenhouse uses one truck for seedling production operations. An estimated 600 gallons of gasoline[6] is used for the 150 hours of truck operation [14]. A tractor was used for some activities requiring an estimated 85 gallons of diesel for 150 hours of operation [14].

*Pesticides*: For weed control, multiple types of pesticides were applied during the production of seedlings (Table 2). A portion of weed control at Shand Greenhouse involved hand pulling of weeds shortly after seeding and then a second time when plants are established and soon to be packaged for distribution [14]. Chemical treatment occurs for winter-grown seedlings and those sown in early spring, prior to being moved to an outside growing area for weather conditioning [14].

*Materials*: The other material inputs required for tree seedling production included seeds, materials required for seed stratification and storage, planting materials (fertilizer, trays and containers), and materials for packaging (boxes and plastic wrap) (Table 3). These are described below where unit p denotes piece or singular unit of the listed input.

*Seeds*: Tree seeds used by Shand Greenhouse are primarily collected from different provincial forestry nurseries, located in Ontario, Manitoba and Alberta. As reported earlier, Shand Greenhouse has stockpiled a large quantity of seeds, which is where they currently draw the seed required for the annual seedling plantings.

*Planting Media:* The planting media used during seedling production operations is a soil-less, peat-based mix. The mix is sourced from a Canadian sphagnum processor, Premier Tech (Sun Gro). Shand Greenhouse managers estimate two crops (summer and fall) require roughly 117,700 litres of mixed media, which leads to 660 bales of planting media being ordered, and approximately 555 of those are used for production related activities [14].

***Table 2.*** *List of chemicals used for production of 500,000 tree seedling at Shand Greenhouse 2018 operations.*

| Input | Annual amount | Unit |
|---|---|---|
| Avid (Insecticide) | 22.5 | ml |
| Citation (Insecticide) | 300 | g |
| Dipel (Bioinsecticide) | 285 | g |
| Dynomite (Insecticide) | 72 | g |
| Enstar (Insecticide) | 6 | ml |
| Intercept (Insecticide) | 98.4 | g |
| Maestro (Fungicide) | 8170 | g |
| Pylon (Insecticide) | 450 | ml |
| Round-Up Weather Maxx (herbicide) | 6 | L |
| Senator (Fungicide) | 7400 | g |
| Trounce (Insecticide) | 4200 | ml |
| Truban (Fungicide) | 543 | ml |
| Zerotol (Fungicide) | 10.46 | L |

*Fertilizer:* A high nitrate fertilizer [7] (Plant-Prod 20-9-20{©}) (Master Plant-Prod Inc., 2019) is used at Shand Greenhouse. The quantity of fertilizer required annually is estimated at 645 kilograms (kg) (or 43 bags at 15 kg per bag). Fertilizer is applied frequently throughout the seedling growing cycles with the majority applied through the water application system during seedling growth period [14].

*Plastic and Packaging:* Most of the seed stock is grown in Styroblock containers, as well as in Spencer-Lemaire{©} foldable plastic sleeve/trays, both ordered from Beaver Plastics{©}, which is located in Alberta, approximately 1,000 km from Estevan, SK. An estimated 8,500 Styroblock containers and 100 trays with 1,000 inserts are used annually. All of the previously mentioned plastic materials have a life span of about 5 years; however, environmental events, such as hailstorms, may decrease this life span [14].

Five-inch meat wrap plastic is used during the seedling packaging stage. The quantity of plastic wrap required is dependent on the size of seedling plugs and the bundles of seedlings, as well as on the experience of the wrapper. In addition to packaged bundles, Shand supplies roughly 25,000 individual-packaged seedlings for promotional purposes. The small promotional plastic packages weigh 1.75 g per bag.

5 Although there are some differences in the timing of their planting, the cultural practices for various species remains the same.

6 In this estimation, octane level of the fuel was not considered. Typically a fuel with an octane level of 91 is purer than one with a value of 87. Although gasoline and diesel could produce different C emissions, the differences were considered to be small and therefore, ignored.

7 Although fertilizer application produces nitrous oxide, in this study this emission was excluded.

Cardboard boxes are also used during the seedling packaging stage. Larger boxes of seedlings sized 8” x 15” x 18”, weigh 1 kg when full, and small boxes of seedlings, size 8” x 7.5” x 18” weigh 400 g [14].

*Energy and Heating*: For the Shand Greenhouse operations, electricity was used for power and heating of all infrastructures, except greenhouses. The total annual electricity consumption for the site is 1,270,800 kWh [14]. Electricity is sourced from the provincial electrical grid. Roughly 84% of SK’s electricity is generated from fossil fuels, with 49% coming from coal and 35% from natural gas. Renewable energy, primarily hydroelectricity, provides the remaining 16% of energy [10].

***Table 3.*** *Inventory of inputs used for production of 500,000 seedling at Shand Greenhouse.*

| Input | Amount | Unit |
|---|---|---|
| 20-8-20 All Purpose high nitrate fertilizer | 645 | kg |
| Sulphuric acid | 1 | L |
| Clorox bleach | 1 | L |
| Incubators | 2 | p |
| Nylon mesh bags | 50 | p |
| Purified water | 50 | L |
| Seeds | 4,203,390 | P* |
| Spencer-lemaire foldable plastic trays | 2 | p |
| Styroblock containers | 8500 | p |
| Meat Wrap (plastic) | 2.50 | g |
| Small plastic bags | 1.75 | g |
| Large box | 1 | kg |
| Small box | 400 | g |

* Pieces of seed.

As mentioned earlier, the heating requirements for Shand greenhouse were not available since the waste heat produced by the neighboring coal power station was used to heat the greenhouses. The greenhouse heating cost was estimated using data from comparable greenhouses heating with natural gas-based furnaces. The three bay, gutter connected greenhouse has 1,486.5 $m^2$ of space. The structure has a tempered glass roof and polycarbonate exterior wall [14]. The inside temperature is set at 25°C although, depending on the exterior temperature, the indoor temperature can reach 30-40°C [14]. A calculator provided by [1] was used to estimate the heating requirements of a greenhouse using a similar area and structure, inside set temperature, average regional low temperature, number of heating months, and the heat loss value. The heat loss value (R-value) represents a building’s capacity to resist heat loss; a higher value represents greater insulation. Shand Greenhouse has an R-value of 0.90 $ft^2$ Fh/BTU[8] [1]. Based on these parameters, an estimated 80,512.5 $m^3$ of natural gas was required to heat this operation. A comparison of this value was made with two other greenhouses – one at the University of SK’s Ground Greenhouse, the other Agriculture Greenhouse. The estimate value above was considered comparable by scale and regionally to that of Shand Greenhouse. The natural gas usage for the Agriculture Greenhouse (size 1,041 $m^2$) was 71,641.62 $m^3$ and was 397,931.52 $m^3$ for the Ground Greenhouse (size 3,523 $m^2$) (Kevin Hudson, University of Saskatchewan). Since the Agriculture Greenhouse was more similar in size to the Shand Greenhouse, it was used to represent average heating requirements. The natural requirement per area for the Agriculture Greenhouse was 90.27 $m^3/m^2$ and the estimated value for Shand Greenhouse, if it were using natural gas rather than waste heat, is 54.16 $m^3/m^2$. It is important to note that the value for the Agriculture Greenhouse is annual (12-months) whereas the value for Shand Greenhouse is for a 10-month operational period (December through September).

### 3.3. Transportation of Seedlings

Shand Greenhouse has three methods of transporting tree seedlings to farms where they will be used to establish shelterbelts– landowners can pick up seedlings from Shand Greenhouse, small deliveries by Shand employees to destinations close to the greenhouse, or large deliveries to central hubs in the province. The three delivery hubs used by the Shand Greenhouse are the cities of Regina, Saskatoon, and Prince Albert [14]. This seedling delivery method adopted in this study with the delivery completed using a commercial transportation carrier, Jay’s Transport{©}. This company uses a straight truck, which weighs 7,711 kg (personal communication with Jay’s Transport managers). The average shipment load was 600-700 boxes of seedlings annually under normal demand, with upwards of 1,000 boxes during periods of higher demand. As mentioned previously, there are two different sizes of boxes and therefore two different weights of shipments. For simplicity, it was assumed that only the larger sized boxes were used, which can accommodate 200-250 seedlings, depending on the species. Assuming a shipment of 600-700 large boxes the estimated weight of the shipment was 700 kg.

Transportation activity in SimaPro is reported as tonne-km, which is the unit of mass multiplied by distance traveled. In this study Saskatoon (approximate central point for the agricultural zone of SK) was selected as the hub for transportation. This city is located approximately 464 km from the Shand nursery. The transport carrier was assumed to complete a return trip going empty from Saskatoon to the Shand nursery (464 km, 3,577,904 kg-km), and then returning with seedlings (3,902,704 kg-km) with a total kg-km value of 7,480,608 kg-km or 7,480.6 t-km.

### 3.4. Transportation of Seedlings to the Farm

Once the seedlings are delivered to the designated hub (Saskatoon), they must be transported by the landowners for planting on their farm[9]. To estimate the GHG emissions for this activity, it was assumed that the farm is located on average 50 km away from the delivery hub and a small transportation vehicle (such as farm pickup truck) is used. This truck was assumed to weigh roughly 2,041 kg [21]. However, the

8 Fh stands for Fahrenheit heat loss value per square feet of insulating material

9 Shipping these seedlings using commercial trucks or regular mail system would be at a prohibitive cost.

number of seedlings ordered and therefore weight of seedlings varies and is dependent on the species, as well as length and number of rows a landowner wants to plant. In this study, for a one row one-km long shelterbelt, the number of seedlings varied from 277 (coniferous) to 1,000 (shrubs) [3]. Using information gathered from the Shand Greenhouse, 200 to 250 seedlings can fit in a box, and a full box of seedlings weighs roughly 1 kg. In order to fill an order of 1,000 trees (assuming a larger order is more commonly placed), 4 to 5 boxes of seedlings is required, total weight of 4-5 kg. For the LCA, the higher weight of 5 kg was used. The fuel consumption required for this trip would be roughly 2 gallons of gasoline to travel 50 km [21]. The $CO_2$ emission for the additional travel of 50 km from a distribution hub is 41.9 kg.

## 4. Results

Total GHG emissions from seedling production and transportation were estimated using the SimaPro model, based on the above discussed required inputs to parameterize this LCA phase.

***Table 4.*** *$CO_2$ emissions associated with inputs in production phase of 500,000 seedlings (as actual values and proportional percentages of all inputs).*

| Label | Total amount of carbon dioxide emitted (kg) | Percent of total emissions |
|---|---|---|
| Electricity | 914,712 | 83.22 |
| Heat (natural gas) | 121,000 | 11.02 |
| Infrastructure | 28,600 | 2.61 |
| Polystyrene | 13,600 | 1.23 |
| Tractor | 7,590 | 0.69 |
| Greenhouse | 5,620 | 0.51 |
| Nitrogen fertilizer | 3,610 | 0.33 |
| Irrigation | 1,770 | 0.16 |
| Gasoline | 1,010 | 0.09 |
| Peat | 851 | 0.08 |
| Fungicide | 173 | 0.02 |
| Diesel | 138 | 0.01 |
| Polypropylene | 76.7 | 0.01 |
| Insecticide | 64.4 | 0.01 |
| Glyphosate | 63.2 | 0.01 |
| Transport | 37.3 | 0.003 |
| Captan | 31.2 | 0.002 |
| Packaging film | 30.3 | 0.0028 |
| Acetic acid | 20.9 | 0.0019 |
| Land use change (annual crop) | 10.9 | 1.00E-03 |
| Nylon 6-6 | 3.32 | 3.00E-04 |
| Sodium Hypochlorite | 2.63 | 2.00E-04 |
| Purified Water | 2.18 | 2.00E-04 |
| Sulphuric Acid | 0.139 | 1.26E-05 |
| Total | 1,100,000 | 100.00 |

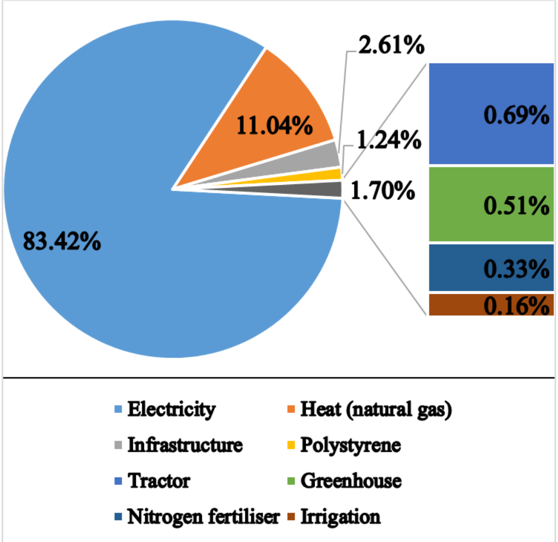


***Figure 2.*** *Distribution of total $CO_2$ emissions for seedling production activities.*

### *4.1. $CO_2$ Emissions from Seedling Production*

The total annual $CO_2$ emissions from the production stage for 500,000 shelterbelt seedlings by Shand Greenhouse, was 1,100,000 kg (Table 4). This translates into 2.2 kg per seedling. As noted above, due to identical maintenance and cultural practices followed by the Shand nursery, it was not possible to identify specific emissions for each type of seedling (conifer vs deciduous). Electricity was the highest $CO_2$ producing input for seedling production at 83.42% of the total $CO_2$ emissions, or roughly 914,712 kg $CO_2$ to produce 500,000 seedlings. Heating, which accounted for 11.04% of emissions, or 121,000 kg of $CO_2$, was the next largest contributor to the total emissions (Figure 2). Use of infrastructure and polystyrene were the only other inputs representing more than 1% of total emissions for seedling production. The other inputs in the production process that emitted at least 1,000 kg of $CO_2$ included: use of tractor, use of greenhouse facility, application of nitrogen fertilizer, irrigation, and use of gasoline and diesel. However, on a relative basis, these emissions contributed only between 0.1 to 0.7% of total emissions.

The total amount of emissions for 1,000 seedlings for one-km long caragana shelterbelt was 2,200 kg $CO_2$. Since $CO_2$ emissions per seedling were the same for all varieties of shelterbelt tree species, for a one-km shelterbelt total emissions varied based on the specific spacing, and therefore number of trees required for a shelterbelt of that length.

***Table 5.*** *Breakdown of $CO_2$ for each life cycle stage for one-km of shelterbelt planted, by type of species.*

| Shelterbelt Type | No. Of Seedlings Required | $CO_2$ emissions (kg) | | | |
|---|---|---|---|---|---|
| | | Production of seedlings | Transportation of seedlings to Hub location | Transportation from hub to farm | Total emissions |
| Coniferous | 277 | 609.40 | 12.18 | 41.90 | 663.48 |
| Deciduous | 400 | 880.00 | 42.30 | 41.90 | 964.20 |
| Shrubs | 1,000 | 2,200.00 | 84.60 | 41.90 | 2,326.50 |

### *4.2. Transportation of Seedlings*

As discussed above, the transportation unit for seedling shipment between the Shand greenhouse and Saskatoon, SK, was 7,480,608 kg-km. This value is representative of a total shipment to a delivery hub. However, when considering the carbon footprint of a shelterbelt on an individual's land, it does not include the entirety of the emissions produced for a full shipment. In order to determine the environmental burden for an order of seedlings necessary to establish a one-km long shelterbelt, the percentage of seedlings that would be required from the full shipment was determined. A shipment of 1,000 seedlings represents 0.006% of the total shipment. The emissions produced for a full shipment to Saskatoon is 14,100 kg $CO_2$ while, based on the above estimates, the emissions attributable to 1,000 seedlings was 84.60 kg $CO_2$.

### *4.3. $CO_2$ Emissions for Production and Transportation Phases*

The $CO_2$ emissions were generated from the production and transportation activities for 1,000 seedlings (one-km long shrub shelterbelt). As noted above, the $CO_2$ attributable to a one-km long shelterbelt varied by tree species due to their respective spacing requirements. The recommended minimal spacing for shrubs is one meter, while for deciduous and coniferous trees is 2.5 m and 3.6 m, respectively [3]. Thus, the total number of seedlings needed for a one-km coniferous shelterbelt would be 277, while 400 seedlings are required for a deciduous shelterbelt. Using these values, total $CO_2$ emissions for combined production and transportation of seedlings were estimated (Table 5). The values for a one km long coniferous shelterbelt were estimated at 663.48 kg, while the highest level of $CO_2$ emissions were generated by a shrub shelterbelt at 2,326.5 kg. These amounts were based on the assumption that production of a seedling, regardless of type, generates 2.2 kg of $CO_2$ per seedling.

Since these results are point-based, an uncertainty analysis was conducted using the Monte Carlo simulation included in SimaPro. The purpose of this estimation was to assess uncertainty associated with variation in these estimates using a 95% confidence interval. Based on this analysis, the range in $CO_2$ emissions associated with the production of 500,000 seedlings could vary between 889 to 1,370 tonnes. Similarly, the 95% confidence interval for transportation was estimated to be between 11.7 and 17.2 tonne of $CO_2$. Thus, combined overall $CO_2$ emissions from seedling production and transportation activities are estimated to fall within a range of 900.7 to 1,387.2 tonnes for a one-km long shelterbelt. This range in emissions could have resulted from a combination of natural variability in seedling production, as well as assumptions used in this study.

## 5. Discussion

In a life cycle assessment of shelterbelts, the information related to GHG emission and/or carbon sequestration from all phases of shelterbelt establishment is needed. Production of seedlings and their shipping to producers (transportation) are vital parts of shelterbelt development before they can be planted in the field. Both of these activities result in net emissions of $CO_2$. This study is the first reported application of LCA to seedling production and transportation. Although the case study is for Saskatchewan conditions, we believe that results are generalizable to other areas under similar climatic conditions and location of farms, since production and maintenance techniques in seedling production and transportation in most nurseries are virtually the same.

Based on the results of this study, if a one-km long shelterbelts exclusively made of shrubs is planted, the total $CO_2$ emissions for seedling production and their transportation to final users would be 2.33 tonnes. Corresponding emissions for an equivalent length of shelterbelt of coniferous or deciduous tree species would result in 0.66 tonnes and 0.96 tonnes of $CO_2$, respectively. It was found that in this task of making shelterbelt seedling available to final users (farmers), production-related activities emit approximately 95% of the total emissions generated from various seedling production-related activities. Among these production-related emissions the primary emission source was use of electricity and heating of buildings. The estimated $CO_2$ emissions as reported in this study could be affected by climatic differences, plus the generation of inputs (primarily electricity) used for seedling production may make these estimates close to a case study. If the heating source is through electricity, that is generated using renewable resources, GHG emissions would be lower than those were reported in this study. Perhaps some other prairie provinces may be similar but transferring these values to other parts of Canada should be done with some caution.

GHG emissions from transportation of seedlings, while constituting a small proportion of total seedling production emissions, are affected by species used for shelterbelts by producers and the distance they travel to reach the farmer. This is because of the fact, as noted above, the number of trees that can be planted in a kilometer linear row is based on the tree species and their recommended spacing. For reference, caragana is a shrub species, hybrid poplar, Manitoba maple, and green ash are deciduous species, and white spruce and scots pine are coniferous species. The recommended minimal spacing for shrubs is 1 meter, for deciduous and coniferous trees is 2.5 m and 3.6 m, respectively [3]. Based on these recommended spacing, the maximum number of trees planted in a km long shelterbelt are as follows: 1,000 shrubs, 400 deciduous trees, and ~277 coniferous trees. Furthermore, as shelterbelts are planted on farms, their carbon sequestration levels would overshadow the GHG emissions form seedling production and transportation. For example, a one-km long shelterbelt, made up of caragana shrubs, could provide a net carbon dioxide sequestration of 406-450 tonnes over a 60-year period, depending on the climate of the region. In contrast, the same length shelterbelt comprised of hybrid poplar, could sequester 1481 tonnes over a 60-year period, including GHG emissions from shelterbelt seedling production and transportation.

Results of this study are useful in developing a complete life cycle analysis of shelterbelt, including seedling related emissions of GHGs. Such an application is reported in [26]. Similar studies can also be followed for other regions of Canada and the world. Policy makers should base their decision on the net GHG (mainly the carbon dioxide) sequestration of trees from cradle-to-gate including farm level growth of shelterbelt trees.

## 6. Conclusions

GHG emissions from shelterbelt seedling production and transportation are an important component of first five-years of shelterbelt growth on farms but differ by type (species used). However, in terms of first five-year GHG emissions from planting shelterbelts, seedling GHG emissions are high. The proportion of seedling GHG emissions was estimated to be around 46% of the total GHG emissions for the first five-year of planting shelterbelts on farms, regardless of species [25].

In order to conduct the LCA a significant number of assumptions were required to address missing or incomplete data sets for all required inputs in the research. Clearly several of these assumptions impact the overall representativeness and accuracy of the results. However, the results still provide a useful insight into the relative importance of different stages of shelterbelt production and establishment. LCAs are a useful tool to characterize the whole aspect of a good or service and how it impacts the environment. Furthermore, it is anticipated that this information will help inform the development of a more comprehensive LCA of shelterbelts in SK. However, since these results are location specific; any further generalization should be carried out with caution.

## Conflicts of Interest

The authors declare that they have no competing interests.

## Ethics Approval

No ethics approval was deemed necessary by the University of Saskatchewan for this project.

## Consent to Participate

All authors have consented to work on this project voluntarily. Lindsey Rudd was provided remuneration as a graduate stipend for undertaking this research.

## Acronyms and Abbreviations

| | |
|---|---|
| AAFC | Agriculture and Agri-Food Canada |
| ALCA | Attributional Life Cycle Analysis |
| CLCA | Consequential Life Cycle Analysis |
| $CO_2$ | Carbon dioxide |
| GHG | Greenhouse gases |
| ISO | International Organization for Standardization |
| LCA | Life cycle analysis |
| LCIA | Life cycle impact assessment |
| SK | Saskatchewan |

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