PATHWAY TO 2040

REDUCING EMISSIONS FROM PEI AGRICULTURE

PRINCE EDWARD ISLAND
FEDERATION OF AGRICULTURE

Pathway to 2040
Reducing Emissions from PEI Agriculture

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2023

Published by:
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EXECUTIVE SUMMARY

The goal of this document is to inform Island farmers about the reality of the carbon question in agriculture. It will help Island producers make informed decisions about why they should reduce their carbon footprint, how they can do so, and what the best way to benefit from that reduction is.

Across Canada and particularly in Prince Edward Island (PEI), the agriculture industry is being called upon to lead towards government's greenhouse gas emissions reduction targets. Goals have been set and in response, best management practices (BMPs) have emerged for farmers to implement.

This document, the Pathway to 2040, assesses the impact of these BMPs on emissions from PEI agriculture. The Government of Prince Edward Island has set an emissions reduction target for agriculture of 35-40% below the 2015 baseline by 2040. To reach this, farmers will have to reduce emissions from crops and livestock and improve soil health and its ability to absorb carbon.

In 2015, agriculture on PEI produced approximately 300,000 tonnes of carbon dioxide equivalent emissions, 25% of the province's total. These emissions are primarily from livestock and crop production. Meeting the reduction target will require a decrease of at least 105,000 tonnes by 2040. Using AAFC's HOLOS modelling software, this document shows that, through the adoption of best management practices, PEI agriculture can meet the target.

Best management practices for crop production include reduced nitrogen, increased use of cover cropping, reduced tillage, and increasing rotation length. Through widespread adoption of these BMPs, particularly the first two, emissions from crop production in PEI can be reduced by more than 40,000 tonnes.

Best management practices for livestock production include changes to animal housing, animal diet, and manure management. Through widespread adoption of these BMPs, particularly changes to animal diet, emissions from livestock production in PEI can be reduced by approximately 100,000 tonnes.

This projected reduction of 140,000 tonnes will place PEI agriculture in a leadership position in the marketplace. The consumer's tastes are shifting towards a more climate friendly agriculture. A timeline has been included to track progress towards the 2040 target.

Government subsidy has begun to arrive to adopt these BMPs, but this is not the only pathway to incentivize emissions reductions. Island farmers have begun to hear more about the potential of carbon credits. This document details the current state of the carbon marketplace for reductions of emissions from agriculture, and the PEIFA is working diligently to bring those opportunities to PEI agriculture.

This document will form the foundation of the carbon strategy for Prince Edward Island farmers. Information found herein will be shared with government, industry, and the general public. It will form the technical basis of the PEIFA's effort to guide Island farmers down the path to 2040.

ACKNOWLEDGEMENTS

The PEIFA would like to acknowledge the in-kind support from Roland Kroebel and Aaron McPherson of the AAFC HOLOS team. Several software updates were required for the models to reflect PEI conditions. The PEIFA would also like to acknowledge support from Adam Maclean at PEI Agriculture and Land. Adam helped navigate the overlap between existing / forthcoming EG&S support programs and carbon markets, providing guidance on how the two can work together for Island farmers. Finally, we would like to acknowledge the support from the PEI Certified Organic Producers Cooperative and Sebastian Manago, for coordinating discussions with Alloporus Environmental on a carbon market pathway.

LIMITATIONS

Software modeling has inherent limitations and error margins which must be factored into interpreting this report. While IPCC-Tier 2 models are intended to provide an intermediate level of complexity and factor in locally specific data, cropping systems can only be modeled based on constant fertilizer rate assumptions, tillage regime, and pesticide applications. As such, this report can only estimate variation between cropping systems and not variation between specific, individual farms. Spatial data on rotational crop structure and crop frequency is also based on remote sensing technology with a published error margin of 15%. By cross-referencing model data and crop inventory data with existing literature and statistics, we can ensure readers that all efforts were made to ensure accuracy in GHG estimations. Furthermore, model results will ultimately require in-field verification before GHG emissions and associated reductions can be marketed as carbon credits or ecological goods and services.

CONTEXT

THINKING ABOUT GREENHOUSE GASSES AND CARBON

As governments and industry develop policy for curbing greenhouse gas emissions to achieve net zero by 2050 (federally), the process of quantifying greenhouse gas emissions in terms of carbon dioxide equivalents (CO2e) presents both risks and opportunities for agriculture. Government carbon policy (fuel taxes, emissions policy, etc.) and supply chain emissions requirements (sustainability and GHG intensity auditing, etc) represent a non-voluntary category of climate change mitigation. It is expected that as governments and markets move closer to emissions reduction target years (2030 & 2040), non-voluntary obligations will become increasingly disruptive for primary producers. Emissions from agriculture are diverse and cannot be mitigated with singular scalable solutions. Livestock and crops represent different sources of emissions and together pose a sizable mitigation challenge. See Table 1 for a summary of Prince Edward Island's net zero emissions goals as they relate to agriculture.

TABLE 1 - Summary of PEI Agriculture estimated baseline and GHG emission reduction targets

Jursdiction	Baseline	Sector	Baseline Emissions (Tonnes CO_2e)	Target year	%GHG Reduction from 2015	Min Expected Reduction in Tonnes CO2e from Baseline
Provincial	2015	Crop	84,360	2030	10-15	29,800
		Livestock	163,931			
		Fuel	49,866	2040	35-40	104,300

Sources: Data compiled from National GHG Inventory and PEI Net Zero Framework.

CARBON/GHG ACCOUNTING

Carbon and Greenhouse Gas (GHG) can be used interchangeably when measured in CO2 equivalents (CO2e). One unit of Carbon is equivalent to 3.67 units of CO2e.[1] Carbon accounting is similar in many ways to financial accounting. It is "the process by which organizations quantify their GHG emissions, so that they may understand their climate impact and set goals to limit their emissions." All flows of CO2 equivalent gases (CO2e) are measured to determine whether an industrial activity is a net source (emission) or a net sink (storage) of greenhouse gases. As such, it is important to differentiate between carbon accounting as it relates to both voluntary and non-voluntary risks and opportunities. Greenhouse gases (GHG) of concern to agricultural supply chains are:

Greenhouse gases (GHG) of concern to agricultural supply chains are:

1. Methane (CH4) – Enteric fermentation and manure emissions
2. Nitrous Oxide (N2O) – Nitrogen containing fertilizers and amendments
3. Carbon dioxide (CO2) – Burning of fossil fuels, decomposition of organic residues on plow-downs

[1] This is the amount of CO2 that can be produced by a unit of Carbon. The atomic weight of CO2 is greater than that of Carbon.

[2] https://supplychain.edf.org/resources/carbon-accounting

Reporting emissions differs from quantifying emission reductions for voluntary carbon markets in terms of legal obligations, but much overlap exists in how GHG accounting is used (see Table 2). The GHG Protocol is the only internationally accepted standard for reporting direct (Scope 1) and indirect (Scope 2 & 3) emissions from the public and private sector. Scope 1 and 2 emissions are considered mandatory reporting categories for large emitters (e.g. Governments, Food Processors, Millers, QSR) whereas Scope 3 emissions are generally optional.[3] In terms of selling carbon credits, one of the primary standards for verification and marketing of carbon credits is the Verified Carbon Standard (VCS) administered by Verra.[4]

TABLE 2 - Use cases for GHG and Carbon Accounting

Non Voluntary	Scope 1 and 2 Emissions Reporting	Purchasing Verified Carbon credits to offset reported GHG emissions for large emitting companies	
Voluntary	Scope 3 Emissions Reporting	Purchasing Verified Carbon Credits	Verifying and Selling Carbon Credits

It is estimated that "Roughly thirty percent of global greenhouse gas (GHG) emissions are caused by forest destruction and poor agricultural practices." [5] On-farm emissions captured within the Scope 3 emissions of processors, millers, and consumer facing retail can represent significant portions of corporate totals once factored into GHG reporting.[6] In addition to meeting provincial and federal GHG targets for agriculture by 2030, 2040, and 2050, Island farms must also consider carbon competitiveness as a foundational value chain stakeholder and a key determinant of ultimate GHG intensity per unit of food. This highlights two evolving risks that, without proactive voluntary practice changes, may become disruptive to Island agricultural producers as we near 2030 and 2040:

Boosting carbon sequestration in the Agriculture, Forestry and Other Land Use (AFOLU) sector is an effective approach to reduce and remove emissions.

1. Political urgency coupled with the possibility of legislated GHG targets and/or additional regulation may create less graduated transitional pathways to net-zero agriculture

2. The increasing brand value of low carbon food and the associated corporate incentivization to procure raw products with lower GHG intensity will put increasing pressure on producers to adapt or risk losing market access.

[3] https://ghgprotocol.org/about-us

[4] Within this standard, agricultural systems fall within the Agriculture, Forestry and Other Land Use (AFOLU) sector. Other registries include American Carbon Registry and Climate Action Reserve, Gold Standard, and Plan Vivo System, but they are less applicable to PEI Agriculture and generally result in fewer total credits being sold.

[5] https://verra.org/wp-content/uploads/2016/05/FactSheet-AFOLU-2013-UPDATED.pdf

[6] https://ecometrica.com/scope-3-emissions-and-why-you-should-report-them/

CARBON MARKETING AND ECOLOGICAL GOODS AND SERVICES

Payments for ecological goods and services (EG&S) are becoming more common, in part due to the reality that investments in low carbon agriculture require cash flows beyond what current food prices factor in. Programs such as On-Farm Climate Action Fund (OFCAF) and Alternative Land Use Services (ALUS) pay farmers to adopt best management practices to provide various ecological/environmental services, including GHG reductions. The next iteration of the Canadian Agricultural Policy Framework (SCAP) will also include payments for ecosystem services and practices that reduce GHG emissions, store carbon, and increase sustainability. In addition to EG&S programs, carbon markets represent a longer term opportunity for farmers and farm supply chains to finance transitions to more sustainable agriculture. Two types of markets currently exist:

OFCAF On Farm Climate Action Fund

The PEIFA delivers the On Farm Climate Action Fund to Island producers. The goals is to encourage the implementation of beneficial management practices that reduce GHG emissions and promote carbon squestration. To learn more about the activities supported through the program visit: www.peifa.ca/ofcaf

Voluntary Markets - Issuance and trade of carbon credits is governed by carbon registries (e.g. Verra). Carbon accounting standards facilitate the registration of verified carbon credits as a marketable good or a verified carbon unit (VCU). Third party validation/verification bodies (VVB's) are also required to ensure practices are actually reducing/avoiding the predicted volume of GHGs. This is a cost intensive component of carbon marketing and will require VVB's to (1) calibrate model scenarios and (2) collect field data. In most cases, collectives as opposed to single farms would be best positioned to achieve a positive net benefit from a carbon marketing project due to minimum volume requirements, scale, etc.

Buyers in voluntary markets purchase credits to meet GHG reduction commitments for various reasons:

Branding and corportate responsibility
Supply chain presssure
Individuals offsetting travel related emmissions

Compliance Markets - In order to facilitate the purchasing of carbon offsets/credits for regulated emitters, the federal government GHG offset credit system allows CO2e reduction and avoidance activities (credits) to be sold to regulated emitters who are required to purchase carbon offsets. Non-regulated organizations can also buy credits from compliance markets to meet voluntary emissions goals. These markets can represent a larger financial opportunity in terms of the estimated price per tonne of CO2e, however it is unclear how widely they will be used as voluntary markets provide more competitive credit options. See Table 3 for a comparison of compliance and voluntary markets.

TABLE 3 - Comparison of voluntary and compliance markets

Market Type	Geography	Structure	Estimated Pricing ($/mt CO_2e)
Voluntary market	Global	Voluntary buyers and sellers	$5 - $40
Compliance market	National	Voluntary sellers, voluntary and/or regulated buyer	$40 - $60

ADDITIONALITY

Carbon storage practices must be considered over and above what is mandated by governmental policies and initiatives (which may include existing ecological goods and services payments). [7] This principle is referred to as additionality and is a central concept to carbon marketing as well as several new governmental GHG related initiatives.[8] Business as usual activities do not qualify for carbon marketing projects. This makes the requirement of additionality a moving target; as government policy shifts, the agricultural carbon storage and/or emissions reductions practices that could be eligible for a carbon market payment will also shift. As such, additionality is relative to the status quo and must be continuously reevaluated. However, most carbon marketing projects will allow for a lookback period of 5 years or more.[9]

[7] This represents a risk and challenge in developing credits for a voluntary market.
[8] OFCAF has an additionality requirement. It is expected future support programs will require a certain level of additionality
[9] According to an internal carbon marketing report, 5 years is reasonable to assume
[10] https://verra.org/wp-content/uploads/2016/05/FactSheet-AFOLU-2013-UPDATED.pdf

LEAKAGE

Another constraint that can affect carbon market eligibility is the risk that adding carbon storage in one area can alter land use practice in another. This is referred to as leakage and all Agriculture, Forestry and Other Land Use (ALOFU) projects must address this risk.[10] Over time, this constraint has become less prohibitive in terms of voluntary markets, but in terms of policy driven emissions requirements (non-voluntary), it is likely to become more important to ensure a net decrease in GHG emissions across all farms (see Table 4).

TABLE 4 - EXAMPLES OF LEAKAGE TO CONSIDER FOR ISLAND-WIDE CARBON STRATEGY

GHG emissions reductions practices	Offsetting GHG emissions in another area
Lengthened crop rotations	Increased deforestation
Lengthened crop rotations	Intensified crop rotations
Intensive grazing with lower stocking rates	Intensified livestock production, limited manure storage

INDUSTRY LED SCOPE 3 EMISSIONS

TARGETS AND LAND USE POLICY

Consumers are are putting a higher value on sustainablility when making decisions on products and companies they support. Producers that implement sustainable agricultural practices and meet GHG emission targets remain competitive

In terms of industry led non-voluntary risks, the accounting of Scope 3 emissions is perhaps the most significant. Given that Scope 3 emissions travel further down the supply chain to account for GHG emissions occurring on-farm, processors and buyers are increasingly incentivized to manage and reduce these Scope 3 emissions to uphold brand value, meet sustainability commitments, and remain competitive in a low carbon economy. As previously noted, the overarching risk is that over time, market access could be limited for non-compliant producers as consumers and consumer facing retailers (quick service industry, grocery chains, etc) look to sell products that meet a minimum GHG intensity threshold.

CAVENDISH FARMS

Companies are adopting high quality environmental standards to meet industry and consumer demands for sustainability.

Currently, Cavendish Farms is the only agricultural emitter on Prince Edward Island that is required to offset GHG emissions. To date, the Potato Sustainability Initiative (PSI) is the only documentation required to meet industry demands for sustainability auditing. As net-zero deadlines get closer, it is expected that Scope 3 emissions will come under more intense scrutiny as processors look to reduce GHG emissions associated with primary producers.

MCCAINS

McCains has issued a Sustainability Report, outlining their commitments to reducing GHG emissions.[11] While they currently only include Scope 1 & 2 emissions reductions in their targets, they are targeting a 25% reduction in GHG intensity of their raw potatoes through sustainable farming practices which is approximately 366 kgCO2e per acre (proportionate to a 30-40% nitrogen rate reduction).

FRITO LAY & PEPSI-CO

Pepsi-Co has set a goal that by 2030, 100% of their key ingredients will be sustainably sourced. Sustainably sourced refers to “meeting the independently verified environmental, social and economic principles of PepsiCo’s Sustainable Farming Program, enabling continuous improvement for farmers, communities and the planet”.[12] The Sustainable Farming Program (SFP) contains goals with specific implications for land use, including a commitment to zero-deforestation, reducing Scope 3 emissions by 40% from the 2015 baseline, and spreading regenerative agriculture across 7 million acres. Presently, zero-deforestation, along with many other best practices, are considered critical, fundamental principles.[13]

[11] https://www.mccain.com/media/3377/mccainfoods_sustainabilityreport2019.pdf
[12] https://www.pepsico.com/docs/default-source/pepsico-positive/pep_positive_target_summary.pdf?Status=Master&sfvrsn=c1e1a530_3
[13] https://www.pepsico.com/docs/default-source/sustainability-and-esg-topics/pepsico-sustainable-farming-program-fundamental-principles.pdf?sfvrsn=526d10b4_3

ARLA

Arla is a 12,500 member dairy cooperative with aggressive sustainability goals. They aim to reduce Scope 3 emissions by 30% per tonne of milk by 2030 and achieve net-zero across all scopes (1,2, and 3) by 2050.[14] ADL and ARLA are currently engaged in strategic partnerships. Over time, companies such as ADL may adopt similar climate goals.

Given that Scope 3 emissions reporting views the entire value chain as a single process, it is important for primary producers to consider how carbon accounting presents risks and opportunities for each primary sector. This evolving non-voluntary risk must be taken seriously as large companies work more aggressively to limit GHG emissions and uphold brand value. Proactive adaptation comes with the reward of keeping brand-value and associated premiums (carbon revenues, certified low carbon branding, etc) on-farm whereas a reactive approach will see these rewards realized further up the supply chain.

[14] https://www.arla.com/sustainability/arlas-climate-ambition/

THE ROLE OF PEIFA IN NET-ZERO PLANNING

Net Zero Goals for PEI Agriculture [15]

1. Reduce emissions from crops and livestock
2. Improve soil health and the ability to absorb carbon
3. Accelerate use of advanced agricultural clean technologies

The PEIFA aims to inform primary producers of the risks and opportunities while time exists to position the Island as a low carbon food producer. As policy shifts and new GHG focused programming is rolled out, the opportunities for voluntary carbon revenues may become more limited in terms of meeting additionality requirements. A GHG reduction strategy for meeting voluntary and non-voluntary emissions targets must include:

1. A baseline analysis of current GHG emissions for various crop and livestock production systems.
    a. National Inventory GHG estimates allocate a percentage of GHG emissions to agriculture, but to prioritize systems with the most GHG reduction potential, a sample of several systems is required.

2. A preliminary analysis of best management practices (BMP) that will make meaningful reductions in GHG emissions.
    a. Crop system modeling and external research review provide estimates of carbon and C02e avoidance/reduction potential that can be assessed for incremental cost and revenue potential.

3. A pathway analysis for securing carbon revenues from voluntary and/or compliance markets will provide protocols for in-field verification and a workflow for documenting change of practice and engaging carbon registries.
    a. Not every BMP can be packaged into a carbon market protocol. Identifying the most promising from a registry and documentation perspective is critical.
    b. Developing relationships with carbon registries and verification bodies will need to happen concurrently with the development of components 1,2, and 4 to ensure a market is in place by the time on-farm projects are initialized.

4. A feasibility assessment that considers the probability of achieving published Net-Zero targets [15] under current BMP implementation assumptions (guided by cost/revenue and practicality for producers) with contingencies for addressing GHG reduction shortfalls
    a. If emissions reductions from actionable BMP's fall short of Provincial targets, what other options can be considered to ensure farmers continue to lead GHG reduction efforts.

Agriculture activity is unique as the majority of greenhouse gases emitted from the sector are nitrous oxide, methane and carbon dioxide.

[15] https://www.princeedwardisland.ca/sites/default/files/publications/2040_net_zero_framework_for_feb_23_2022.pdf

CURRENT LAND USE PATTERNS FOR BASELINE ESTIMATION

On Prince Edward Island, forested area is approximately 35-45% of total land area, or 600,000 acres, and represents a significant store of carbon. Agriculture utilizes 42.5%, or 592,324 acres composed primarily of potatoes, cereals, pasture, forages, oilseeds, and corn (see Table 5). According to the AAFC annual crop inventory (ACI), these crops make up approximately 95% of crop land use on average from 2015 to 2021. There are approximately 11,700 acres of certified organic production.[16] Blueberries and other specialty annual and perennial crops make up the remaining 5% (see Figure 1).

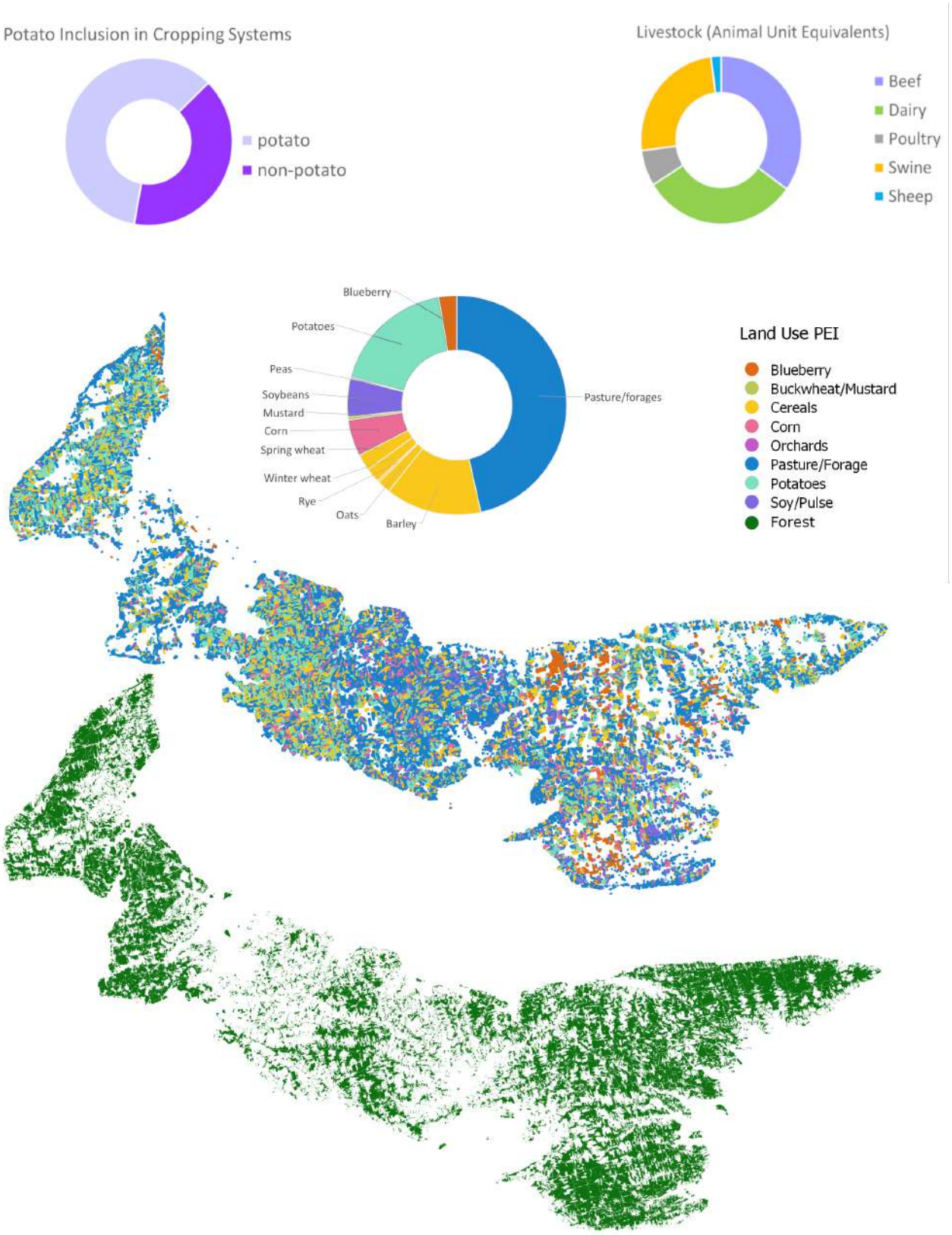
[16] https://www.princeedwardisland.ca/en/information/agriculture-and-land/agriculture-pei

TABLE 5 - LAND USE ON PRINCE EDWARD ISLAND

	Acres	Hectares
PEI Total Area (acres)	1,412,146.5	571,719
2000 Forest Cover (acres)	635,723.13	257,378
2000 Forest Cover (%)	45	
Agriculture (acres)	594,324	240,617
Agriculture (%)	43	

Blueberries and other specialty annual and perennial crops make up 5% of PEI's agricultural crop land use.

Figure 1 – Land Use and Livestock Estimates Based on Annual Crop Inventory and Census Data 2015-2021



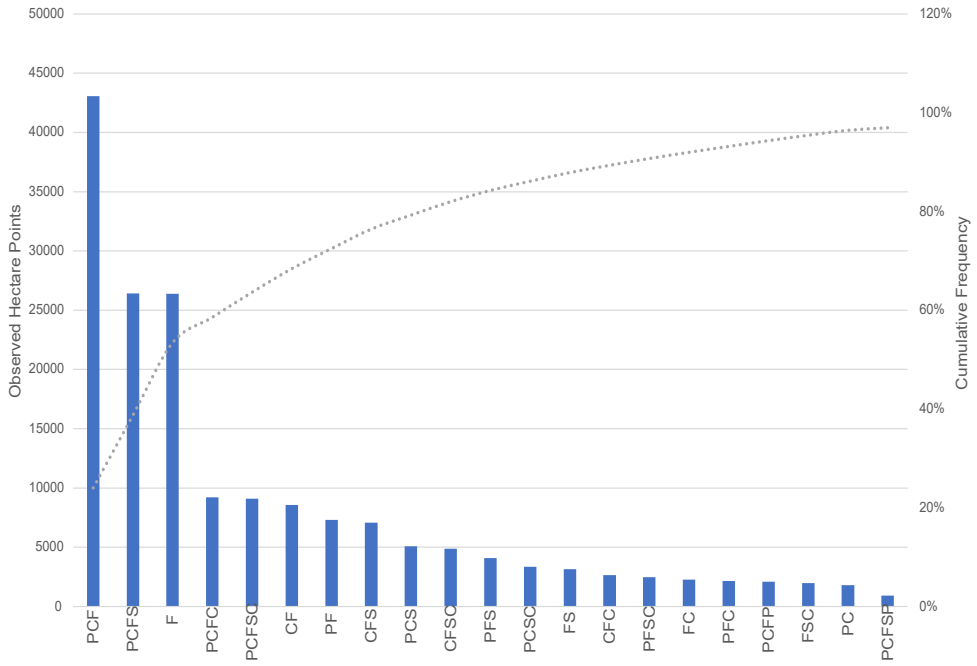
CROPPING SYSTEM SCENARIO DESIGN

To develop estimates for the cropping intensity of the main crops grown on PEI, annual crop inventory (ACI) maps produced by Agriculture and Agri-food Canada were used. These maps provide crop inventory data at an accuracy of 85% at a 30 meter spatial resolution. For the purposes of this analysis, raw, 30 meter resolution images were sampled on a 100 x 100 meter grid to reduce data processing requirements and create a single dataset containing all available PEI years (2011-2021).

From this dataset, rotation and crop intensity data could be extracted and filtered to generate intensity distributions for each crop to further refine GHG modeling inputs. Higher prevalence crops and cropping systems (Potato, Cereal, Forage, Soy, Corn) were prioritized to maximize land area represented in emissions estimates while minimizing the number of systems to model (see Figure 2). [17]

Three 9 year phases, each beginning with a potato crop, were extracted and averaged to generate intensity estimates for Potatoes, Cereals, Soybeans, Pulses, Corn, and Forages. For non-potato rotations, a checksum was used to filter out data points that had less than 8-10 valid crop codes for a 9 or 11 year cycle.[18] After filtering, ACI maps showed approximately 180,000 hectare points (100x100 meter grid points) of unambiguous crop data (general categories excluded), which is proportional to land statistics reported in Table 4. While potatoes only represent approximately 35,000 hectares (85,000 acres) in any given year, the amount of land on which potatoes are rotated is estimated to be 67% based on ACI rotational data (see Figure 1 above).

FIGURE 2 – Cropping Systems in ACI Data



Note: Rotation codes follow a potato-cereal-forage-soy-corn-pulse format. Example: A second 'C' or a 'C' after an 'F' or 'S' represents Corn

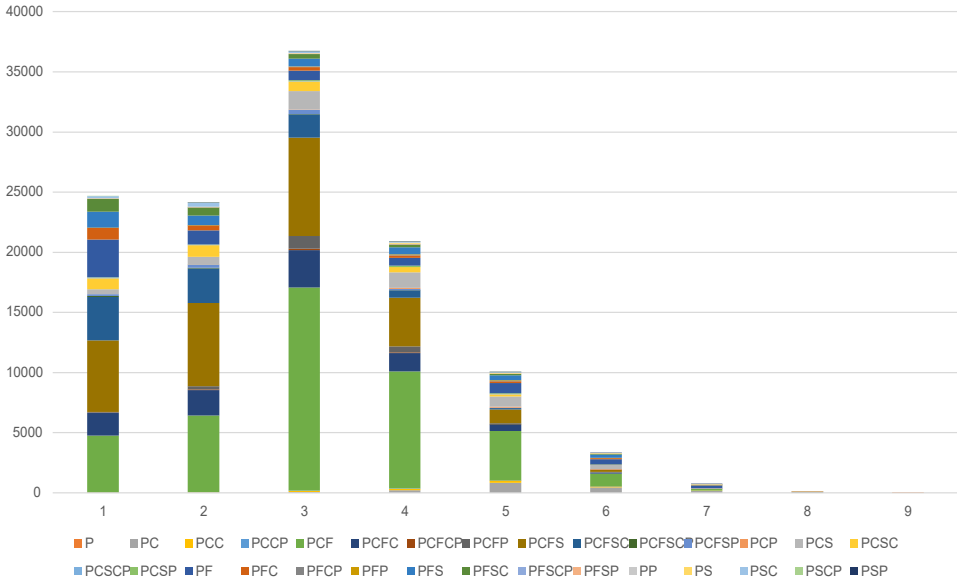
[17] 20% of systems representing 80% of frequency were modeled. Niche sectors such as blueberries, orchards, and intensive grazing systems are reviewed as one-off systems and not included in the main cropping mix intensity analysis due to limited data.

[18] This accounted for land that may have been cleared in year 1 or taken out of production, but filtered out anything that may have been a field border or marginal land with data ambiguity. 11 total years of data were available, but 9 year cycles were used to analyze potato cropping systems

[19] Wheat and corn could also be considered high intensity crops in terms of nitrogen and tillage, however, because they tend to follow potatoes, potato intensity serves to indicate cropping intensity without adding more variables. Statistical analysis below demonstrates how potato and forage intensity appear to dominate GHG emissions estimates

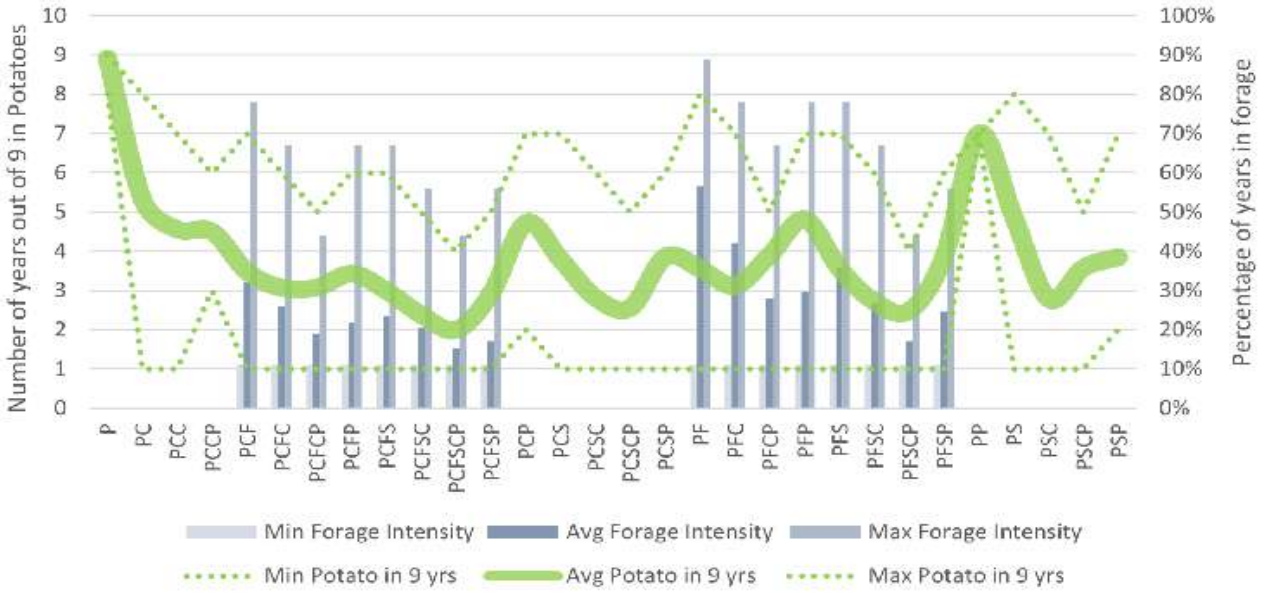
To maintain comparative integrity, manure associated emissions were excluded from cropping systems scenarios and added on based on beef and dairy livestock numbers. Potato intensity was measured as the number of years out of 9 that potatoes are grown. Forage intensity was measured as the number of crops per cycle divided by cycle years (forage years / 9 or forage years / 11). While the traditional 3 year potato rotation is still the dominant rotation on the Island, there are a significant amount of potatoes grown on rotations other than a 3 in 9 intensity (see Figure 3). In systems that include forages, forage is present 20-50% of the rotation on average (see Figure 4). [19]

Figure 3 - Potato Intensity Statistics



Note: ACI uses satellite imagery and covers all land area, including trial plots or narrow strip cropping which may include high intensity potatoes. As such, the maximum potato intensity numbers (7 -9 out of 9 years) don't represent a significant land area.

Figure 4 – Potato & Forage Intensity Statistics



Note: This represents all potato systems in ACI, some of which have low occurrence and were not included in the modeling run.

SOIL CARBON & GHG EMISSIONS MODELING FOR DOMINANT CROPPING SYSTEMS

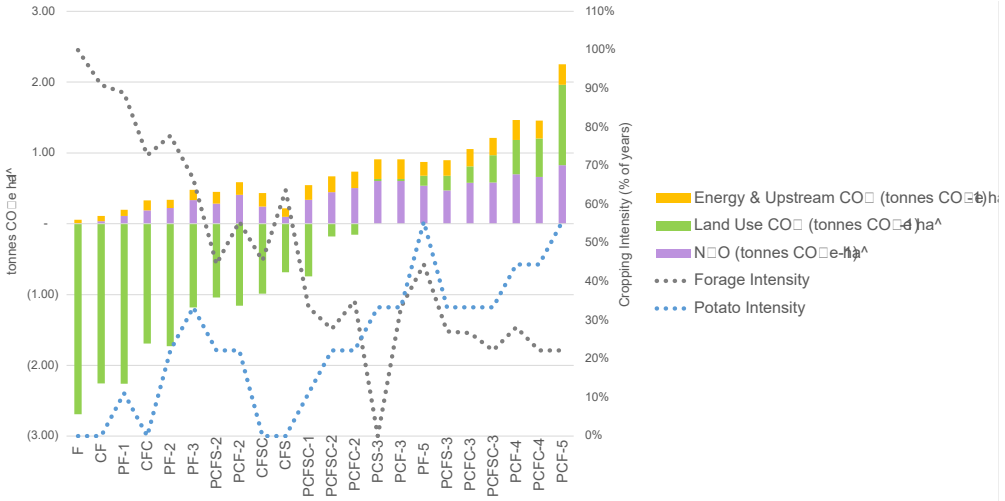
To model cropping systems GHG emissions, HOLOS, a free software program developed by AAFC, was configured with crop systems and intensity data, as well as soil type and climate parameters. HOLOS uses internationally recognized carbon models, including ICBM and IPCC-Tier 2, and is available as an open source package of algorithms for further development. PEIFA worked closely with the HOLOS development team to ensure model results were as accurate as possible. Short-listed cropping systems data from ACI analysis was fed into HOLOS to estimate GHG emissions per year, as well as soil carbon change over time. To further reduce complexity, potato intensity was limited to the most frequent intensity scenarios in a given potato system.[20] As suggested by Figure 3, two, three, and four year potato rotations were on average the most prevalent in any cropping system. Systems were added to the model until sufficient coverage had been reached for the various system/intensity scenarios (80% system frequency and 80% potato/forage intensity within each system).

[20] This ultimately resulted in a matrix with cropping systems on one axis and potato and/or forage intensity on another to represent two key variables: (1) crops grown in a system and (2) rotational structure over time

VARIATION IN GHG EMISSIONS BY CROPPING SYSTEM

Estimated GHG emissions represent the relative annual carbon balance of each system, accounting for emissions from fertilizers (e.g N2O), energy use, and land use change CO2 emissions (assuming no deforestation occurred). All GHG estimations are represented as CO2 equivalents (CO2e), which allows for direct comparison between each emission source. Forage and potato intensity (number of years per 9 year cycle) appear to explain the most variation in cropping system GHG budget among the subset of rotations modeled (see Figure 5). It's important to note that these estimates represent probabilities for carbon storage before accounting for specific nuances to individual systems. Nutrient use, tillage regime, soil pH, forage type and quality were chosen based on existing data, crop removal tables, and agronomic consulting to provide a controlled comparison of different crop mixes and rotational structures.

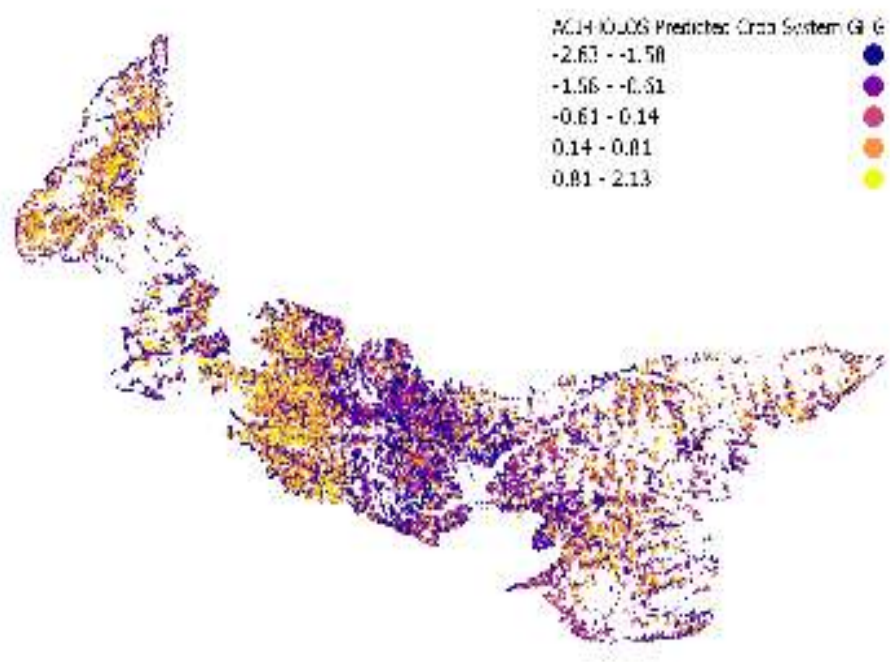
FIGURE 5 – Modeled average annual GHG emissions per hectare for primary cropping systems



Note: Crop systems follow a Pot-Cer-For-Soy-Cor-Pul coding. A "C" following a "C", "F", or "S" would mean Corn. A hyphen and number indicates a potato rotation and the intensity (years out of 9) of potatoes in the rotation. These GHG estimates include a land use change component which differs from how the National Inventory reports annual emissions. This chart represents variation between systems measured as average annual net emissions per area (based on total emissions per total land area of a rotation) and assuming no recent land conversion has been applied to cropland. Negative values indicate net carbon storage or negative GHG emissions.

The dataset produced by HOLOS GHG reporting on dominant cropping systems allowed for further analysis of the main predictors of GHG emissions across all systems. A random forest regression analysis showed that forage and potato intensity predict a significant amount of variation in CO2 and N2O GHG emissions per hectare, with cereal and soybean frequency predicting a smaller amount. Generally speaking, regression modeling suggested that the higher the potato intensity and the lower the forage intensity, the higher the CO2 and N2O emissions (see Appendix B for statistical output). The regression fit allowed for a larger scale, whole-island spatial GHG estimate of all cropping systems in addition to the 11 dominant crop systems directly modeled (see Figure 11). CH4 emissions associated with livestock and manure were not included as they could not be spatially estimated. Livestock GHG estimates must be added to crop systems estimates as a separate layer given no data exists on associations between livestock and cropland. In terms of specific crop system GHG emissions, areas with high intensity potato production generally have higher modeled GHG emissions, suggesting they are the areas with the most potential to make sizable gains in reductions. In the context of carbon markets, this presents an opportunity to generate carbon revenues to help offset the increased costs of deploying enhanced GHG reduction BMP's in those areas.

FIGURE 6 – Modeled average CO2 + N2O emissions (tonnes CO2e ha-1 yr-1)

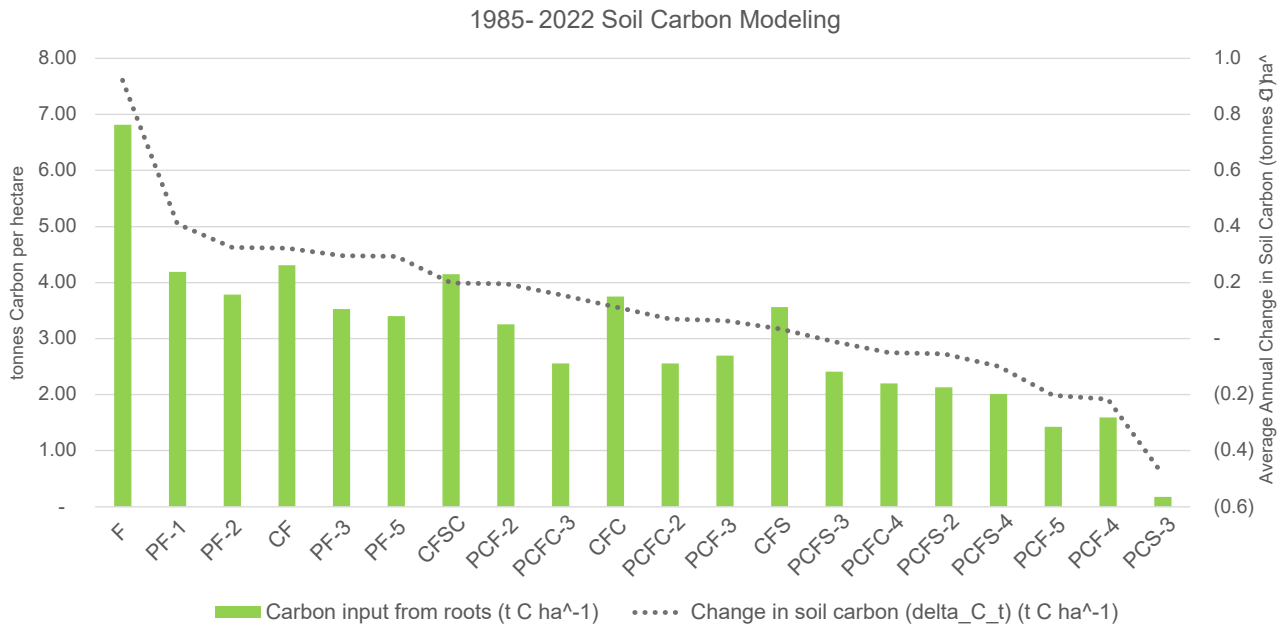


Note: This map includes land use change CO2 emissions from perennials. Random forest regression performed similarly with or without land use included, suggesting that potato, forage, and cereal intensity are good predictors of GHG emissions as reported in the National Inventory Annual Emissions table (excluding land use change). This map does not account for land that has been recently converted from forest to farmland and represents GHG balance only from the cropping system, including perennial storage. Land conversion would offset storage/emissions reductions.

SOIL CARBON MODELING

As is observed in GHG estimates for cropping systems, perennial forage/pasture inclusion in rotations has a distinct effect on the carbon dynamics of the cropping system. Figure 7 represents the estimated relative changes in soil carbon over a period spanning 1985 to 2022 for dominant crop systems and crop intensities. As discussed above, some systems with higher potato frequencies may be comparable to those with lower frequencies, but generally, the trend suggests that lower intensity systems with more forage increase the probability that appreciable amounts of carbon can be stored. [21]

FIGURE 7 – Carbon input from roots and modeled change in soil carbon for different crop systems



Note: The data presented here is best used to understand differences between systems and not whether a given system will yield an exact carbon gain or loss. PEI soil quality monitoring [22] suggests intensive cropping systems have seen decreases in soil organic matter and provides a secondary confirmation of modeling estimates, but the rate of increase or decrease may vary with management factors and changes in climate.

[21] These figures are intended to represent change in carbon storage potential (in terms of probability). The scales on each axis do not represent with any certainty the exact amount of soil carbon a given system has accumulated. In the context of carbon marketing, these estimates would be verified by in field measurement. As such, this is step one of a two-step process.

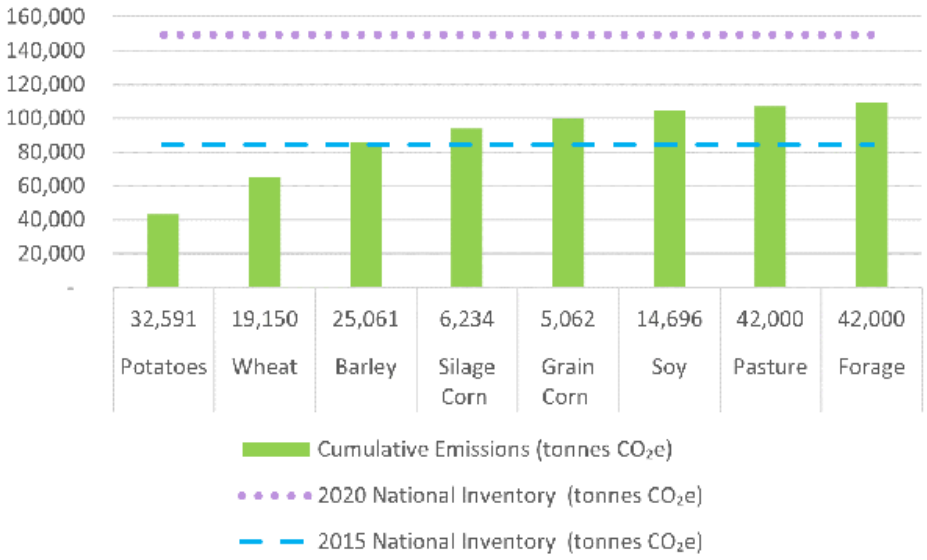
[22] https://www.princeedwardisland.ca/sites/default/files/publications/pei_soils_quality_monitoring_report_2020.pdf

Photo: https://www.dekalbasgrowdeltapine.com/en-us/dekalb/products/alfalfa.html

PEI CROPLAND TOTAL EMISSIONS

In addition to crop system modeling on a per hectare basis, annual cropland estimates were used to model PEI's annual cropland emissions for comparison with annual National Inventory Estimates. Because the main crops identified above represent approximately 95% of the land use, niche crops such as other vegetables, blueberries and orchards were excluded and/or modeled separately (see Appendix C for blueberry estimates). Modeled cropland total emissions fell within the National Inventory annual emissions estimates between 2015 and 2020. With the addition of crops not included in the model (blueberries, orchards), the totals may be slightly higher but would remain proportional (see Figure 8).

FIGURE 8 – PEI Crop Inventory Modeled Total Emissions



Note: Cropland area is in hectares and is reported above crop axis labels in the chart. Crop emissions data from HOLOS GHG model. Estimated Total Emissions from NIR Table A12-3: GHG Emissions for Prince Edward Island by Canadian Economic Sector

LIVESTOCK EMISSIONS

As has been reported in the literature, beef and dairy production produce the majority of emissions in the livestock sector. On a per head basis, significant variation exists across jurisdictions so it can be difficult to verify modeling data against other publications. [23] Pasturing, diet, stocking rates, and bedding can all impact GHG emissions per head. GHG emissions estimates were compared with National Inventory reporting to assess accuracy (see Figure 9). Additionally, emissions per head were compared with external estimates for certain classes of animal (feeder, lactating cow, etc) and were generally slightly lower; largely due to the averaging effect of young and mature animals versus reported figures for mature animals only (see Figure 10). Manure emissions were estimated by taking total GHG emissions from manure and dividing by estimated total production of manure based on PEI livestock inventory to generate an emissions intensity for each type of applied manure (see Figure 11).

[23] Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A. & Tempio, G. 2013. Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO), Rome.

FIGURE 9 – Modeled Livestock GHG Emissions per year

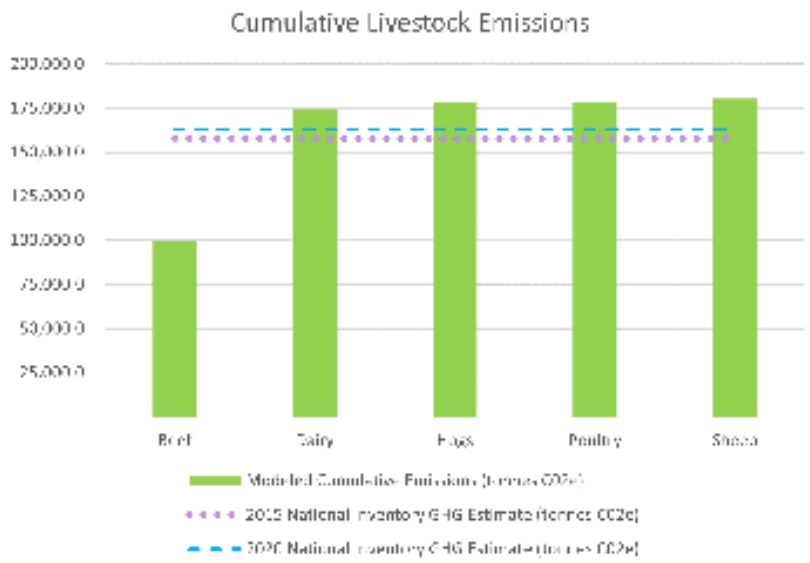
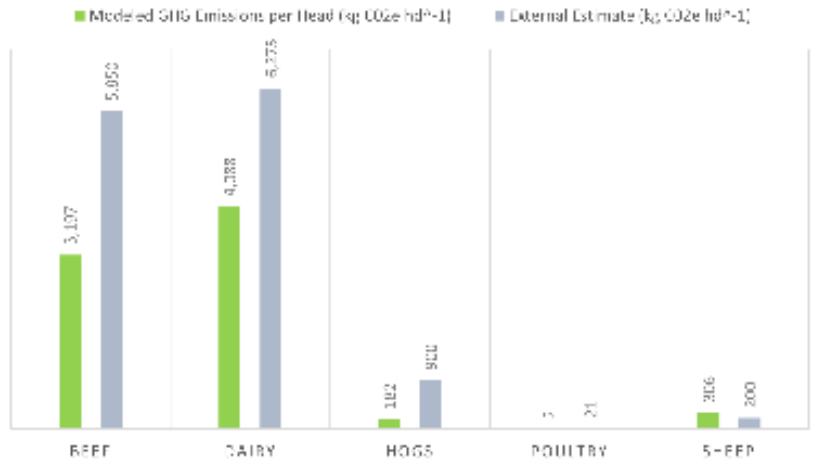
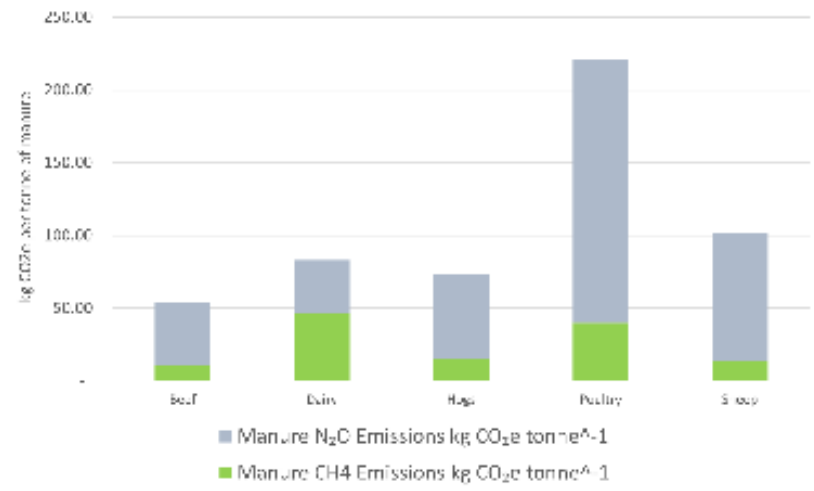


FIGURE 10 – Modeled Livestock GHG Emissions per head per year



Note: External emissions estimates for dairy, beef, and hogs are based on lactating, feeder, and grower animal types which would be higher than the average across all animal types (young and mature).

FIGURE 11 – Modeled GHG Emissions Per Unit of Manure Based on PEI Inventory

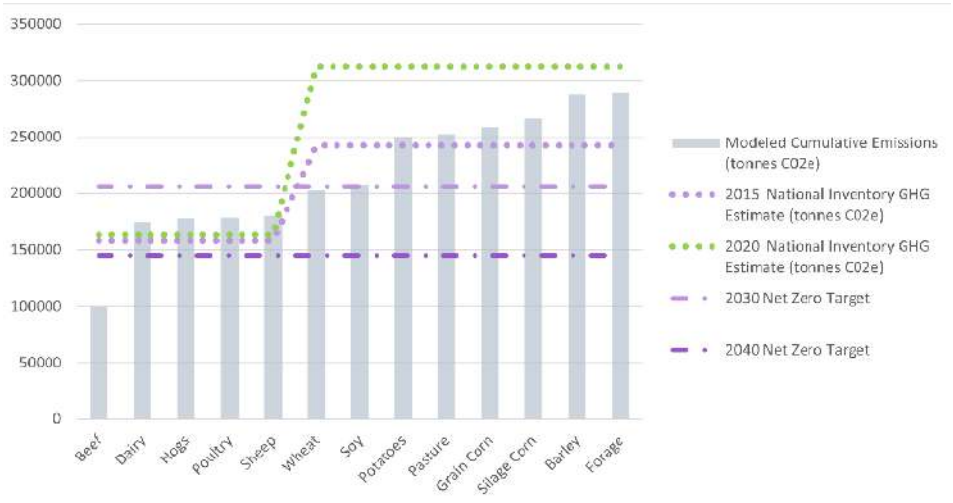


Note: This chart represents modeled total manure GHG emissions (in kg C02e) for each livestock sector divided by total manure produced in metric tonnes. It does not account for soil carbon increases as a result of land application.

TOTAL GHG EMISSIONS FOR PEI LIVESTOCK AND CROPS

Emissions estimates were compared with National Inventory reports to assess if the models were capturing a proportionate amount of emissions such that the modeled baseline would serve as an indicator of GHG reductions potential using various BMPs. Livestock emissions slightly overestimated National Inventory estimates for livestock in 2015 and 2020 whereas crop GHG modeling was within the range of 2015-2020 emissions (see Figure 12). Baseline estimates were considered adequate to model BMP's and estimate GHG reduction potential.

FIGURE 12– Total GHG Emissions Based on PEI Livestock and Crop Inventory



GHG REDUCTION PRACTICES

The PEIFA intends to refine GHG baseline estimations over time as modeling accuracy improves and more in-field data is produced. As practices change, the baseline will continue to shift. Using model data in this way it is possible to continuously calibrate and examine change of practice effects on shifting GHG baseline estimates to maintain strategic focus on the practices which offer the most reductions for the least disruptive adaptations that must happen on Island farms. The primary practice changes reported in the literature are as follows:

1. Longer and/or improved crop rotations – Improved rotations can add up to 1 t/ha/yr of soil Carbon.[15] This includes reducing high intensity crops allowing more time for soil roots to build Carbon. Modeling estimates above (Figure 7) suggest a range of 0.6 t/ha/yr (2.2 t CO2e/ha/yr) between a potato cereal soybean and the permanent forage system.
2. Cover Cropping - Cover cropping extends root growth longer into the cool season and protects soil against wind and rain erosion. Literature suggests a range of .32 - 1 t/ha/yr of soil Carbon (1.0-3.7 t CO2e/ha/yr).[15]
3. Nutrient management – Optimizing nutrient use efficiency, especially for Nitrogen fertilizers is shown to reduce N2O emissions. The use of slow-release fertilizers combined with rate reductions and biological nitrogen supply testing has resulted in N2O reductions of up to 100% in PEI Trials.[24] Modeling shows reductions of up to 250 kg CO2e per hectare are possible with rate reductions alone.
4. Tillage reduction – Decreasing soil disturbance and slowing down decomposition of soil carbon can add up to 0.4 mt of soil Carbon per hectare per year (1.5 t CO2e/ha/yr).[15]
5. Increased Perennials in Rotation – Perennials offer rest periods for soil and enhance soil carbon stocks via root systems. They also represent an alternative source for Nitrogen. It is estimated increased forages can add up to 0.5 mt of soil Carbon per hectare per year (1.8 t CO2e/ha/yr).[15] Modeling suggests the ratio of forages to cash crops is a strong predictor of average annual GHG emissions in cropping systems (Figure 5).
6. Restoration of grassland and woodland – One hectare of woodland represents 100-250 metric tonnes of Carbon.[25] It would take 10 hectares of sustainably managed farmland (1-2 t/ha/yr soil C additions) 10 years to offset this carbon loss if deforested. Afforestation and/or grassland restoration can add up to 1 tonne of soil Carbon per hectare per year (3.7 t CO2e/ha/yr).[15]
7. Agroforestry and willow plantations – Recent research on planting willows in erosion deposition prone areas found they can intercept significant quantities of nitrogen and store 15 t CO2e /ha/yr of carbon.[26]

[24] Burton, D., Stiles, K., Watt, S. (2022). Implementation 4R Nitrogen Management Practices to Reduce N2O Emissions from Rainfed Potato Production [Report]. Submitted to Fertilizer Canada.

[25] Anthony R.TaylorA.R. Taylor, Jian R.WangJ.R. Wang, and Han Y.H.ChenH.Y.H. Chen. Carbon storage in a chronosequence of red spruce (Picea rubens) forests in central Nova Scotia, Canada. Canadian Journal of Forest Research. 37(11): 2260-2269. https://doi.org/10.1139/X07-080

[26] Willows are not as scalable as cropland so total GHG reductions would be limited by land area. See Ramsay, Murphy. (2021). Economics of Willow Buffers. Updated cost-benefit analysis of willow production on Prince Edward Island. East Prince Agri-Environmental Association

8. Improved grazing practices – Can add up to 0.7 t/ha/yr (2.6 t CO2e/ha/yr) through intensive management (stocking rates and density, paddock design) and productivity maximization (cultivar selection, nutrient management, etc)[27]
9. Improved diet, vaccines, and feed quality for methane reduction - CH4 reductions can be realized from 5-100% depending on the practice.[28] Asparagopsis has been found to reduce methane emissions in lactating dairy cattle by 50%.[29] Modeling suggests reductions potentials of 1.2-1.3 t CO2e per head of beef and dairy (Figure 14.1).
10. Improved Manure Management - Sulfur additions to liquid manure are found to significantly reduce CH4 emissions by >75%. Injection of liquid manure and/or incorporation of solid manure immediately after application with cover crops can also reduce nitrate leaching and N2O emissions.

[27] Paustian K, Larson E, Kent J, Marx E and Swan A (2019) Soil C Sequestration as a Biological Negative Emission Strategy. Front. Clim. 1:8. doi: 10.3389/fclim.2019.00008

[28] Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A. & Tempio, G. 2013. Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO), Rome.

[29] Roque, B. M., Salwen, J. K., Kinley, R., & Kebreab, E. (2019). Inclusion of Asparagopsis armata in lactating dairy cows' diet reduces enteric methane emission by over 50 percent. Journal of Cleaner Production, 234, 132-138.

MODELING CHANGE OF PRACTICE FOR GHG EMISSIONS REDUCTIONS

Change of practice was modeled for practices that could be configured in the current HOLOS software package to develop GHG reduction factors (see Table 6). Cover cropping and reduced tillage on applicable crops together with nitrogen rate reductions of approximately 20% on potatoes, wheat, and corn suggests there is potential to reduce cropping system emissions by 45,000 tonnes CO2e (see Figure 13). Nitrogen rate reductions alone could reduce emissions by 0.2 - 0.3 tonnes CO2e per hectare per year (see Figure 14). Soil carbon modeling suggests that by transitioning to cover cropping and reduced tillage as a widely adopted practice, a hectare of Island cropland would, on average, hold 12 tonnes more Carbon per hectare (.32 tonnes per hectare per year) by the year 2070, with maximum increases of 20 tonnes Carbon per hectare (.54 tonnes per hectare per year) in cropping systems with low potato intensity and higher forage intensity (Figure 15). This agrees with published literature as well as baseline soil carbon modeling above which shows approximately 0.3 tonnes of Carbon per hectare per year as the differential between permanent grassland and more intensive rotations. In terms of GHG reductions, potatoes respond the strongest to BMP implementation, due to targeted nitrogen reductions and the magnitude of nitrogen used.

If cover cropping and reduced tillage were widely adopted a hectare of land could hold 12 tonnes more carbon per hectare by 2070.

TABLE 6 - Modeled Crop System BMP GHG Reductions

Practice	Units	Annual GHG Reduction (t Co2e/yr)	Hectares Assumed	Modeled GHG Reduction Per Hectare (t Co2e/ha/yr)	Max External Literature Estimates (t Co2e/ha/yr)
Reduced N	t C02e/yr	16,068.96	102,793.52	0.16	0.25
Cover Cropping	t C02e/yr	31,223.20	65,139.27	0.48	3.67
Reduced Tillage	t C02e/yr	4,379.80	29,971.66	0.15	1.5
Rotation Length	t C02e/yr	6,371.33	11,406.88	0.56	3.67

Note: Only a subset of GHG reducing practices could be modeled in HOLOS.
The remaining practices are evaluated in Sections 3 & 4

FIGURE 13 – Modeled Annual GHG reductions with reduced tillage, cover cropping, and 20% reduced nitrogen rates

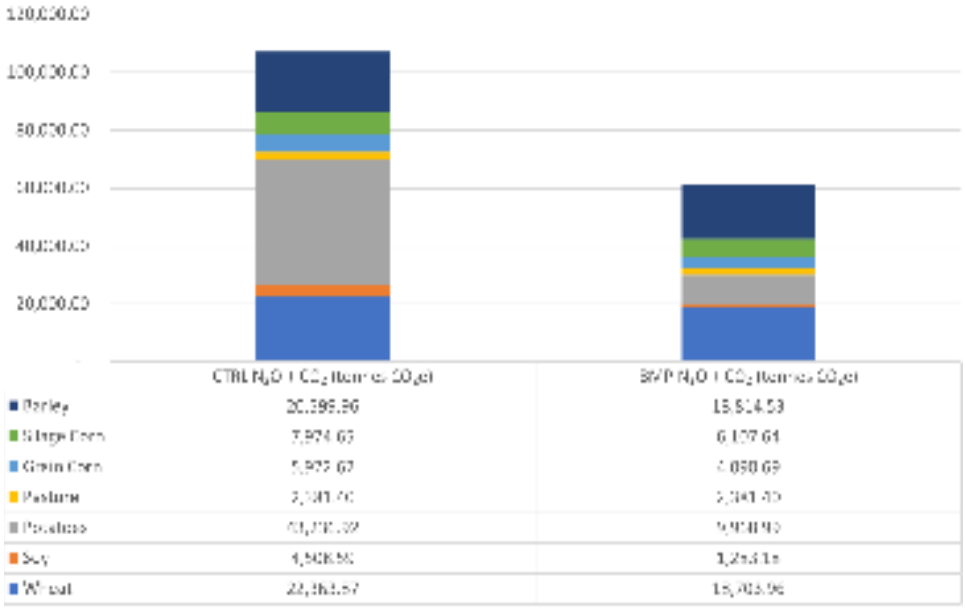


FIGURE 14 – Modeled N2O Emissions Reductions at Various N Rates

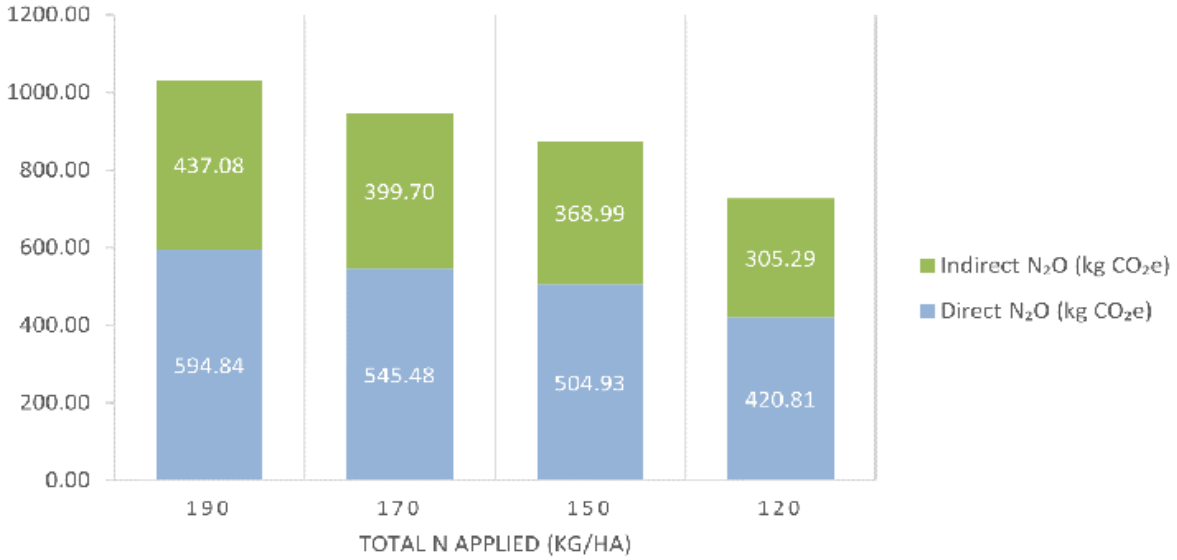
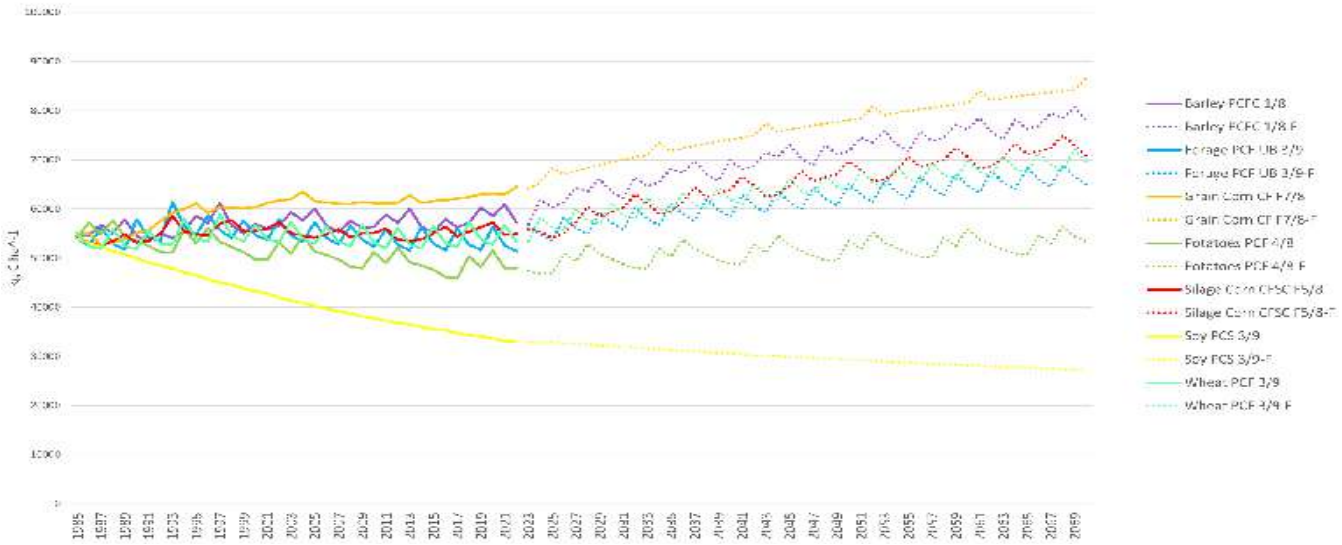


FIGURE 15 – Modeled Soil Organic Carbon Change Over Time Using Cover Crops and Reduced Tillage



Note: These models were done using the Introductory Carbon Balance Model (ICBM) with assumed management and climate factor adjustments. HOLOS modeling software is currently shifting to IPCC-Tier 2 soil carbon modeling which will provide more accuracy in terms of specific values for each system. This chart models variation between systems arising from current and projected practices.

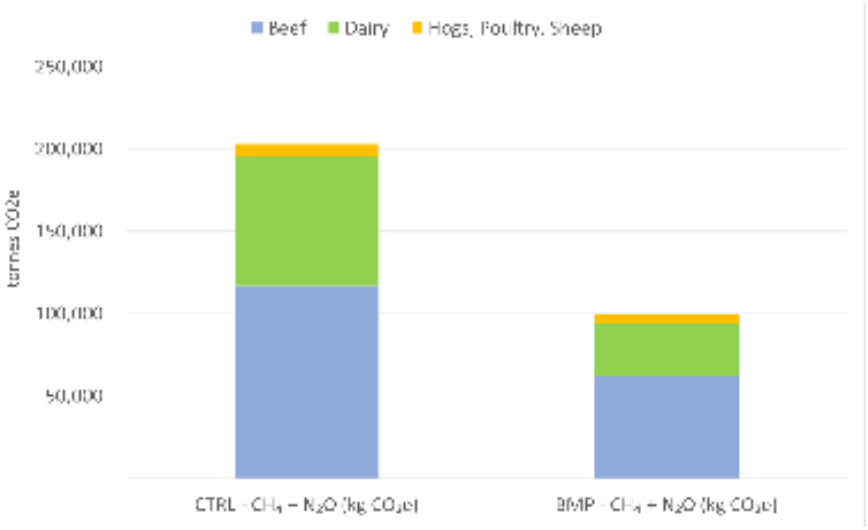
Livestock emissions reductions were estimated based on livestocks models used for baseline analysis combined with best management practices for reducing CH4, N2O, and CO2 emissions through both diet changes and manure management. Table 7 outlines the changes included for estimating potential livestock GHG reductions. See Figures 16 - 18 for GHG emissions reductions results.

TABLE 7 - Modeled Changes to Livestock & Manure Management

Sector	Housing	Manure	Diet	Supplement
Beef	Confined to pastured	Solid to pastured	Increased Pasture	No supplement + asparagopsis
Dairy	No change	Covered storage + acidified with sulfur + anaerobic digestion	No change	No supplement to 5% fat + asparagopsis
Hogs	No change	Covered storage	No change	No change
Poultry	No change	No change	No change	No change
Sheep	Confined	Solid to Pasture	Increased Pasture	No change

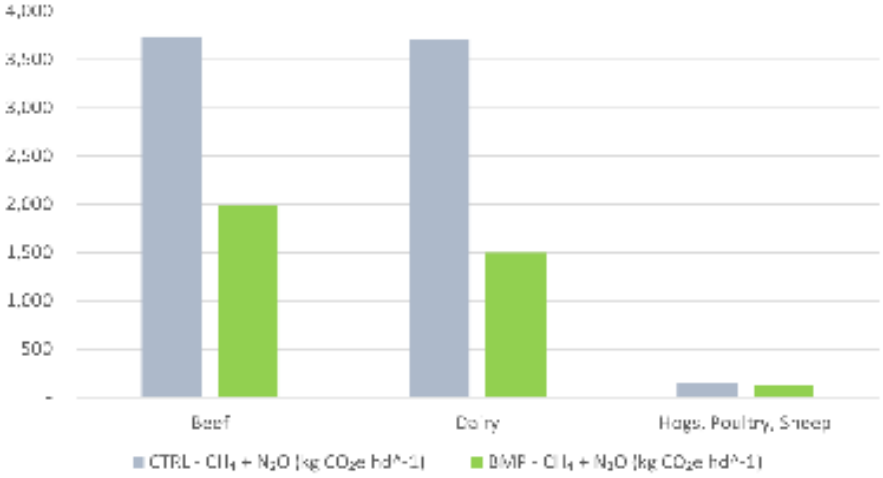
Note: Intensified grazing may not be fully accounted for as the HOLOS software does not distinguish the types of pasturing. It is reviewed separately in sections below. Anaerobic digestion assumes solid dairy manure would be diverted at a rate of 100 tonnes per day from an estimated manure inventory of 660,000 tonnes of wet weight manure, including solid and liquid.

Figure 16 – PEI Livestock Emissions Reduction Potential



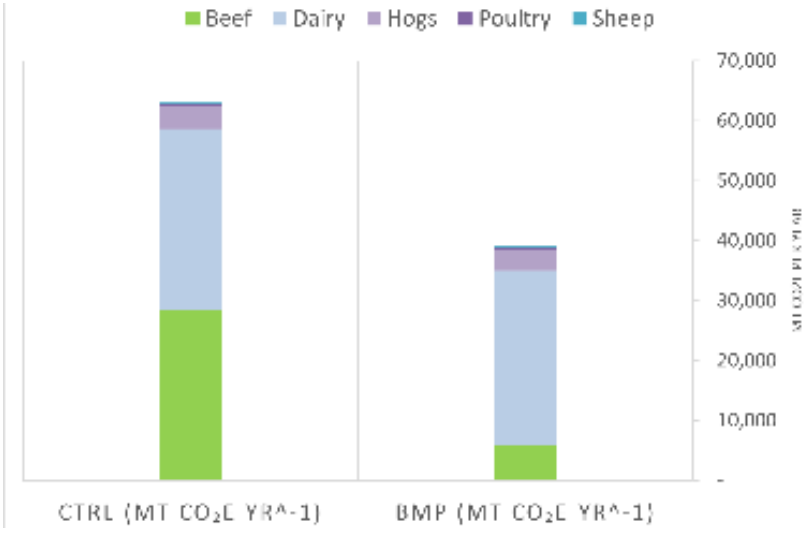
Note: GHG reductions are approximately 80% derived from asparagopsis for enteric methane reduction and the inclusion of sulfur for liquid manure storages. Asparagopsis has been commercialized in Australia and New Zealand and will soon be available in Canada. Acidification of liquid manure with sulfur is still in the research phase and concerts about acidification on equipment and ecosystem effects are still being evaluated. The remaining 20% of reductions are derived from other BMP's listed in Table 7.

Figure 17 - Modeled Livestock Emissions Reductions Per Head



Note: This represents GHG reductions that were modeled based on reported BMP's for GHG reduction. GHG reductions for hogs, poultry, and sheep may increase as more modeling improves and more BMP's are developed.

Figure 18 – PEI Manure Emissions Reduction Potential



PATHWAY TO CARBON REVENUES

In order to initiate wide scale adoption of practices identified above, investments in infrastructure and incremental costs of adoption must be offset in order to ensure practice adoption can continue in the face of limited profitability arising from increasing costs, depressed price growth, and variable weather. As noted, environmental goods and services (EG&S) programs are positioned to provide payments for some of these practices, but in order to ensure long term cash flows, carbon markets can be pursued for a subset of these practices. As the price of carbon increases, the potential to produce carbon alongside food presents a synergistic opportunity for Island producers in that, in addition to Carbon revenues, farms will also benefit from healthier soil, stronger crop yields, and overall increased resilience to climate change.

CARBON MARKET PATHWAY

Alloporus Environmental consulting services were contracted by PEIFA to develop a pathway sequence for obtaining carbon credits. It was determined that Verra is the appropriate carbon registry for a project focused on cropland best management practices given that VM0042, Methodology For Improved Agricultural Land Management, will accommodate specific cropping system BMP's identified as currently practical. The modeling data and estimates reported here serve as a baseline description of where Island agriculture currently stands (on a systems level of detail), and what the most obvious paths to carbon revenues may be. Pathway analysis includes a sequence of steps that will ultimately determine the feasibility and scope of a carbon credit project registration process. To develop an application for registration, the following sequence must be completed:

1. Scope and describe the common practice for the dominant PEI arable production systems
    a. ACI data provides good data on crop rotation, but much less is known about the variation in fertilizer usage and soil amendments for each cropping system. Ranges are known and may suffice, but further engagement with industry will be needed to determine how much rate reduction potential exists. Modeling provides an estimate of GHG reductions from average agronomic rates.
2. Scope the project activity options that would be a change to common practice
    a. Cover cropping, improved Nitrogen management, reduced/zero tillage, increased perennials, improved rotations, intensive cell grazing, and forestry/agroforestry are the primary activities that represent potential from a carbon storage perspective.
3. Create detailed descriptions of realistic project activities AND assess the frequency and extent of these activities among PEI farms AND assess the likelihood of farmer uptake

Potential to produce carbon alongside food presents a synergistic opportunity for Island producers. Farms will benefit from healthier soil, stronger crop yields, and overall increased resilience to climate change.

a. Improved rotations, increased perennials, and cover cropping

i. Lengthening rotations will be a slow graduated process assuming policy remains unchanged. The carbon gains associated with potato/forage intensity are significant over time. Transitioning more land to perennial production and lengthening potato rotations would likely require additional incentives beyond projected carbon revenues but does represent sizable carbon storage potential.

ii. Winter rye following potatoes, corn, or soybeans - Increasing acres each year, potentially 20-30% of acres in last 5 years with good probability for more

iii.Annual cereals/oilseeds/pulses preceding potatoes - Increasing acres each year, potentially 20-30% of acres in last 5 years with good probability for more

iv. Annual/perennial ryegrass in corn - Less than 20% with some resistance to adopt.

b. Reduced/zero tillage

i. Many producers have switched to residue tillage equipment within the last 5-10 years. Additionality may be more challenging to demonstrate here without farm records and/or GIS records of field operations showing number of passes. The traditional practice of plow-disc-harrow for land preparation would still serve as a baseline.

ii. Some producers are experimenting with no-till but it's unknown to what extent it has been adopted for grain and oilseed crops. No-till practices will be easier to demonstrate additionality.

c. Improved Nutrient Management

i. Overall rate reductions based on better estimations of alternative sources of N and crop response, which can include nitrogen benefits from cover crops. Frequency and adoption is variable with growers concerned about yield loss. Increasing fertilizer prices are incentivizing more radical rate reductions.

d. Improved Grazing Practices

i. Transitioning to intensified grazing for ruminants - There is interest in the beef sector to decrease feed costs and improve branding around beef production. At present the frequency is low and it is expected uptake will follow a slower curve than dietary change practices.

e. Agroforestry

i. Willow plantations and alley cropping represent novel approaches to incorporating trees and shrubs into cropland without taking an entire field out of production. The carbon gains from willows are documented and it is assumed strips of shrubs and trees in fields could achieve similar carbon storage. Frequency and uptake are limited by land topography for willows and willingness to defer revenues into the future for alley cropping involving cash crop trees such as a hazelnut, walnut, cherry, sugar maple, etc.

4. Determine ownership of the project and the credits
   a. Ownership and compensation structure should be determined based on any carbon and/or land rights or proposed contractual arrangements for project instances.

What Verra calls the project proponent can be different to the project owner (eg a carbon project developer and a farmer), but project activity requirements are met by the project owner

5. Rank the project activity options on ease of implementation after a ballpark assessment of credit volume
    a. Table x outlines the estimation ease of implementation and ballpark assessments of credit volume for various practices.

ALTERNATIVE EG&S REVENUES

Practices not covered by VM0042 or not currently eligible for carbon markets are equally important to consider in the larger context of meeting emissions targets. To that end, PEIFA is working to identify pathways and programs that will provide offsetting revenues. Practices with significant GHG reduction potential not accommodated by a carbon project using VM0042 include:

1. IMPROVED LIVESTOCK DIET AND MANURE MANAGEMENT
    a. Methane (CH4) reductions from asparagopsis are significant and are considered to be a practical option for all ruminant production. This represents a substantial opportunity for GHG reductions (50-80% of reductions in enteric methane emissions), but little information is available on costs. Other methane reducing technologies can cost as much as $300 per head per year. Methane reductions from covered lagoons and the use of sulfur acidification technology can reduce emissions by up to 88%. These two BMP categories represent approximately 80,000 tonnes of CO2e reduction; almost twice that of modeled crop system reductions. A phase 2 Carbon market project would fit under Verra's VM0041 methodology for livestock.

By improving livestock diet and manure management represent approximately 80,000 tonnes of CO2e reduction.

2. AFFORESTATION AND REFORESTATION
    a. Taking marginal land out of production entirely and reforesting can add significant carbon storage to a project area, especially when other agronomic options may be limited. Shelter-belts, refuge areas, and complete afforestation represent the highest carbon storage potential but perhaps the lowest scale up and uptake potential without additional incentives beyond carbon revenues. One hectare of established forested land can represent up to 300 tonnes of Carbon composed of biomass and dead organic matter. In order to store carbon, forests must be sustainably planned and managed. [30]

3. ANAEROBIC DIGESTION, BIOCHAR PRODUCTION AND ON-FARM WETLANDS
    a. Diverting a portion of manure to an anaerobic digester can produce a renewable natural gas revenue opportunity as well as reduce GHG emissions by an estimated 0.15 tonnes of CO2e per tonne of wet weight manure as well as producing a nutrient rich digestate that can be applied to fields as an amendment. All full cost-benefit analysis and farm cluster evaluation would be required to ensure economic feasibility.
    b. Biochar is an emerging technology that partially combusts carbon sources to produce a highly stable carbon amendment that holds nutrients and enriches soil. GHG reductions will vary depending on the source of the raw material (local versus imported, biomass type, etc.

[30] Not all forests are carbon sinks. Certain tree species and management methods (or lack thereof) can lead to forests becoming a source of carbon in some years.

Biodiesel can be produced through the biochar process as well. Currently, carbon markets treat biochar as a waste stream so there are no credits assigned for the increase in soil organic matter through using biochar. However, there is potential to produce biochar to create an enriched soil amendment that would (1) create a carbon stable end use for forestry waste products and (2) accelerate increases in soil organic matter, water holding capacity, and nutrient buffering on lands where biochar is applied.

c. On-farm wetlands also have the potential to sink carbon and are currently being researched for carbon credit potential

In addition to the mitigation value (GHG reduction value, risk mitigation value) most, if not all of the practices listed provide numerous co-benefits which increase the adaptive capacity of farms. Adaptive value includes increased resilience in soils to buffer against extreme weather events, increased animal well-being and farm profitability from more productive, cost efficient pasturing, and healthier ecosystems from reduced nutrient usage and increased perennial and forest cover. Given that most of these adaptive values are unlocked slowly over time, generating direct revenues from practice change is critical to address identified risks and take advantage of opportunities as quickly as possible while ensuring that new programs and incentives do not cannibalize the opportunity to leverage practice change in carbon markets (in terms of additionality). Table 8 provides a summary of proposed general practice categories for a roadmap to net-zero. Table 9 provides a summary of specific practices, cost estimates, and documented GHG reductions as they relate to carbon markets and/or EG&S revenues.

Note: OFCAF and SCAP payments are excluded as long term revenue options as they generally apply to a short term and are negotiated on <5 year cycles and, in the case of OFCAF, exclude land that has been previously cover cropped. By contrast, carbon market projects are usually at least 10-20 years and generally include a lookback period of 5 years. Only programs that will provide persistent support for practice change coupled with GHG reductions are included in the EG&S column.

TABLE 8 - BMP CO2e Estimations and Project Sizing for Carbon Marketing

Change of Practice	Carbon Market Eligibility VM0042	Implementation Timeline	Long-term Carbon or EG&S Revenue Options
Improved rotations, increased perennials, and cover cropping	yes	1-2 yrs	Phase 1 Carbon Market
Reduce/zero tillage	yes	1-2 yrs	Phase 1 Carbon Market
Improved Nutrient Management	yes	1-2 yrs	Phase 1 Carbon Market
Improved Grazing Practices	yes	3-5 yrs	Phase 1 Carbon Market
Agroforestry	yes	5 yrs	Phase 1 Carbon Market
Improved Livestock Diet and Manure Management	no	3-5 yrs	Phase 2 Carbon Market (VM0041)
Afforestation and reforestation	no	5 yrs	PEI Carbon Capture
Anaerobic digestion and Biochar production	no	3-5 yrs	Unclear
On- Farm wetlands	no	3-5 yrs	Unclear

TABLE 9 - BMP CO2E ESTIMATIONS AND PROJECT SIZING FOR EG&S AND CARBON MARKETS

Practice	Units	Ease of Implementation	Incremental cost ($/unit)	Incremental Revenue ($/unit)	Min Carbon Price to Offset ($/Tonne CO_2e)	CO2e Sequestration Estimate (tonnes CO2e/unit)	Potential Project Units	Total Sequestration Potential (tonnes CO2e)	Initial carbon Market Project Size (tonnes CO2e)
Cover Cropping [1]	ha/yr	High	(75.00)	71.00	4.00	0.47	65,000	30,550	30,550
Reduced Tillage [6]	ha/yr	High	15.00	-	-	0.15	30,000	4,500	4,500
Increased Perennials [5]	ha/yr	Moderate, Low	450.65	(595.00)	144.35	0.5	11,000	5,500	
Rotation Length [2]	ha/yr	Moderate, Low	250.00	(291.00)	41.00	0.56	11,000	6,160	
Nitrogen Reduction [3]	ha/yr	High	38.47	(48.00)	9.53	0.16	100,000	16,000	16,000
Improved Grazing [4]	ha/yr	Moderate, Low	(400.00)	600.00	-	2	3,000	6,000	6,000
Dairy Improved Diet [7]	head/yr	Moderate	(313.90)	-	313.90	1.2	20,000	24,000	
Beef Improved Diet [8]	head/yr	High	-	-	-	1.6	30,000	48,000	
Manure Management [11]	head/yr	Moderate				0.5	14,500	7250	
Anaerobic Digestion [12]	t/t	Low				0.15	36,500	5475	
Willow Agroforestry [9]	ha/yr	Moderate	(5,000.00)	6,500.00	-	14.5	100	1,450	
Alley Crop [10]	ha/yr	Low	(2,557.62)	15,619.50	-	10	100	1000	
TOTAL								156,220	57,050

1 Average of a 5% yield gain on cereal Barley ($20/a) and Potatoes ($120/a)
2 Average change in profit per acre per year for a potato system. Cereal system would be less but we are targeting potato rotation length increases as they drive GHG more than Cereal
3 Assume a 20% reduction in rate on highest N crops (potato, corn, wheat) and a 5% average yield loss 50% of the time, even though in most cases we won't see a yield loss due to overfertilization and lack of crop response. Costed as Urea
4 Based on trials done by Les Halliday in the mid 1980's using traditional grazing compared to advanced grazing and the increase in lbs beef per acre and incremental costs adjusted for inflation
5 Based on including perennials as an underseed with a cereal crop and selling hay versus growing soybeans. Cost savings from less fertilizer applied. This could be offset by grazing the cattle or by higher yields on hay.
6 Based on a tillage pass reduction *$15/a and a conservative carbon storage number
7 Moraes et al. (2015) Reported changes in diet cost for dairy cattle and at least 80% of max methane reductions. This does not include asparagopsis. Subject to change with better estimates.
8 Based on Roque et al. (2021). Asparagopsis reduces CH4 by 80% or more in Beef Cattle and increases feed efficiency, actually decreasing the cost per gain in beef. This may also apply to dairy
9 This assumes above ground biomass is burned as a fuel replacement value which halves the total 29 mt Co2e / ha sequestration but generates positive cash flows
10 This assumes a walnut harvest amortized over 20 years with initial costs amortized over 20 years and annual maintenance. Lifespan of walnuts would be much higher.
11 Sokolov, V., VanderZaag, A., Habtewold, J., Dunfield, K., Tambong, J. T., Wagner-Riddle, C., ... & Gordon, R. (2020). Modeling suggests sulfur treatment for lactating dairy cattle liquid manure storage would create a 0.5 tonnes CO2e emission reduction per head. Increment costs and revenues are unknown.
12 Modeling suggests that by diverting 100 tonnes of dairy manure daily to an anaerobic digester, 0.15 tonnes of CO2e per tonne of manure could be realized. On an annual basis, this would require 36,500 tonnes of solid dairy manure. Total annual dairy manure inventory is estimated at 660,000 tonnes. Incremental costs and revenues are unknown at present.

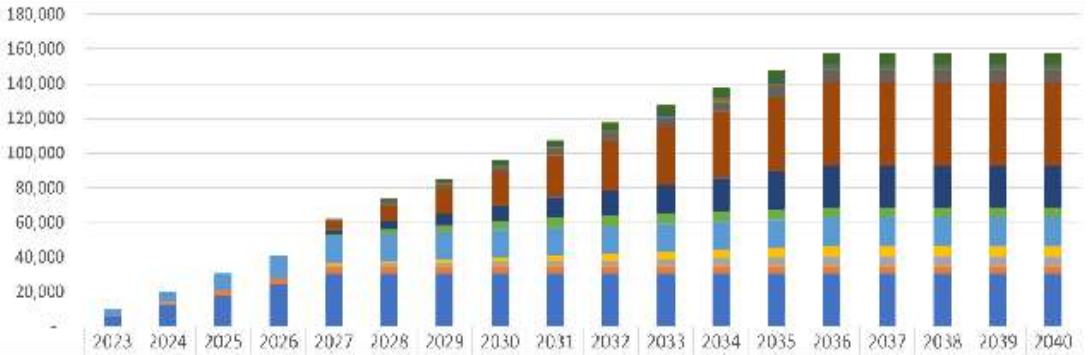
Proposed Roadmap to 2040

Based on (1) estimated land area or head of livestock for each BMP, (2) estimated lead time to initiate transition, and (3) estimated transition time to achieve full reduction potential, a GHG reduction roadmap was developed for PEI crop and livestock systems. As noted, total annual baseline emissions estimates conform to National Inventory Reporting, which reports annual emissions and land use change emissions (LULUCF) as separate categories. While current perennial land area provides significant carbon storage in the LULUCF category, ongoing conversion from forest to cropland offsets the carbon sink potential (see Land Use CO2e in Figure 5). Therefore, the net GHG reductions (including LULUCF) outlined here can only be fully realized on cropland not recently converted from forest (see Appendix A). Within the scope of annual National Inventory reporting however (excluding LULUCF), GHG reductions align with 2030 and 2040 provincial targets and represent additional emissions reduction potential; a portion of which is derived from increasing perennials in cropping systems (see Figure 18).

[31] Forested land removals, harvested wood emissions, and cropland removals/emissions are captured in the LULUCF category on a national and Atlantic Canadian scale whereas annual emissions are reported annually for each province. Land conversion from forest is included in the total emissions from the corresponding LULUCF category; cropland or settlements. Perennial land use change is also included in this category and total emissions/removals vary on a year to year basis depending on crop yields, weather conditions, deforested land area etc. Deforestation creates emissions which offset cropland carbon storage by perennials, making land use change (LULUCF) a reported source as opposed to a sink.

CO2 fluxes vary from year to year, making the LULUCF category harder to estimate and/or model with certainty. National Inventory reporting suggests Atlantic Canadian cropland is a net source of GHG emissions, largely due to the ongoing conversion of forest to cropland and associated emissions that the cropland category inherits.

FIGURE 19 - TIMELINE TO REALIZE GHG REDUCTIONS FROM BMP'S (ANNUAL TONNES CO2E)



	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Anerobic Digestion	-	-	-	-	725	1,450	2,175	2,900	3,625	4,350	5,075	5,800	6,525	7,250	7,250	7,250	7,250	7,250
Alley Cropping Agroforestry	-	-	-	-	100	200	300	400	500	600	700	800	900	1,000	1,000	1,000	1,000	1,000
Willow Agroforestry	-	-	-	-	145	290	435	580	725	870	1,015	1,160	1,305	1,450	1,450	1,450	1,450	1,450
Improved Manure Management	-	-	-	-	725	1,450	2,175	2,900	3,625	4,350	5,075	5,800	6,525	7,250	7,250	7,250	7,250	7,250
Improved Beef Diet	-	-	-	-	4,800	9,600	14,40	19,20	24,00	28,80	33,60	38,40	43,20	48,00	48,00	48,00	48,00	48,00
Improved Dairy Diet	-	-	-	-	2,400	4,800	7,200	9,600	12,00	14,40	16,80	19,20	21,60	24,00	24,00	24,00	24,00	24,00
Improved Grazing	-	-	-	-	1,200	2,400	3,600	4,800	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000
Nitrogen Reduction	3,200	6,400	9,600	12,80	16,00	16,00	16,00	16,00	16,00	16,00	16,00	16,00	16,00	16,00	16,00	16,00	16,00	16,00
Rotation Length	-	-	-	-	616	1,232	1,848	2,464	3,080	3,696	4,312	4,928	5,544	6,160	6,160	6,160	6,160	6,160
Increased Perennials	-	-	-	-	550	1,100	1,650	2,200	2,750	3,300	3,850	4,400	4,950	5,500	5,500	5,500	5,500	5,500
Reduced Tillage	900	1,800	2,700	3,600	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500
Cover Cropping	6,110	12,22	18,33	24,44	30,55	30,55	30,55	30,55	30,55	30,55	30,55	30,55	30,55	30,55	30,55	30,55	30,55	30,55

Note: It was assumed harder to implement BMPs would take longer to realize whereas easier BMP's, some of which have already been implemented within the last 5 years, could be realized sooner.

Scenario analysis of reductions potential indicates the probability of meeting provincial net zero reductions of 15% and 40% by 2030 and 2040 is sensitive to a few key practices and scale up assumptions. While the assumed units (hectares, head, tonnes) of adoption for each BMP were based on practical constraints, key questions remain around the incentivization and transition curve for each BMP. BMP's with the largest reduction potential represent the largest risk of overestimating adoption capacity. Cover cropping, nitrogen reduction, and livestock diet change (asparagopsis) significantly influence the probability of meeting net-zero targets. The proposed roadmap for meeting 2040 targets is necessarily contingent upon successfully incentivizing BMP's and has an implicit margin of error. Adoption modifiers were applied to reduction estimates to include an error band for expected annual GHG emissions (baseline less reductions curve estimates outlined above) relative to net-zero targets for PEI agriculture (see Figure 19).

FIGURE 20 - Annual GHG Emissions Relative to Net Zero Targets Based on BMP Implementation Timeline and Adoption Scenarios

Note: The minimal scenario assumes minimal adoption of Cover Crops, Reduced Tillage, Nitrogen Reduction, and Improved Diets for Dairy and Beef) at 50% of estimated units (area, head, tonne). The moderate scenario excludes Rotation Length, Improved Manure Management, and Agroforestry and assumes 80% of estimated units (area, head, tonne). The aggressive scenario assumes full BMP adoption at 100% of estimated units

SUMMARY OF BUSINESS RISK AND RATIONALE FOR ACTION

To date, voluntary and non-voluntary emissions reductions efforts have been minimally disruptive to primary producers in terms of both risk and reward. Taking a proactive approach provides the advantage of allowing farmers to decide how to meet emissions targets as opposed to being subjected to restrictive and/or prescriptive policy as we approach 2030 and 2040. The risks associated with a reactive wait and see approach seem to far outweigh the environmental, social, and economic benefits of taking a proactive approach to greenhouse gas reduction; particularly considering there is a compounding effect to risk under a business as usual strategy:

1. The longer industry waits to adapt, the more prohibitive market access for both carbon and commodities will become as government and industry seek to aggressively curb emissions.
    a. The opportunity for marketing carbon will only exist so long as BMP's are considered additional, novel, and over and above business as usual
        i. Opportunity for carbon revenues is highest in the immediate term for cropping
        systems that have high intensity cash cropping rotations and low intensity perennials and are ready to adopt eligible BMP's
        ii. Opportunity to develop carbon revenues for reducing ruminant livestock emissions over the next 5 years coincides with commercialization trajectory of high efficacy diet and manure additives (asparagopsis and sulfur) and can leverage the groundwork laid by cropping systems carbon credit verification.
    b. As the probability of additional carbon revenues decreases, the probability of increased costs (resulting from government and/or industry pressures) wil increase.
    c. A proactive carbon approach can be coupled with a branding strategy such that
        Island agriculture can differentiate itself as a verified, sustainable source of food.
        This opportunity will also diminish over time.
2. Concurrently, the effects of extreme weather, increased temperatures,and variable precipitation patterns will most affect cropping systems that have not incorporated regenerative, climate-forward approaches to bolster resilience in soil and crop. Practices that store carbon often have several co-benefits (in addition to carbon revenue) that improve productivity:
    a. Increased organic matter and water holding capacity, improved soil structure, enhanced nutrient cycling and microbial respiration, and decreased soil loss all
        contribute to higher yielding crops.
    b. In addition to improved water quality from better soil and nutrient management, longer rotations provide passive integrated pest management and can also provide opportunities for creating pollinator and wildlife refuge.

We encourage all farmers to consider the risks and rewards associated with climate change mitigation/adaptation and the GHG reducing practices that best fit your farm. This can be as simple as discontinuing the practice of deforestation for land conversion; as it carries a high carbon cost and is one of the foremost practices that could impact market access (e.g. Pepsi-co and Frito-Lay) and increase Land Use Change (LULUCF) emissions; putting Island agriculture further away from meeting targets. Additionally, cover cropping, reduced tillage, nutrient management, manure management, improved grazing, and livestock diet changes are among the most cited management practices for reducing on-farm greenhouse gas emissions. The PEIFA welcomes all stakeholders to collaborate with our climate action team and discuss how we can realize the benefits of low carbon food on Prince Edward Island.

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APPENDIX A - LAND USE, LAND USE CHANGE AND FORESTRY (LULUCF) EMISSIONS RANGES

Figure 21 - Provincial LULUCF Estimates 2000-2020

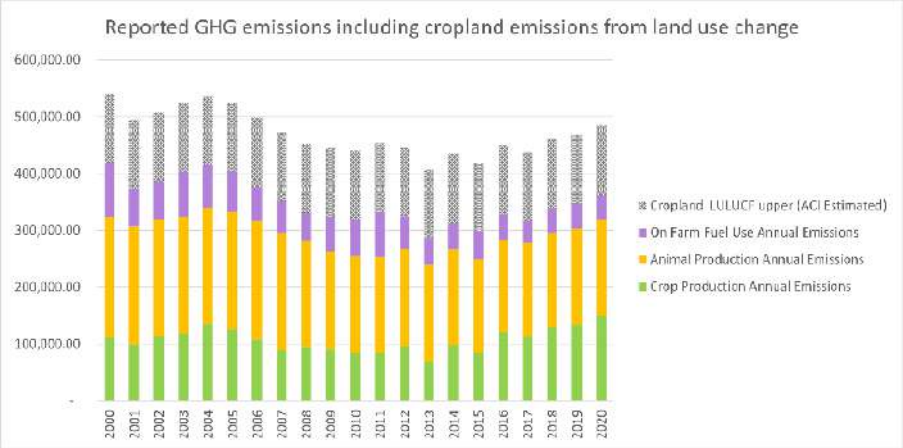
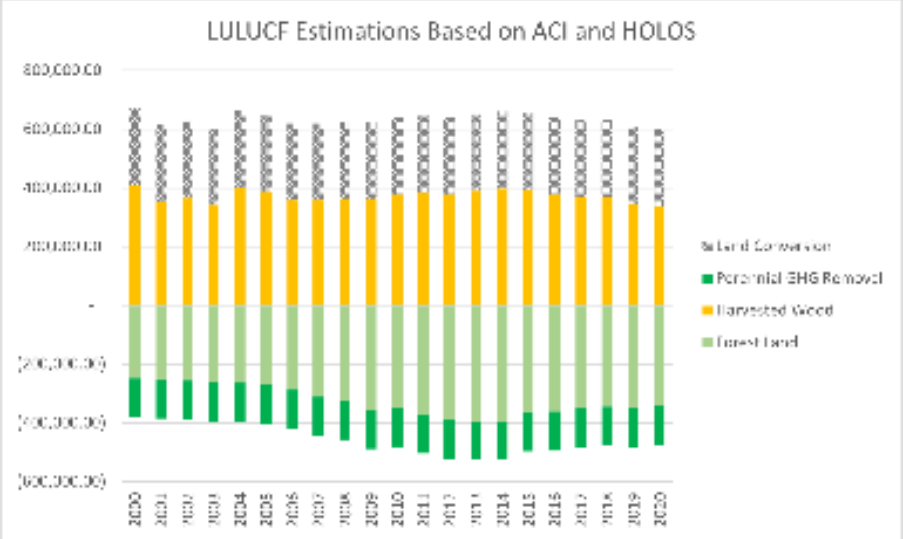


Figure 22 - Opportunity Cost of Land Conversion Emissions on Perennial Carbon Sink Potential



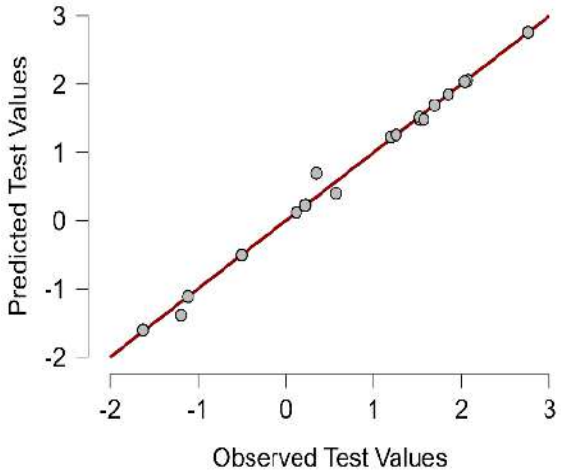
APPENDIX B - RANDOM FOREST REGRESSION ANALYSIS OF GHG PREDICTORS

Trees	Predictors per split	n(Train)	n(Validation)	n(Test)	Validation MSE	Test MSE	OOB Error
5	2	14041	3511	4387	0.002	0.002	0.004

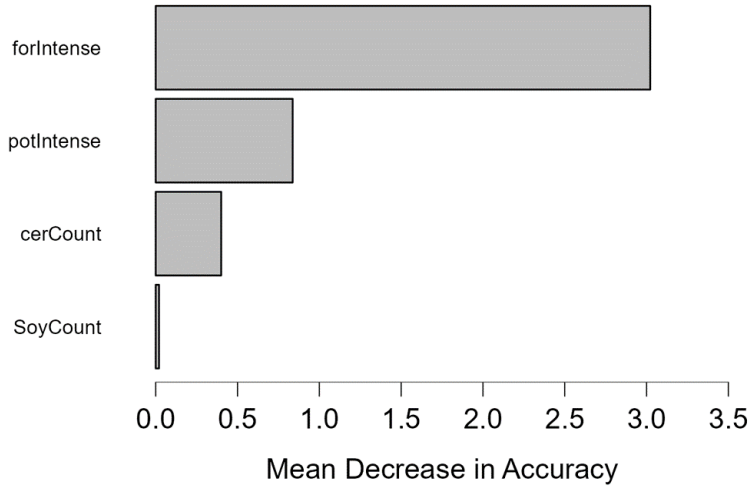
Note. The model is optimized with respect to the out-of-bag mean squared error.

EVALUATION METRICS

MSE	0.002
RMSE	0.045
MAE	0.019
MAPE	1.9%
R^2	0.999



VARIABLE IMPORTANCE



APPENDIX C - EMISSIONS ESTIMATES FOR PEI BERRY & GRAPE PRODUCTION

Emmision Type	Modeled GHG Emissions (kg CO_2e ha^-1)
Direct N_2O (kg CO_2e)	227
Indirect N_2O (kg CO_2e)	166
Land Use Change CO_2 (kg CO_2e)	2,033
Farm Energy CO_2 (kg CO_2e)	198
Upstream CO_2 (kg CO_2e)	-
Net Emissions with Land Use (kg CO_2e)	2,624
Annual Emissions (kg CO_2e)	591
Hectares	3,000
Total Annual Emissions (tonnes CO_2e)	1,772

Note: Table 32-10-0364-01 from Statistics Canada shows an average 2500 hectares of blueberry production, with other fruit and berries such as apples, strawberries, and cranberries representing 180 hectares. The table above estimates emissions for 3000 hectares of berry production with a factor for land use change (from clearing land) as well as an estimate of annual emissions without land use. It is assumed these emissions estimates would cover apple production as well.