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Disruptive forces influencing the sustainability of Canada's agri-food sector

A SCOPING REPORT

James Meadowcroft, PhD

The Transition Accelerator
L'Accélérateur de transition

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TABLE OF CONTENTS

About the Transition Accelerator iii

About the Author iv

Figures v

List of Figures v

Acknowledgments vi

Executive summary vii

1 Agri-food systems and the Canadian context 1

1.1 Canada's agri-food sector 3

2 Four dynamic factors 10

2.1 Technological development 10
2.2 Social trends and behaviour 12
2.3 Environmental feedbacks and policy responses 13
2.4 Economics, business practices and production models 14

3 Loci for change 16

3.1 Re-imagining protein 16
3.2 Seeking soil solutions 18
3.3 Taking it indoors 21

4 Conclusion sites for possible intervention to accelerate progressive transformation of agri-food systems 23

Postscript on COVID-19 26

Notes 28

References 29

ABOUT THE TRANSITION ACCELERATOR

The Transition Accelerator (The Accelerator) exists to support Canada's transition to a net zero future while solving societal challenges. Using our four-step methodology, The Accelerator works with innovative groups to create visions of what a socially and economically desirable net zero future will look like and build out transition pathways that will enable Canada to get there. The Accelerator's role is that of an enabler, facilitator, and force multiplier that forms coalitions to take steps down these pathways and get change moving on the ground.

Our four-step approach is to understand, codevelop, analyze and advance credible and compelling transition pathways capable of achieving societal and economic objectives, including driving the country towards net zero greenhouse gas emissions by 2050.

1 UNDERSTAND the system that is being transformed, including its strengths and weaknesses, and the technology, business model, and social innovations that are poised to disrupt the existing system by addressing one or more of its shortcomings.

2 CODEVELOP transformative visions and pathways in concert with key stakeholders and innovators drawn from industry, government, indigenous communities, academia, and other groups. This engagement process is informed by the insights gained in Stage 1.

3 ANALYZE and model the candidate pathways from Stage 2 to assess costs, benefits, trade-offs, public acceptability, barriers and bottlenecks. With these insights, the process then re-engages key players to revise the vision and pathway(s), so they are more credible, compelling and capable of achieving societal objectives that include major GHG emission reductions.

4 ADVANCE the most credible, compelling and capable transition pathways by informing innovation strategies, engaging partners and helping to launch consortia to take tangible steps along defined transition pathways.

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James Meadowcroft is a Professor in both the Department of Political Science and the School of Public Policy and Administration at Carleton University. Meadowcroft has written widely on environmental politics and policy, democratic participation and deliberative democracy, national sustainable development strategies, and socio-technical transitions. Recent work focuses on energy and the transition to a low carbon society and includes publications on carbon capture and storage (CCS), smart grids, the development of Ontario's electricity system, the politics of socio-technical transitions, and negative carbon emissions. Meadowcroft is currently Research Director, alongside David Layzell and Normand Mousseau, of the Transition Accelerator, which utilizes a world-leading four-step methodology to engage diverse societal stakeholders to co-create visions of what a socially and economically desirable net-zero future will look like.

FIGURES

List of Figures

Figure 1.1 Farm market receipts, 2017, billions $ 4
Figure 1.2 Number and size of farms 1941-2016 5
Figure 1.3 Distribution of farms and gross farm receipts, 2016 6
Figure 1.4 Annual total family income — Canada's Agri-food sector 7
Figure 1.5 Canadian Agriculture by Province 8

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EXECUTIVE SUMMARY

This report examines recent developments in Canada's agri-food sector, focusing on emerging trends with the potential to disrupt existing practices and their implications for sustainability.

Over the past century Canada has built a modern, industrialised, and internationally competitive agri-food sector that contributes substantially to the country's employment, exports, and GDP. Yet existing agri-food systems face multiple challenges with respect to long-term economic, social, and environmental sustainability. Getting to net-zero GHG emissions in Canada by 2050 will require a major transformation of the existing fossil-fuel-dependent agri-food sector. (1, 29)

A starting point for exploring *transition pathways,* which can link current circumstances with visions of where we would like to be in twenty or thirty years, is to consider currents which *are already* beginning to shift the alignment of production and consumption practices. [(2)] This can contribute to understanding dynamic processes at work today as well to identifying opportunities for intervention that can orient and accelerate positive system change.

While many factors will determine the evolution of Canada's agri-food sector (including general economic trends, geopolitical re-alignment, trade conflicts, and so on), attention here will be paid to the disruptive potential generated by interactions among four dynamic factors:

- technological development
- social trends and behaviour
- environmental feedbacks and policy responses and
- business practices and production models

These factors are closely intertwined and can combine to generate significant pressure on established ways of doing things and open opportunities for systems transformation. The crisis associated with the Covid-19 pandemic developed after the research for this report was already well underway. Considering the uncertainty surrounding this crisis we have not integrated the pandemic into the body of the report but appended some comments on potential long-term impacts as a postscript.

This report is organized in the following manner. Section 1 offers some necessary background, including a brief introduction to a transition perspective on agri-food systems, and to Canada's agri-food sector. Section 2 reviews developments under the four headings listed above. Section 3 considers the disruptive potential of these developments, including a more detailed analysis of protein production/consumption, soil and land use practices, and greenhouse/indoor production. The final section offers some general conclusions about policy approaches, possible sites for intervention and next steps.

1 AGRI-FOOD SYSTEMS AND THE CANADIAN CONTEXT

Agri-food systems are complex networks of actors, technologies and practices involved with the production and consumption of food. They include agricultural activities (growing crops, raising livestock), but also the provision of necessary inputs (seeds, fertilisers, pesticides, machinery), the manufacture of food products, ancillary services (insurance, finance), retail marketing and distribution, end use consumption (in institutions, restaurants and domestic settings), and the disposal of associated wastes.

These arrangements for societal provisioning can be understood as *socio-technical systems*. They are *systems* because they are composed of multiple interconnected elements with complex functional interdependencies. (2) They are *technical* because they involve specific sets of technologies. But they are also *social* in so far as they rest on distinct social relationships. Agri-food systems are constituted by the interweaving of these technological elements (plant varieties, harvest machinery, processing techniques, etc.), and social dimensions (property rights, financial flows, consumer tastes, regulations, and so on). They can be conceptualized at different geographic scales (region, country, international), as organized around different production chains, and as involving distinct subsystems (fertiliser provision, machinery production, food processing, retail, and so on).

While socio-technical systems experience almost continuous incremental change (which over time can result in substantial gains in efficiency or performance), occasionally they undergo more dramatic reconfiguration. (30) Consider the transition from sailing ships to steam ships, or from gas lighting to modern electrical networks. (31)

Over the past century agri-food systems have gone through significant changes. The most dramatic transformations have been associated with fossil-fuel powered mechanization, growing reliance on chemical inputs (fertilisers, pesticides, herbicides), and the associated specialization, increased scale, and concentration of ownership of agricultural operations. The introduction of improved crop and livestock varieties; consolidation of food processing, manufacture, and retail; growing international trade; diversification of diet and the increased prevalence of prepared foods; have all contributed to system reconfiguration.

The transformation of agri-food systems has been closely linked to developments in other economic sectors. The birth of the automobile accelerated farm mechanization (tractors, combine harvesters, etc.) and reduced transport costs. A chemical industry founded around the quest for synthetic dyes went on to perfect ammonia synthesis (for munitions manufacture) laying the basis for the growth in nitrogen fertiliser application in the second half of the twentieth century. And the diffusion of these and other innovations dramatically increased farm productivity releasing labour to other economic sectors.

As compared to other socio technical systems (for example, electricity provision or freight transport) agri-food systems are:

- *More diverse*: variation includes the types of crop and livestock, the scale of operations, technologies and practices, regulatory arrangements, and the range of implicated subsystems. Soya production is very different from dairy farming, growing peaches from maple sugar production, the international grain trade from local farmers' markets, and so on.
- *More directly reliant on natural cycles and ecological systems*. Most primary agriculture remains tied to seasonal cycles, local soil and climate, and variable weather patterns. It is vulnerable to disease outbreaks and the consequences of long-term ecological deterioration (for example, over exploitation of ground water, soil loss through salination or erosion). Although multinational food companies or large retail chains are somewhat insulated from adverse developments in any particular locality (crop failures, disease outbreak, etc.), their operations ultimately rest on primary producers who, for the most part, still depend directly on sunlight, natural rainfall, and other ecological services (for example, insect pollination).

Other significant features of the existing global agri-food system include:

- The bifurcation of global agriculture into two broad types: Modern, commercial farms oriented towards production for the market (including international markets) and small-scale subsistence farming which remains important in many developing countries.
- The domination of international agricultural exports by a relatively small number of countries, and the concentration of the international agricultural commodity trade in the hands of a few large companies. (33)
- The close association between agriculture and major environmental problems, including climate change (fossil fuel dependence, land use change, enteric emissions from livestock), biodiversity loss (conversion of land to agricultural use, pesticide and herbicide use), eutrophication (nitrogen fertiliser run-off), water depletion and pollution of surface waters and aquifers. (122) Indeed, agriculture is linked to most of the 'planetary boundaries' proposed to assess dangerous human pressures on the earth system. (32)

1.1 Canada's agri-food sector

Canada is a major agri-food producer and exporter. On census day in 2016, the Canadian agricultural sector included 12.5 million head of cattle, 14 million pigs, and 145 million chickens. (3) That year the country produced 8.8 million metric tonnes of barley, 19.5 million tonnes of Canola, 32 million tonnes of wheat, 6.5 million tonnes of soybeans, and 3 million tonnes of lentils.

Agricultural products make up 9.2% of exports, while processed foods comprise an additional 3.7%, for an agri-food total of nearly 13% of GDP. Exports are dominated by canola (seed and oil), wheat, red-meat, soybeans, and lentils, placing the country among the top ten agri-food export nations. About half of agricultural production is exported (and half of that goes to the United States), with most of the remainder going to the food processing industries.

There were approximately 190,000 farms in Canada in 2016. (4) Over the previous forty years the number of farms fell by more than 40%, while average farm size increased almost 65% (to 820 acres) (see figure below). (5) Large farms produce the lion's share of total production: in 2016, the 56% of farms with gross farm receipts of less than $100,000 generated 5% of national farm revenues, while the 8% of farms with receipts of a million dollars or more generated 60% of total revenue (see below). (6) Over time, capitalization of farms has increased as has farm debt. The average age of farmers has risen (to 55 today, with only 9% below 35 years of age), which suggest an important transfer of land ownership will occur over the next decade or two. (3)

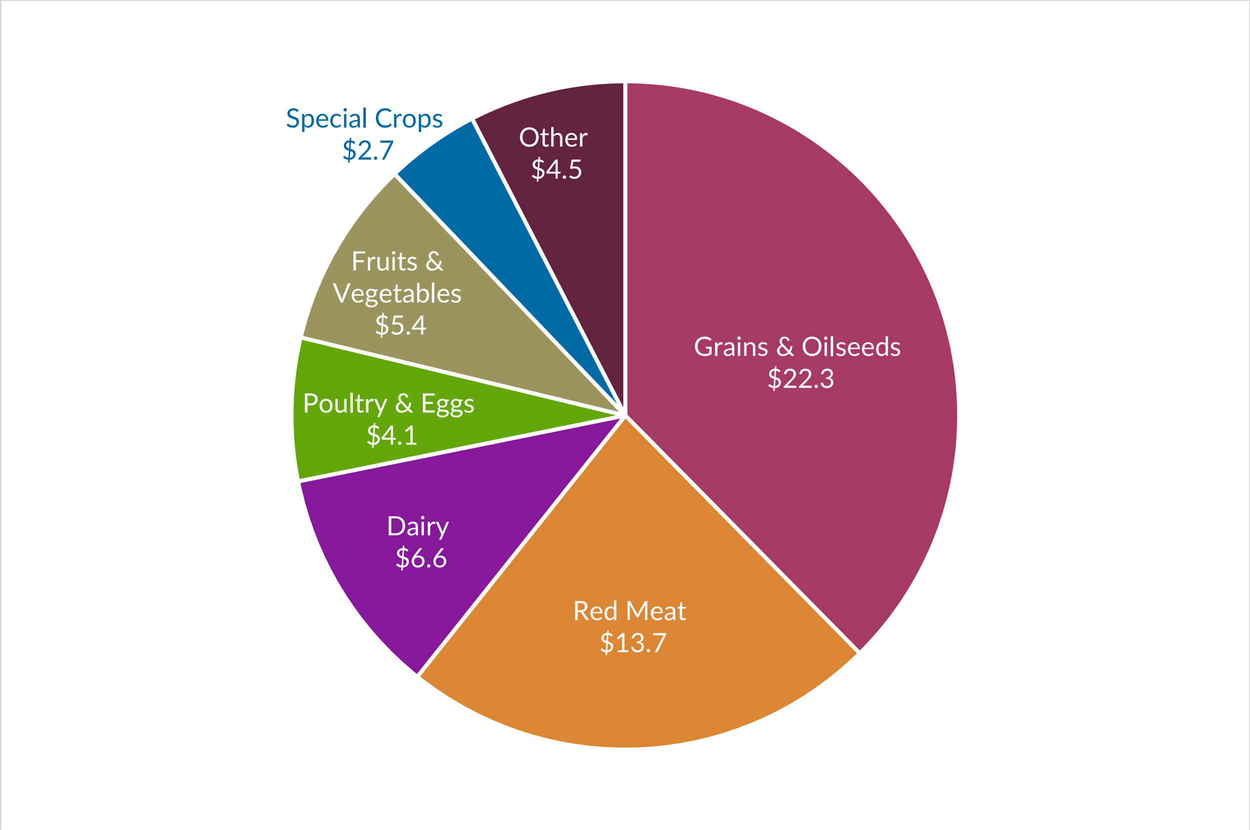

Figure 1.1 Farm market receipts, 2017, billions $

SOURCE: AGRICULTURE AND AGRI-FOOD CANADA, 2019.(34)

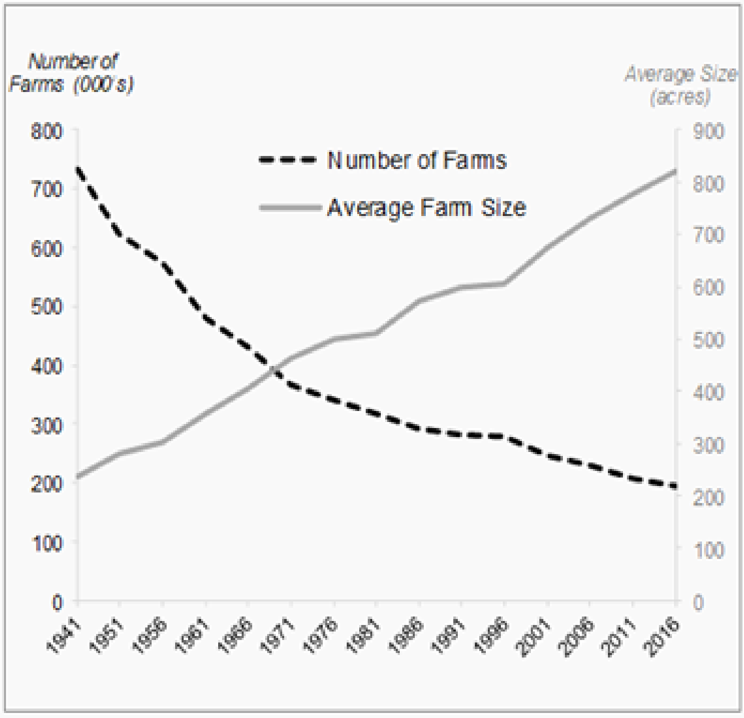

Figure 1.2 Number and size of farms 1941-2016

SOURCE: AGRICULTURE AND AGRI-FOOD CANADA, 2019.(34)

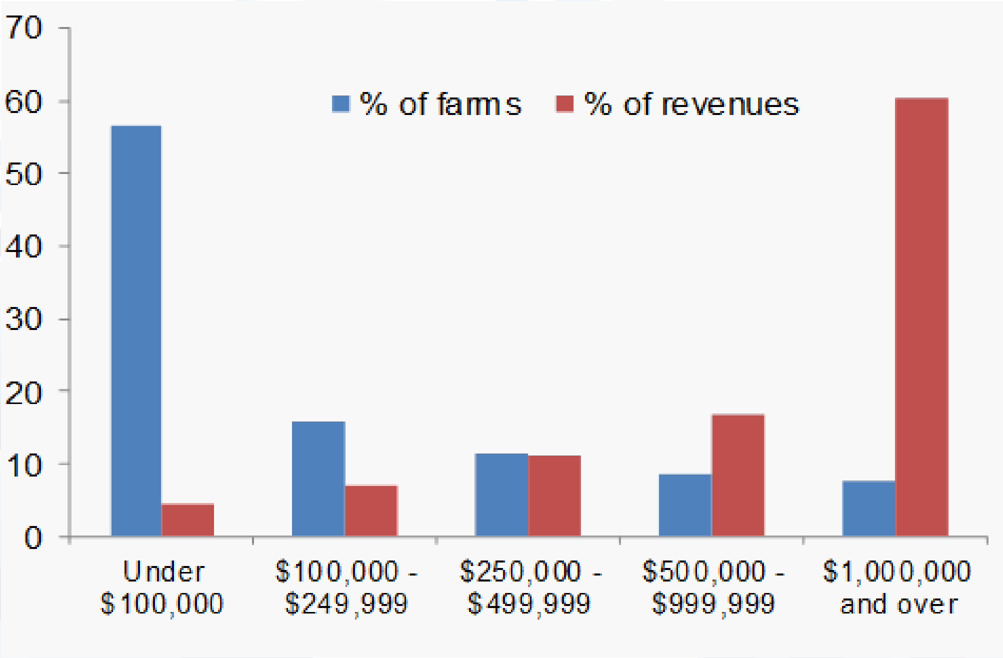

Figure 1.3 Distribution of farms and gross farm receipts, 2016

SOURCE: AGRICULTURE AND AGRI-FOOD CANADA, 2019.(34)

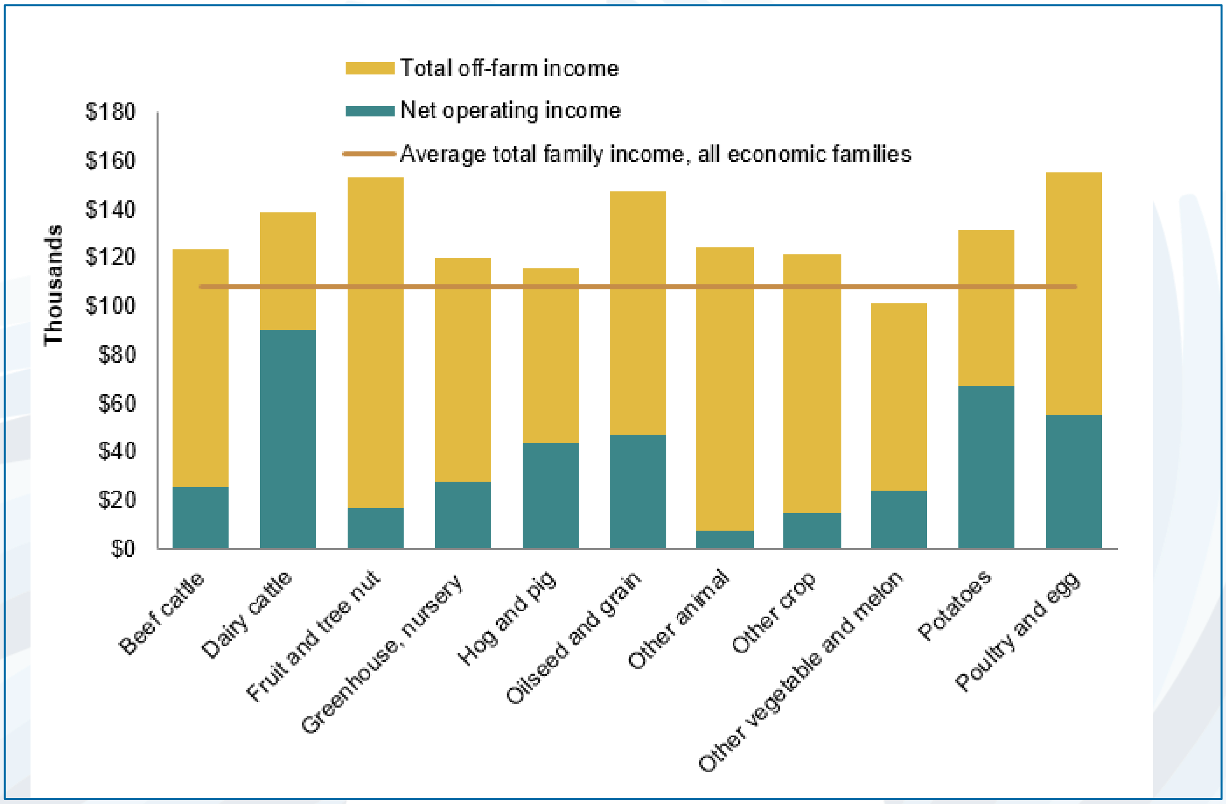

Figure 1.4 Annual total family income — Canada's Agri-food sector

SOURCE: AGRICULTURE AND AGRI-FOOD CANADA, 2019.(34)

Approximately 2.3 million people are employed in the agri-food sector, with 72,000 working in inputs and service supply, and 265,000 in primary agriculture. (7) Slightly more are involved with food and beverage processing (278,000), while the bulk are occupied in food retail and wholesale (637,000), and the food service industry (1,010,000). (7)

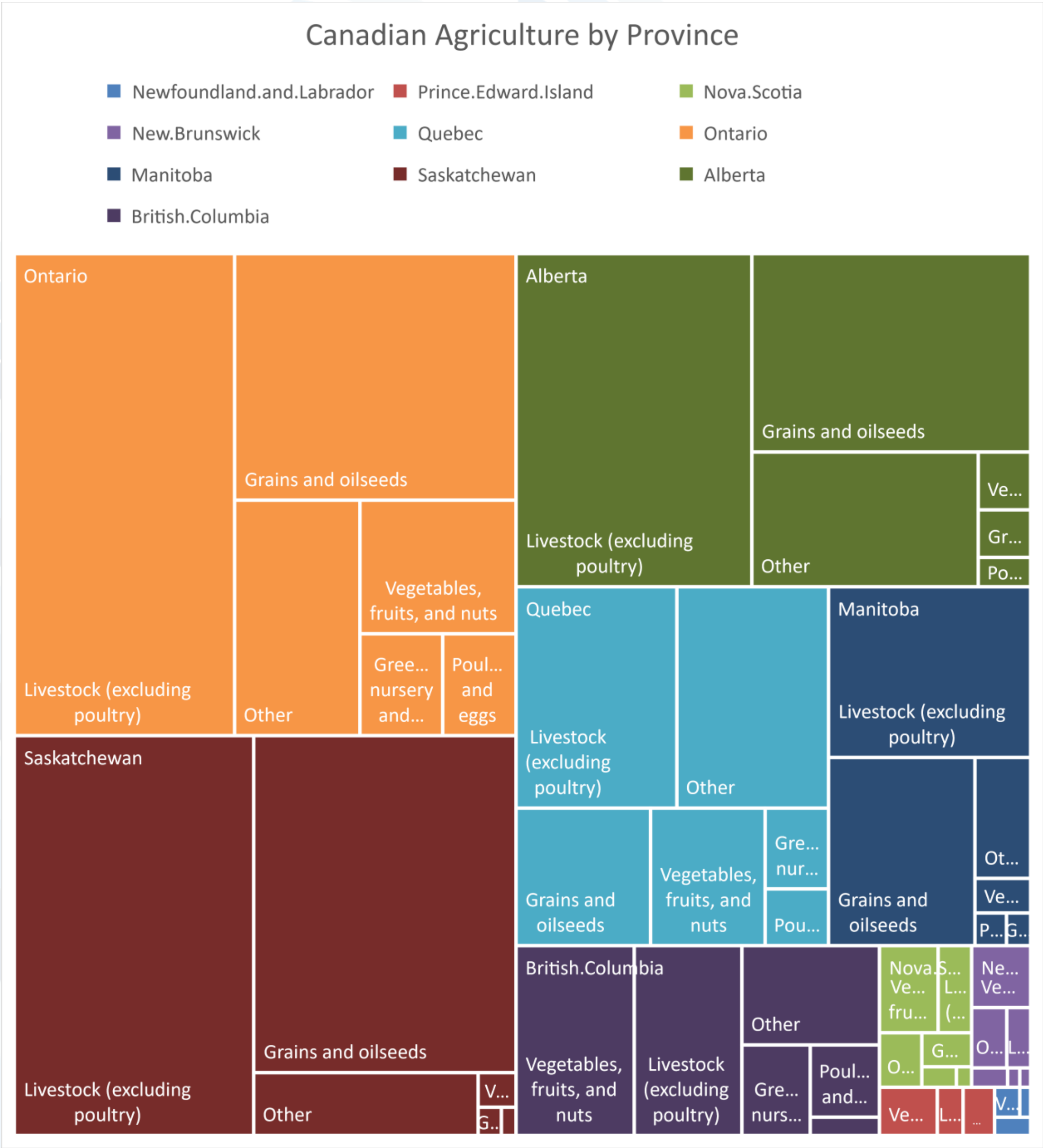

Figure 1.5 Canadian Agriculture by Province

Canadian agriculture imposes a series of environmental burdens, including pressures on biodiversity and GHG emissions.(65) Between 2005 and 2017 artificial fertiliser use rose by 71%.(8) On the positive side, average levels of soil cover in Canada increased by 7.6% from 1981-2011 as a result of reduced/no-till practices, as well as decreases in the use of summer fallow.(9) This, in turn, has led to a reduced risk on the Soil Erosion Indexi (from 65 in 1981 to 84 in 2011) and a consistent improvement in the Soil Organic Carbon Change Index (from 48 in 1981 to 74 in 2011)(10, 11). Agriculture is a significant contributor to greenhouse gas emissions. More specifically, 8.4% of Canadian emissions in 2017 came from agricultural sources (60 Mt Co_2 eq)(8). Emissions from agriculture have increased by 23.6% since 1990, but have been relatively stable since 2005.(8) Two of the major contributors of emissions from agriculture include soil, primarily from nitrogen fertilisers (25 Mt Co2 eq), and methane emissions from enteric fermentation in cattle (24 Mt Co2 eq.).(8) Carbon dioxide emissions also come from combustion of farm fuels; the production of the electricity used on farms; and from the production of farm inputs (fertilisers, chemicals, machinery, etc.). (12)

2 FOUR DYNAMIC FACTORS

In this report we consider four sets of dynamic factors which could contribute to change in existing agri-food systems. Although the notion of 'disruption' is sometimes used to describe (a) short term market perturbations (for example, a shock price increase following a harvest failure, or temporary closure of an established export market), or (b) a particular kind of threat that undercuts an established business model, here we use the term more loosely to explore factors that can 'shake up' established practices and open the door to more permanent-and-large-scale shifts in current agri-food systems (system disruption).

2.1 Technological development

Technological advance in many fields will influence agri-food systems over the next few decades. Two areas will be particularly significant: first, the further unfolding of the digital and telecommunications revolution; and second, the expanding reach of biotechnology and genetic engineering. The two fields are already interrelated as the expanding capacity to store and analyze data is essential to rapid advance in the biosciences.

With respect *to information and communications technologies*, developments relate to sensors, navigation and GPS, drones and satellites, robotics, 3D printing, blockchain, exploitation of large data sets, machine learning and artificial intelligence. (67, 73) Examples of enabled innovations include:

- 'Smart' farm machinery: autonomous equipment for planting, irrigating, and harvesting
- Precision techniques for weeding or herbicide application: for example, weeders which use cameras to identify individual weeds which can then be destroyed (70)
- Real-time monitoring of crops by drones, satellites, fixed sensors or machinery which can direct application of water, fertiliser, herbicides or pesticides as required (69)
- Real-time monitoring of livestock with digital tagging which can identify movement patterns, vital signs, signal need for care, etc.
- Mining farm data to improve cropping and livestock practices, fine tune farm or field cultivation regimes (seed selection, fertiliser and chemical applications, etc.) and/or improve inputs, equipment and techniques

- Digital platforms to sell commodities (allowing farmers access to a wider wholesale pool), and to connect producers directly to consumers (grow to order)
- Improved management of greenhouse operations, including in urban or vertical agriculture: a fully controlled environment, automated production, low energy lighting(68)
- Digital tracking of livestock and other food through the supply chain to monitor problems (disease or contamination) and document sustainability claims, etc.
- Novel food processing technologies

Combined in different ways these developments have the potential to increase economic efficiency (reducing labour inputs and unit production costs), and significantly decrease environmental impacts. Precision application of fertilisers and herbicides may be particularly important in this regard leading to reduced inputs and environmental pressures. But the relative significance of these gains depends on the ways the technologies are deployed. Key concerns about these technologies include high capital costs for individual farmers, and corporate control over data which could further skew the balance of power between individual farmers and multinational equipment and input providers (who manage data for thousands of farms).

With respect to *biotechnology,* developments relate to trans-genetics, genome editing (through CRISPR), marker-assisted selection, and the dramatic fall in the price of these technologies and the speed with which genetic sequencing and manipulation can now be carried out. (71, 72, 74) Enabled innovations include:

- New varieties of crops and livestock with reduced environmental impacts (for example, lower enteric methane emissions from ruminants)
- New varieties of crops and livestock which are adapted to novel climate conditions (for example, to higher temperatures or with reduced water requirements)
- Novel pest control strategies
- Development of fungi and other soil microorganisms that can facilitate nutrient release, improve resistance to salinity or water stress, or potentially fix nitrogen
- Precision fermentation using microorganisms to produce proteins (and other food components): this can include proteins from milk, beef, pork, eggs, and fish, but may ultimately be applied to create entirely novel foodstuffs
- Cultured meats grown at the cellular level on an artificial matrix(49)

Widespread adoption of precision fermentation and ultimately cellular meat could significantly disrupt existing livestock agriculture.(35) Advances in these technologies could also provide inputs outside the food sector, for example, production of leather or fibre. Environmental benefits could be significant, with the release of part of the land currently required by the livestock industry (approximately 75% of world agricultural land), reductions in inputs (fertiliser) and enteric emissions. Still, there are many concerns with these technologies.(82, 104) While widespread adoption of precision fermentation and lab grown meat would reduce the scale of industrial livestock production, it would represent the triumph of an industrial food system and raise heath and ethical concerns.

2.2 Social trends and behaviour

Social and behavioural trends are a significant driver of agri-food system change. Altered priorities and perceptions can be transmitted through shifts in the purchasing choices of individual consumers, but also through pressure brought to bear by societal groups or government regulators. Diet and food choices are sometimes assumed to be reasonably stable, but what Canadians eat and how they access food has changed dramatically over past decades.(61, 62, 63, 64)

Among the most import changes since the 1970s:

- An increase in the availability of fresh produce and other foodstuffs
- The increasing dominance of manufactured and processed foods including chilled pre-prepared meals
- The greater role of snacks and convenience foods in the diet
- A decline in per capita consumption of red meat and an increase in consumption of chicken(13)
- A steady fall in per capita milk consumption and the increased popularity of alternative 'milks' (soy, almond, wheat, oat, etc.)(13, 14)
- A greater proportion of meals taken in restaurants

Important health concerns relate to sugar, salt, saturated fats and (increasingly) the loss of micro-nutrients and potential effects of 'ultra-processed' foods.(15)

Looking forward, while price and convenience will remain critical determinants of consumer choice, concerns over health, the environment (including climate change) and animal welfare appear increasingly important.(16–18) Although the proportion of the population committed to vegan principles remains small, there is a broad tendency to reduce red meat consumption and to move away from dairy-based beverages.(19) Meat substitutes are increasingly acceptable and even fashionable, as evidenced by the success of the Beyond Burger and the tidal wave of vegan products which have been launched by mainstream food companies over the past year and a half. Climate campaigners have increasingly targeted meat consumption (like air travel) as 'killing the planet'.(55, 81) Although there is at yet only anecdotal evidence of the impact of these campaigns, there is reason to believe that they will gain in strength, reinforcing the long-term trend towards lower per capita beef consumption in Canada which has been driven by health concerns and increasingly clear scientific evidence that diets focused on fresh vegetables, pulses, nuts, fish, with only moderate quantity of animal protein, are conducive to health.(53)

The willingness of some consumers to pay a price premium for organic products and support local food (farms, local markets) are also of note, although on their own unlikely to lead to wider transformation of the food system.

2.3 Environmental feedbacks and policy responses

Agriculture has a large environmental footprint relating to land use, water abstraction, and pollution from fertilisers and other chemicals. Environmental 'feedbacks' – the negative impacts generated by farming practices – regularly force adjustments to those practices. For, example, insect resistance to pesticides and soil loss through erosion have stimulated changes to pest and soil management practices. Climate change is the big issue here, however, and it has already begun to impact Canadian agriculture, as adverse weather events including heavy rainfall, floods, frosts, hail, high winds and so on have damaged crops.(38, 66) Although climate warming may have beneficial effects in some regions (for example, through a longer growing season) most analysts anticipate negative impacts will predominate as existing farm practices will be out of step with changing conditions. More than 80% of catastrophic crop loss is currently caused by weather events. As these events become more common farm economics could be compromised: consider crop insurance based on a once-in-ten-year catastrophic loss profile having to shift to a once-in-every-three-year rhythm. Although agriculture in Canada can adapt – altering the pattern of what is grown where, changing varieties and cultivation techniques – adjustment will be expensive and bear disproportionately on certain regions, sectors, farms, etc.

But *policies* targeted at GHG emissions from the farm sector (or encouraging carbon sequestration on farmland) will also increasingly impact farming. Although climate policies have remained comparatively weak in Canada, serious movement towards net-zero-GHG emissions will require a contribution from agriculture.(43) Because of the disproportionate share of emissions contributed by beef and dairy production (through enteric and manure emissions, and feed production) attention will inevitably be drawn to these sectors.(36, 80) It is worth emphasising that actual emissions from livestock operations (GHG intensity of production) varies widely depending on production methods, and there are many ways to secure incremental improvements.(39, 40) On-farm energy use, and fertiliser application are two other areas that will command attention.(41, 43)

There is clearly a potential contradiction between an economic drive to expand Canada's agricultural exports and a desire to address climate change and to enhance biodiversity. If existing extensive and high input production models are extended to increase outputs the result will be greater environmental loading. On the other hand, some alternative cropping and livestock practices could in principle result in increased production *and* reduced environmental pressures.(42, 48) But this would require substantial change in agricultural techniques.

2.4 Economics, business practices and production models

Trends related to the economics of farming, business models and alternative production practices could also generate significant change to established agri-food systems. Factors at play here include:

- The economics for many farms remain precarious. To gain efficiencies farmers increase the scale of their operations, getting access to land and investing in equipment. The resulting debt can make them vulnerable to an economic downturn or serious disruption (disease, trade embargo, etc.). While farms may have substantial gate receipts, high capital and input expenses can make profitability low.(48) This can encourage further consolidation within the sector. It can also increase resistance to change – those only just scraping by cannot afford to take risks trying something new. Yet, it may drive others to seek alternative business and cropping models to gain more favorable economics.
- Consolidation of the agricultural input sector: There is already substantial concentration within sub-sectors (seeds, equipment manufacture, chemical inputs) but there now appears to be a trend for consolidation across sub-sectors as 'digital agriculture' and pressure to reduce chemical inputs spurs consolidation.
- There is some evidence of investment company interest in acquiring farmland and development of a more 'corporate' model of agricultural production.

For decades the dominant, 'conventional' or 'industrial' model of farming has coexisted with alternative agricultural approaches, and new paradigms continue to emerge. Of course, the conventional model has evolved – note the widespread adoption of 'no-till' agriculture in Western Canada. If these alternatives approaches were more widely adopted, or elements from them transferred into the mainstream, the face of agriculture could be transformed. Potentially influential alternative approaches include the following:

Organic agriculture avoids the use of synthetic inputs. Canadian Organic Standards for agriculture have limits and prohibitions on the use of pesticides, fertilisers, drugs, antibiotics, synthetic hormones, biosolids, genetic engineering, and irradiation(20). There are approximately 3,713 certified organic producers working on 841 thousand hectares of land in Canada, accounting for approximately 1.8% of Canadian farms.(21)

Regenerative agriculture adapts existing methods of farming to improve soil health.(22, 105) This includes increasing soil biodiversity, water retention, and carbon sequestration.(23, 106) It uses closed nutrient loops, and relies as much as possible on internal (on farm) resources as opposed to external inputs.(24) Increased plant and animal diversity on farms contributes to the improved soil health of regenerative agriculture.(25)

Precision agriculture uses site or plant specific information to make decisions about the application of inputs.(26) By selectively introducing inputs, it can optimize production efficiency, productivity, and profitability while reducing impacts on the environment and wildlife. Precision agriculture uses state of the art technologies and thus requires continuous innovation and improvement.

Vertical farming stacks production to reduce space constraints, using a controlled environment (humidity, temperature, lighting, CO_2 levels, etc.) to maximize production.(27, 100, 101) Vertical farming has many variations. In addition to stacking plants contained in soil, vertical farming also allows for soilless agriculture including hydroponics, aeroponics, and aquaponics. It can reduce inputs required in production by recycling water and reducing or eliminating the need for herbicides and pesticides.(27, 100) Moreover, vertical farming can eliminate seasonality of food production and is protected from weather related events.

Agroecology is a multi-disciplinary approach that emphasises the interdependence of agriculture and the wider ecological systems within which it is embedded.(108) It deals with the linkages between ecologies and production practices, and natural and social systems.(108, 109, 110) Agroecological practices include protecting soil, applying beneficial cropping practices and mixes of cultivation and animal agriculture, conserving and developing spaces adjacent to crop and grazing land (hedgerows, shelter belts, wetlands, natural corridors), enhancing biodiversity (among natural and cultivated species and varieties), protecting water.

3 LOCI FOR CHANGE

Factors related to each of these four classes - new technologies, changing societal behaviours and concerns, environmental impacts and responses, and evolving business practices and production models - are influencing the evolution of Canada's agri-food systems. Many of the changes over the next few decades will be relatively gradual. But where several of these factors come together, the potential for more significant innovation and system-level change may emerge.(120,121) Here we identify three possible loci of convergence: one related to protein production, a second to soil management and land use, and the third to greenhouse or indoor operations.

3.1 Re-imagining protein

The first nexus is created by interlocking impacts of novel technologies, shifting consumer attitudes towards meat and dairy, and more stringent policy measures to address GHG emissions. This will exert significant pressure on existing livestock and dairy operations while opening markets for alternative protein sources.(54) Alternatives include plant-based proteins (pulses, soya beans, oats, etc.); algae derived proteins; fermentation produced proteins; in vitro or lab-grown meat; and synthetic foods (produced without biological inputs).(85) The greater technical challenges of growing animal tissues, the lack of obvious advantages for algal sources in Canada, and the immature state of technologies for direct food synthesis suggest that in the first instance activity will be concentrated in three main areas:

- *Plant based proteins*, where there is an opportunity to increase production and export of many crop varieties and to strengthen Canada's presence in the manufacture of plant-based foods.(78, 84)
- *Fermentation products*, which in the relatively near future could offer cost competitive inputs to the food industry, disrupting the dairy and then beef industries, and
- The *adjustment of traditional dairy and livestock operations* as these businesses struggle to adapt to new circumstances.

Rapid advances in gene sequencing and bio-processing techniques suggest the cost of microbial production of milk and animal proteins will continue to fall.(35) These products are already being incorporated into manufactured food stuffs, for example ice cream in the United States.(37) A recent report suggests the falling price of precision fermentation will rapidly undercut the economics of dairy farming.(36) It points to the nutritional and environmental benefits of a shift away from 'macro agriculture' towards a more efficient 'micro agriculture'. Rather than devoting land, water, and chemicals to raise crops to feed a cow, precision fermentation can use microbes to directly build the desired proteins (or other food components) from basic biological inputs. The claim is that fermentation products can then be combined to build up foods that are nutritionally superior to animal derived meat at a fraction of the current cost and environmental impact.

Although proponents of 'modern' food neglect significant barriers to the rapid scale up of this technology – including techno-scientific challenges, the power of the dairy/beef lobbies, established regulatory frameworks (including supply management), possible consumer resistance, nutritional worries and unforeseen setbacks – the impact on existing dairy operation is likely to be large. More than a third of dairy output goes to milk solids, where food components (protein, fat, sugars) can be separated, and then used in food manufacture. This part of production is most easily substituted and, as the costs of precision fermentation drops, it may rapidly displace milk. This will undermine the overall economics of dairy operations. Although the disruption to the beef industry may be delayed, the market for fermentation produced beef protein for the food industry can be expected to grow. As precision fermentation is complemented by cell grown meat (perhaps in less than a decade) disruption of conventional beef operations may follow. About 45% of beef (US statistics) is consumed as ground meat, and this will be easiest to displace as it is easiest to replicate.(57)

Potential longer-term consequences of a rapid growth of precision fermentation (and ultimately cell grown meat) include:

- A sharp political battle around the regulatory treatment of fermentation products. Canada has strict rules around the term 'milk' and 'cheese', and supply management requires farmers to own quotas for production but guarantees price. Present regulations would not allow fermentation products to be labelled 'milk'. On the other hand, it is difficult to see how they could be brought under supply management. Lack of the 'milk' label has not prevented the growth of beverage substitutes (soya or almond drinks).
- Sharp discussion within the environmental movement, health advocates and vegans about the desirability of the new products.(82)
- Displacement of a considerable number of producers in the dairy and livestock industry combined with the falling value of the milk quota.
- Release of agricultural land currently used for beef and dairy (or for raising animal feed).
- Decline in sales of farm inputs required to support livestock including animal feed.
- Changing patterns of trade as countries which are currently large-scale importers of meat products shift towards domestic production through precision fermentation and cell culture. Although it has been assumed that any decline in domestic meat sales would be balanced by growing international markets (as China and other developing countries expand consumption) this trend may not last indefinitely.

Nevertheless, it is unlikely that precision fermentation or cell-based meat will entirely replace dairy and livestock operations. Even if over several decades these novel foods displace the bulk of animal-based foods, there would remain a substantial place for high quality or artisanal production of milk, cheese, yogurt, beef, pork, lamb, etc. with customers willing to pay a premium for these items.

The adverse circumstances facing traditional dairy and livestock operations (competition from plant-based alternatives and precision fermentation, pressure to reduce GHG emissions) will spur some producers to innovate to create healthier and more environmentally friendly products. There is a suite of actions which could reduce the environmental footprint of dairy and beef production, with research ongoing in Canada and elsewhere to raise efficiencies and reduce emissions.(36, 43, 48, 50) Although the vulnerability of the dairy industry may cause some producers to retrench, it provides promising conditions to spur innovation and achieve dramatic environmental performance gains.

3.2 Seeking soil solutions

The second nexus is driven by the interlocking impacts of farm economics (high input costs), environmental feedbacks (pollution, falling land fertility) and the policy response to climate change (pressure to reduce nitrogen emissions and exploit the potential for carbon sequestration). Modern industrial agriculture relies on chemical inputs (fertiliser, pesticides, and herbicides) to control growing conditions over increasingly large (and frequently mono-cropped) areas.(88) The introduction of no-till agriculture particularly in Western Canada has slowed erosion and increased soil organic content over the past twenty years. But many farmers remain trapped in a cycle where yields per acre are high, but profitability per acre is low. Farm debt is substantial. This has encouraged some to experiment with alternative cropping regimes which reduce chemical inputs and diversify farm outputs. More recently the idea of 'regenerative agriculture' has placed soil enhancement at the centre of agricultural management.(22–25)

There is substantial evidence that continuous (and often increasing) application of nitrogen fertilisers, as well as herbicides and other agricultural chemicals, has a negative impact on soil over the long term – degrading structure, organic content, water and carbon retention, and the density and diversity of soil microorganisms.(91) Consequences for biodiversity and the wider environment are significant.(89) Although an emphasis on soil as a living medium has long preoccupied some traditions of agricultural production and research, understanding biological activity in the soil (including the ubiquity and scale of mycorrhizal associations), and the ways carbon is captured and released is still developing.

Today, there is growing recognition that *soil solutions, and alternative cropping and land use practices,* lie at the heart of more sustainable agricultural systems.(75) Although definitions of 'regenerative agriculture' vary considerably, they generally emphasize the soil as a living medium that anchors agricultural productivity and the welfare of farming communities.(105, 106) The diversity of the agricultural sector (crops, livestock, soil types, micro-climates, scale of operations, production regimes, etc.) means that approaches will remain varied. But regenerative agriculture is likely to involve different *combinations* of novel high-tech solutions (precision input application, enhanced plant and animal genomics) with a revitalization of practices that were familiar to farmers before the ascendance of modern monocropping and synthetic inputs (including crop rotations, intercropping, green manures, careful nutrient recycling, and closely integrating plant and animal agriculture).(106, 107)

The longstanding debate over the comparative advantages of 'high yield industrial' agricultural systems and 'organic' agriculture (and other alternative cultivation regimes) is likely to continue. Advocates of the former emphasise the reduced yields and increased land requirements of organic agriculture with the attendant consequences for biodiversity pressure.28 Proponents of the latter argue organic yields can increase over time as soil fertility is built up and observe that biodiversity damage inflicted by industrial agricultural practices extend well beyond farm borders. Although markets for organic produce and products continue to expand, less than 2% of Canada's agricultural land is farmed organically and it seems unlikely this model can be generalized across the industry. So multiple solutions, adapted to different localities, crops, and farm scales, that can exploit opportunities for expanding markets and capture more value on the farm, will be required.(76, 77)

Concern with soil, cultivation techniques and land-use can become a critical impetus for innovative practices that can reimagine conventional high input/high impact agriculture. This will require innovation in cultivation practices but also a reorientation of plant and animal breeding, equipment and input manufacture, and agricultural support industries, towards more balanced goals.

The theme of *managing for multiple outputs* is a constant in discussion of increasing farm (and agricultural system) resilience in the face of uncertainty and disruption (weather, climate change, disease, trade disputes, etc.), as well as of more widespread application of agroecological principles that set production within wider ecological landscapes and the biosphere.(44, 46) Specialization and economies of scale have often been seen as the path to profitability. But in the future diversification and attention to managing multiple outcomes may become more common.(44, 47) This could involve yields of multiple crops and varieties, combinations of animal and plant agriculture, promotion of on-farm processing and direct marketing, attention to soil health, GHG management and soil carbon sequestration, increasing biodiversity, and promoting other ecological or social values.(87) An array of win/win approaches that are profitable, reduce climate altering emissions and are kind to biodiversity are likely to be possible – but finding them across diverse regions, landscapes, crops, and farm types will be a challenge.(48, 50, 51) Developing accurate metrics to assess progress, and techniques to track food sustainability across value chains, will be important to validate advances and attract customers in a world increasing sensitive to ecological (and/or climate) performance.

Raising the organic content of soils can have multiple benefits (increased fertility and water retention, prevention of erosion, etc.), but the potential for agricultural soils to act as carbon sinks – to counterbalance residual emissions from agriculture or other difficult to decarbonize sectors in a net zero economy, or as a negative emissions option to reduce carbon dioxide concentrations in the atmosphere (net negative), has attracted considerable interest.(42, 50) Soil carbon can be increased with additions of organic matter and is decreased by processes of decay.(117) The deeper the carbon is buried and the more it is bound up with soil particles, the slower the decay and more rapid the accumulation. While modified tillage practices (no or reduced till, green manures, cover crops, perennial cropping, etc.) can raise carbon levels, it is unclear how far this can go above pre-agricultural baselines. At present, research suggests substantial (but declining) carbon uptake from Canadian farmland over the next three decades. Much of the opportunity is located on degraded land in central and eastern Canada. But the longer-term potential of carbon uptake on farmland beyond that is uncertain.(45)

Incorporating biochar, a charcoal-like solid produced by heating biomass without oxygen (pyrolysis), is a possibility. Evidence of biochar use to enhance soil fertility goes back millennia, but further research is required to determine the long-term sequestration potential, how it can best be applied in different conditions, and associated environmental effects.(52) Other land use changes can also store carbon, including avoided conversion of natural ecosystems to agriculture, restoring wetlands, streams, and field margins, etc..(118)

In recent decades there has been increasing criticism of the productivist orientation of mainstream agricultural support programs, and interest in payments to farmers for adopting more conservation, biodiversity, and climate-oriented practices. Payments for ‘ecosystem services’ has been promoted by a number of international organizations and explored through a variety of pilots in Canada. Nevertheless, persistent problems with operationalizing the range of ‘ecosystem services’ and conducting the comprehensive economic valuation exercises which some interpretations demand have limited the applicability of the paradigm. In practice, payments are typically fixed by ‘rule of thumb’ approaches (for example, historical comparisons to existing conservation support programs) rather than through any comprehensive valuation approach.(123)

Nevertheless, the basic idea that agricultural systems should contribute to goals other than production, and that famers should be compensated for promoting these values remains powerful. Reform of Canada’s agricultural support mechanisms to better integrate ecological and climate concerns will be an important step forward. So too would be a national offset mechanism to allow farmers to get credit for improved GHG management. Alberta has run an agricultural offset program for over a decade, and a national scheme now appears to be in the works.

Thus issues of soil and land management will remain at the cutting edge of agricultural and environment innovation in coming decades and can be expected to drive significant change in the sector.(48, 119)

3.3 Taking it indoors

The third nexus - the transfer of agricultural production 'indoors' - is being driven by technological advances (lighting, control systems, automation), economics, and environmental and health concerns. The conventional greenhouse sector is well established in Canada, currently growing at 4 or 5% a year. Around 900 greenhouse operations now produce more than $1.5 billion in farm gate receipts.(97,98) The sector makes up 42% of Canada's fresh produce exports, with the industry concentrated in Ontario, Quebec, and British Columbia. The main products are tomatoes, cucumbers, peppers, lettuce, and herbs. Operations have become progressively more sophisticated with controlled lighting, heating, CO_2 enhancement, and pest control strategies. During the last decade there has also been increasing interest in 'indoor' agriculture – where crops are grown under fully controlled conditions. 'Vertical agriculture' refers to the stacking of crops and can be applied to operations that still exploit some natural light as well as to those that rely entirely on high intensity artificial illumination.(96, 100) Plants can be grown in a soil/substrate medium, by hydroponics or aeroponics. First generation vertical farms monitor and control lighting, water, nutrients, temperature, and humidity. More advanced systems increasing involve automation (planting, tending, harvesting), and intensive data management (learning from experience to optimize plant growth).

Indoor agriculture allows comprehensive control over the growing environment (heat, light, water, nutrients), protection from unfavorable weather, improved management of pests and waste, and a reduction of water and chemical inputs.(100, 101) Location within urban centres means lower transport and packaging costs, fresher (and potentially more nutritious) produce, and the possibility for direct farm to customer business models. There are also claims that vertical agriculture can improve food security and food safety.(102) Since productivity per square meter can be dramatically higher than field grown crops and conventional greenhouse operations, large scale adoption might ultimately release agricultural land to conservation uses. Disadvantages include high start up capital costs (particularly if the facility is substantially automated), and high energy costs (for lighting, heating, cooling, automation). Land can be expensive in the urban core, although the potential to repurpose existing structures can bring this down. One approach uses old shipping containers to create modular growing structures.

There is an ongoing debate over the GHG footprint of vertical agriculture. Production is energy intensive, because enclosed systems must replace natural sunlight (which provides much of the light and heat in the traditional greenhouse). Energy requirements are the primary driver of the GHG footprint, which is sensitive to the carbon intensity of electricity and heating fuels.(102) Typically, this more than compensates any GHG gains from reduced transport or chemical inputs. However, the move towards net zero electricity (whether grid supplied, or from on site solar), linkages to urban heating and cooling systems (exploiting waste heat from other structures or district energy schemes), and a switch to net-zero heating fuels (electricity, biogas, or hydrogen) could in principle drive emissions towards net zero.

Vertical agriculture is only beginning to emerge today, with entrepreneurs exploring niche markets serving restaurants, environment- and health-conscious urban consumers, and possibilities for year-round production in remote and indigenous communities. One rapidly expanding venture in Montreal (Lufa Farms) positions facilities on roof tops (using some natural light and waste heat from the underlying structure), using digital technology to maintain direct contact with consumers and organize delivery at local collection points, and supplementing income from growing vegetables by distributing a range of regional organic products.(103)

Significant learnings will be required to drive down costs, extend the range of produce that can be grown profitably, find the sweet spots between mechanization and exploitation of local labour (with a trade off between capital and running costs), and develop successful business models. While it is unlikely the approach will become a viable option for major commodity crops such as grains and pulses, or bulky vegetables such as broccoli, cauliflower, cabbages or potatoes (except in very particular circumstances) moving production to controlled and vertical environments has enormous potential over the long term. Vertical production is currently attracting entrepreneurial producers and venture capital, and there is continuous experimentation with new equipment and business models. The dramatic and continued improvement and falling prices of lighting technologies, and the possibility to fully exploit controlled growing conditions, data analytics and AI, and novel plant breeding approaches bode well for the future. Thus 'growing it indoors' represent an important site for innovation and disruption and the quest for business opportunities and health and environmental gains in the future.

4 CONCLUSION

SITES FOR POSSIBLE INTERVENTION TO ACCELERATE PROGRESSIVE TRANSFORMATION OF AGRI-FOOD SYSTEMS

This report has examined some of the currents shaping the evolution of Canada's agri-food system, focusing on emerging trends which may disrupt existing practices and their implications for sustainability. It has emphasised distinctive features of the sector including its direct dependence on natural systems (climate, soil, ecological process), its complexity and heterogeneity, and Canada's dependence on international developments and markets. Agri-food is a cornerstone of economic activity, and a place where multiple trends and perspectives interact, including those of small-scale producers and corporate giants, traditional practices and novel scientific and technological approaches, public health and environmental concerns, business models and cultural expectations.

Thinking about agri-food from the perspective of the transition to net zero greenhouse gas emissions (and more generally the reduction of the ecological footprint of agri-food systems), makes clear that we are only at the beginning of the journey.(92) Transitions in systems of societal provisioning typically go through three distinct stages: '*emergence*' where problems with the existing way of doing things become manifest and experiments with alternatives proliferate, but where new approaches have functional weaknesses and are not yet economically competitive; '*diffusion*' where new approaches stabilize and positive feedbacks lead to improved performance, lower costs and rapid scale up; and finally 'realignment' where change is carried through to the system level and new arrangements solidify. On this measure the transformation of agri-food systems is largely at the emergence phase.(90) We have ample evidence of problems and an array of elements that may contribute answers – but these have yet to be integrated into solution complexes that can readily be scaled up. Industrial agriculture has proven remarkably successful, providing high yields of inexpensive food which is processed into products delivered to consumers. But environmental costs are significant, and many economic, social and health issues persist.

Precisely because agri-food transitions are at the emergence phase, *traction can be gained by bringing pressure to bear on the most unsustainable practices, directing attention to areas which constitute the largest part of the problem, and focusing resources where at least partial solutions are available and there is enthusiasm for change*. Above all, there is a need *to develop a wide variety of experiments, pilots and tests to explore, improve, and scale up promising approaches*. Only by supporting an array of innovations across agri-food production/consumption chains will it be possible to identify the most promising elements that can be combined to build more profoundly transformative pathways.(86, 87) At the policy level this requires clear signals that the most damaging practices must stop, and the deployment of an array of policy instruments to encourage innovation, support widescale experimentation with alternative approaches (technologies, farming practices, business models, regulatory schemes, etc.), including the creation of 'protected niches' where novel approaches can mature.

But if policy is important, it is far from the whole story – for the knowledge, enthusiasm, and resources from a wide constellation of actors will be required to secure change. 'Bottom-up' innovation driven by producers, companies, consumers, and other societal groups is essential. Networking innovators, to encourage exchange and mutual learning about alternative approaches, and building coalitions or consortia to develop and scale up experiments are crucial. This can in turn prepare the way for more ambitions policy frameworks and goals.

Many industry, stakeholder and government initiatives are underway in the sector to deepen the response to climate change and enhance the sustainability in the agri-food sector. Examples include:

- The *Sustainable Protein Challenge Dialogue* initiated by the government of Manitoba to explore protein futures, linking regenerative agriculture and ecosystem issues to sustainable meat, dairy, plant-based and alternative, protein production.(111)

- *McCain Foods 'Farms for the future'* program, a company led effort with three demonstration farms that will explore how regenerative agriculture can be applied at scale to potato farming (reducing GHG emissions, water requirements and waste).(112)

- *Regeneration Canada*: a grass roots organization founded in Quebec, focused on soil regeneration to promote biodiversity and healthy food systems. It undertakes educational activities with farmers, communities, businesses, and governments to build understanding of soil solutions.(113)

- *Alus Canada*, a national program to deliver conservation by supporting farmers and ranchers to improve environmental performance. Funding from corporate, charitable and government sources is channeled to landowners to enable restoration of degraded land, wetlands, field boundaries, and so on.(114)

- *Nourish*, a community of practice focused on food and health care, which links health providers and agricultural producers to improve education and implement local solutions around nutrition and climate.(115)

- *Farmers for Climate Solutions*: a national alliance of farm organizations developing policy proposals and engaging farming communities that has placed particular emphasis on peer-to-peer education to identify and scale up successful practices. A critical goal is to provide farmers with an alternative point of reference to the company-tied experts and consultants who provide advice to farms but are closely linked to dominant equipment and input suppliers.(116)

Notwithstanding these and many parallel efforts, much remains to be done to accelerate transition in agri-food systems, and there are many additional sites where foundations or intermediary organizations (such as the Transition Accelerator) could contribute. For the Accelerator, considerations in selecting such sites include:

- The significance of the GHG emissions that could be avoided.
- The potential for other system improvements above and beyond emissions reductions (enhanced lively hoods, health benefits, environmental gains, and so on).
- The presence of willing partners, and
- An unfulfilled need where value can be added to existing efforts.

Although it is beyond the remit of this paper to define specific projects, the analysis suggests that opportunities to develop focused research and to work with stakeholders to define and build out transformative pathways (that engage with existing disruptive currents and emerging patterns of change in the sector) to enhance agri-food system sustainability lie in the following key areas:

- Encouraging more sustainable approaches to dairy and beef production that respond to multiple challenges including economic viability, alternative proteins, and net zero GHG targets.
- Developing cultivation, soil and land management centered initiatives that apply regenerative and agroecological practices to improve farm economics and environmental performance (for example, reducing nitrogen emissions, enhancing carbon storage, and linking to GHG offset mechanisms).
- Developing the alternative protein sector (particularly plant based and fermented proteins) to build value-added industries, while assessing (and encouraging the enhancement of) associated nutritional and environmental characteristics.
- Encouraging indoor and vertical agriculture, focusing on business development, technology advance, and the potential contributions to improved nutrition, food security, community engagement and reduced environmental impacts (for example, in urban centers and remote, Northern and Indigenous communities).
- Exploiting existing linkages such as food system value chains to enhance multiple societal values (environmental, social, economic) and create new interactive and practice-oriented sites where producers and consumers can be brought into contact to enhance dialogue and engagement to define transformative pathways.

POSTSCRIPT ON COVID-19

Since February 2020, the Covid-19 pandemic has represented a significant health and economic threat to the welfare of Canadians. It has also highlighted weaknesses in existing institutional arrangements (for example in senior care facilities, the coordination of federal and provincial responses, and so on). Preliminary analysis suggests that overall, the farm sector has weathered the turbulence relatively well, with some tailored assistance programs (and established insurance mechanisms as potential back up) proving adequate to prevent widespread economic dislocation. (93, 94)

In many cases farmers have been able to refocus on other areas to replace lost sales in disrupted markets. Smaller local producers focused on niche products (for example organic vegetables for the restaurant trade, or for farmers markets) may have suffered disproportionally with the collapse in sales to these venues.

More broadly, there have been significant issues in three areas:

- In both Canada and the United States slaughterhouses have been sites of significant disease outbreak, and at one point (especially in the US) there was discussion of a possible disruption to meat supplies to consumers. Two issues are relevant here (a) the large number of employees massed together in cramped working conditions and (b) the concentration of production in a few large processing facilities that manage the bulk of the meat supply for the whole country (constituting a potential vulnerability to the entire production/distribution system). Both issues relate to long term industry trends towards industrial consolidation and achieving economies of scale. Although there has been talk of trying to 'thicken the chain' so multiple facilities would be available, this runs against the structure and economics of the existing industry, and it remains to be seen whether this will result in any fundamental change over the longer term. Similarly, the existence of political will to address issues related to wages and working conditions in slaughterhouses after the COVID-19 crisis recedes remains unclear.

- In several provinces there were serious disease outbreaks among foreign farm laborers who work in close contact with one another and are often accommodated in cramped temporary housing.(95) Independent of the specific measures taken to address these outbreaks, and to protect the health of migrant farm workers, this raises broader questions about the sustainability of the labor model on Canadian farms. Many farms could not operate without these seasonal migrant workers because Canadian workers are not willing to take these often physically demanding jobs at the wages offered. It remains unclear whether addressing this issue will be seen as a political priority once the COVID-19 crisis recedes.

- The health crisis and restrictions imposed to contain the disease outbreak is resulting in significant stress on the restaurant industry, and hardship for food services employees and restaurant proprietors. At different points in time restaurants faced limits on seating capacity, have been confined to patio service or take out, or even closed completely. Independent of legal restrictions, many (especially older) patrons have been hesitant to socialize while infection rates remain high. Despite financial assistance provided by various levels of government, many restaurants will not survive, and there will be a major shakeout in the industry. This represents a tragedy for many individual businesses and employees (and some communities losing local amenities), but it is doubtful that it will result in long term change in the sector. Once the crisis recedes business is likely to pick up and new establishments will enter the market.

Notwithstanding these observations, it is still too early to make definitive judgments on the potential longer-term implications of the COVID-19 crisis for the evolution of the agri-food sector.

NOTES

[1] The agri-environmental performance index shows environmental performance state and trends over time, based on weighting the percentage of agricultural land in each indicator class, such that the index ranges from 0 (all land in the most undesirable category) to 100 (all land in the most desirable category). The equation is simply "(% in poor class multiplied by .25) plus (% in moderate class multiplied by .5) plus (% in good class multiplied by .75) plus (% in desired class)." As the percentage of land in the "at risk" class is multiplied by zero, it is not included in the algorithm.

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