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Review

Energy Policy for Agrivoltaics in Alberta Canada

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Abstract:
As Alberta increases solar power generation, land use conflicts with agriculture increase. A solution that enables low-carbon electricity generation and continued (in some cases increased) agricultural output is the co-locating of solar photovoltaics and agriculture: agrivoltaics. This study reviews policies that impact the growth of agrivoltaics in Alberta. Solar PV-based electricity generation is governed by three regulations based on system capacity. In addition, agrivoltaics falls under various legislations, frameworks, and guidelines for land utilization. These include Land Use Framework, Alberta Land Stewardship Act, Municipal Government Act, Special Areas Disposition, Bill 22 and other laws/policies all of which are reviewed in the context of agrivoltaics. Several policies are recommended to support rapid diffusion of agrivoltaics. First, open access research into agrivoltaics, which not only will help optimize agrivoltaic systems for the region, but also coupled with public education is expected to galvanize social acceptability of large-scale PV deployment. Clearly defining and categorizing agrivoltaic technology, developing agrivoltaic standards, making agrivoltaic technology-friendly regulations/frameworks and developing programs and policies to incentivize agrivoltaic deployment over conventional PV will all accelerate diffusion. Through these measures, Alberta can achieve conservation and sustainability in food and energy sector while simultaneously addressing the renewable energy and climate-related goals.

Keywords: agriculture; agrivoltaic; Canada; energy policy; farming; Alberta; photovoltaic; solar energy

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1. Introduction

In a large part due to consistent solar photovoltaic (PV) system cost declines [1, 2], solar electricity is often the least costly electricity source globally [3, 4]. Even in harsher northern environments like those found in Canada, grid-connected solar PV systems are already past grid-parity with solar projects in Alberta being proposed at CAD$47/MWh and power purchase agreements (PPAs) with renewable energy credits (RECs) attached are being contracted for less CAD$70/MWh [5]. The return on investment (ROI) generally varies by province and utility [6]. Surprisingly, PV costs have declined to the point that they can be used to subsidize heat pumps to enable profitable electrification of gas-based heating in Canada [7]. These cost-related issues have ensured PV electricity production in Canada continues to grow, although this growth must be put in context. Solar still makes up less than 1% of electricity generation [6].

This Canadian PV growth is good for the local, national and global environment as solar PV is a well-established sustainable energy source [8] and shows promise to be integrated into farms [9]. PV is a net energy producer, which makes up for the invested energy in its production many times over its 25 or 30-year lifetime under warranty [10]. These values only get better as the energy conversion efficiency of all the major commercial and precommercial PV types are increasing [11]. Today PV energy payback times have dropped below a year [12]. As PV costs have declined, more have been installed and large surface areas are needed to power high-population-density cities, which are normally supplied in large PV tracts located in rural agricultural areas [13]. City dwelling has become dominant globally [14]. This also occurred in Canada with the four largest urban regions in Canada (the Calgary-Edmonton corridor, Southern Vancouver Island, Lower Mainland, and the Extended Golden Horseshoe in Ontario) housing more than half (51%) of the population [15]. Wind power siting conflicts [16, 17], are increasingly becoming a barrier to large-scale PV primarily because of the potential interference with agricultural production [19-22]. Land-use conflicts are expected to increase as population increases (1.15%/year) [23] and the need for food production must increase [24]. Both historical and current programs to convert crop land to energy (ethanol) production had detrimental effects of increasing both global food costs and world hunger [25-27]. Canada is dealing with these issues on a smaller scale as the population growth rate is 0.86%/year [28] and urban growth encroaches on agricultural land. Fortunately, a long and rapidly expanding list of studies show that it is possible to have large-scale solar PV growth while protecting agricultural production using the new innovation of agrivoltaics. Agrivoltaics is the strategic co-development of land for both solar PV electrical generation and agriculture production [9, 29- 32].

This study will review policies that impact the growth of agrivoltaics in Alberta as Alberta intends to increase renewable energy generation in the coming years and solar power generation has enormous potential in Alberta. PV has already penetrated in the agriculture sector. Solar PV-based electricity generation is governed by three distinctive regulations based on the capacity of solar system. In addition, agrivoltaics in the province of Alberta falls under various legislations, frameworks, guidelines for land utilization. These include Land Use Framework (LUF), Alberta Land Stewardship Act (ALSA), Municipal Government Act (MGA), Special Areas Disposition and the newly introduced "Bill 22", all of which will be reviewed in the context of agrivoltaics. Finally, policy measures and guidelines will be evaluated to enable Alberta's full agrivoltaic potential.

2. Agrivoltaics Background

Agrivoltaics is a symbiotic system that overall provides a dozen services summarized in Figure 1. Of the fifteen benefits of agrivoltaics, the first two are easy to understand as PV systems generate renewable electricity and this electricity offsets fossil-fuel electricity production that in turn decreases greenhouse gas (GHG) emissions [33]. The reduced GHG emissions thus help alleviate global climate change and the concomitant adverse effects on the environment and the economy [34]. In addition, a common misperception is that shaded crops from solar panels would reduce crop productivity, but less clearly intuitive, there are now many studies that show agrivoltaics *increases* crop yield for a wide variety of crops [35, 36]. For example, yield produced in agrivoltaics setting showed 72% of lettuce production compared with traditional farms while 60% of silver beet yield compared with traditional farms based on fresh mass [37]. Similarly, crop yield increased for peppers in the U.S. [38]. Investigation in Japan revealed augmented production of sweet corn in agrivoltaic applications [39]. There is even evidence of enhanced output of grain crop when farmed with solar PV systems [40]. Land use efficiency increases when PV-generated electricity is added to crop production for a farm, particularly when crop yields increase [40]. This nonintuitive result is possible because agrivoltaic arrays create microclimates beneath the PV modules that alter air temperature, relative humidity, wind speed and direction, and soil moisture [41].

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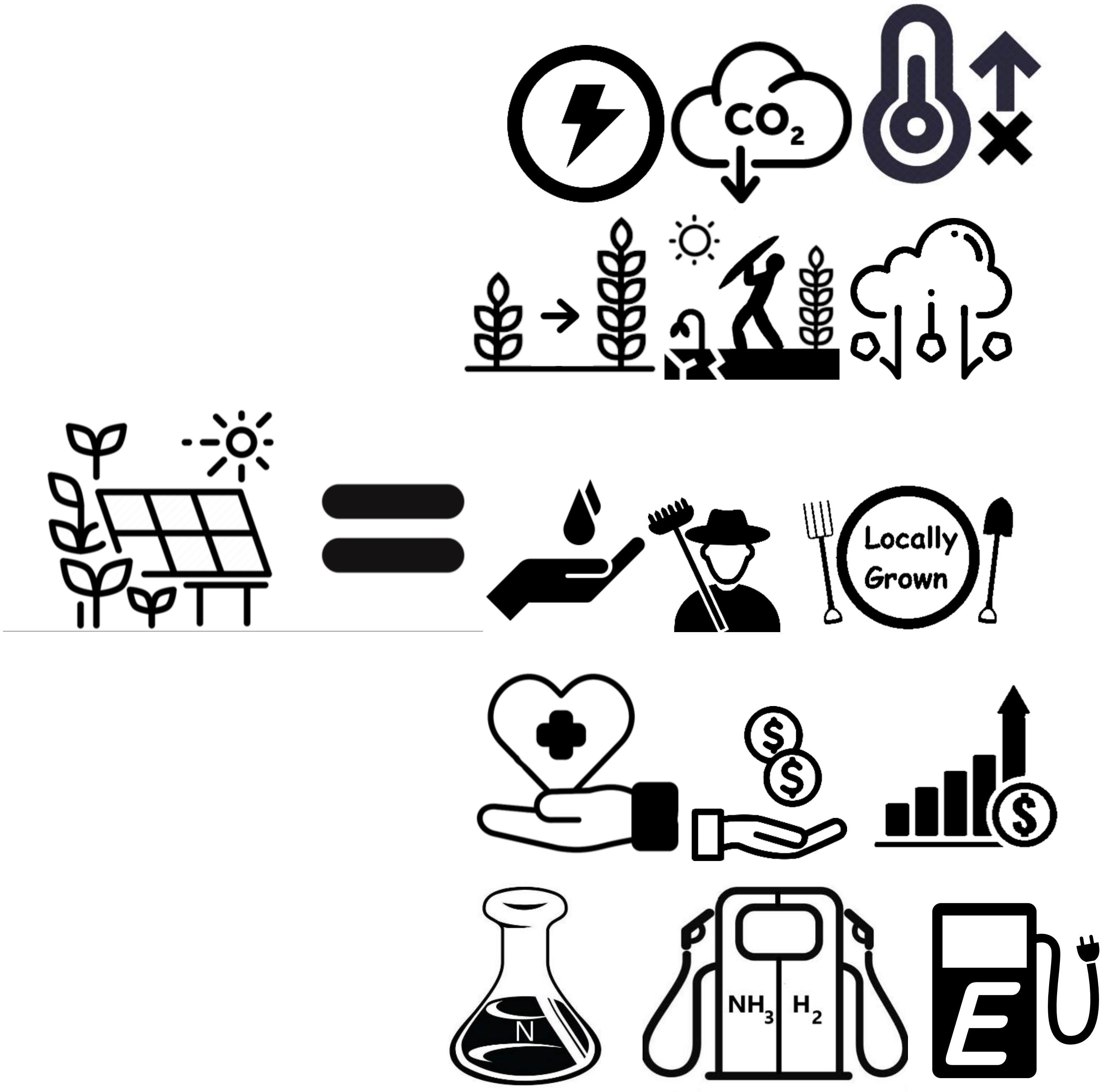

Figure 1. Services provided by agrivoltaics are a) renewable electricity generation, b) decreased greenhouse gas emissions, c) reduced climate change, d) increased crop yield, e) plant protection from excess solar energy, f) plant protection from inclement weather like hail, g) water conservation, h) agricultural employment, i) local food, f) improved health from pollution reduction g) increased revenue for farmers, h) a hedge against inflation, i) the potential to produce nitrogen fertilizer on farm, j) on farm production of renewable fuels like anhydrous ammonia or hydrogen, and k) electricity for EV charging for on or off-farm use.

This microclimate can be beneficial to crops because the PV protects crops from excess solar energy and inclement weather such as hail or high winds, while also improving PV performance because of lower operating temperatures created by the crops underneath the panels [38, 42, 43]. Remarkably, a study by Mow et al., showed that agrivoltaics has the potential to increase global land productivity by 35–73% [44]. Real agrivoltaics also minimize agricultural displacement for energy [32, 44, 45]. In addition, to the benefits for the PV array and the crops, agrivoltaics also can benefit water systems as it enables more efficient use of water for farming and thus provides for water conservation [46- 49].

PV can also be used to power drip irrigation [50] and vertical growing [51], which uses a fraction of the water of field-based crops. Unlike conventional solar farms that eliminate agricultural employment when they are installed, agrivoltaics maintains agricultural employment and the farmers provide local food along with all the benefits of reducing food miles and providing fresh food [52-54]. Fresh food has health benefits, but agrivoltaics because it can offset fossil-fuel pollution that is also linked to health problems [55], also can improve human health and even prevent premature deaths [56]. Reduction in pollution is primarily attributed to (Scope 1) minimizing emissions related to products produced remotely and brought onto farms for crop production purpose (i.e. fuel, electricity and fertilizers), (Scope 2) minimizing emissions generated during farming operations particularly if electric vehicles (EV) and processing are used and (Scope 3) minimizing emissions related to transportation of produce from farmland (again being used for EVs). In addition, both the increased solar energy production and the increased land use efficiency has an economic value and thus increases revenue for a given acre [57]. In addition, because PV is a capital asset that generates value that increases with inflation, it can be used as an inflation hedge during times of high inflation (e.g, 2021 and 2022) [58]. Lastly, agrivoltaics has the potential to be used for on farm production of nitrogen fertilizer [59], renewable fuels like anhydrous ammonia [60] or hydrogen [61-63] or electricity for EV charging for on or off-farm use.

Agrivoltaics is available at all scales. Normally it is seen at a large scale, but even for the home gardener, parametric open-source cold-frame agrivoltaic systems (POSCAS) have been developed [64]. Agrivoltaics also works with different levels of shade tolerant crops. Full array density PV modules are beneficial for shade tolerant crops, while half or three-fourth array density PV is beneficial for shade intolerant crops [65]. Considering crop performance, East/West facing vertical bifacial solar panels can be the preferred fixed tilting scheme to be employed for agrivoltaic applications [65]. For bifacial PV modules installed in agrivoltaic applications, increased irradiance and bifacial gain is observed by elevating the height of PV arrays [66]. This also results in convenience of operation for conventional agricultural machinery. Moreover, increasing row spacing reduces electrical output per unit area, though, it increased ground irradiation [66]. South facing topologies are conducive for cultivation during summer for farming shade tolerant crops whereas East-West vertical arrays are beneficial during non-summer, and hence, advantageous for permanent crops [66].

Agrivoltaics has been demonstrated in Canada such as in the Arnprio tri-part agrivoltaics that consists of a monarch butterfly conservation subproject, a bee and honey production subproject and a solar grazing and natural weed cutting subproject [67]. Currently, most Canadian agrivoltaics systems are made up of conventional solar PV farms that are also used for grazing sheep. This does have positive benefits for both the sheep (i.e. both thermal protection [68] and more importantly, higher-quality grazing areas [69]), but also the PV systems (i.e. reduced costs for weed abatement) and when combined the global environment [70]. These uses are considered agrivoltaics, but they are not the highest value benefits seen in Figure 1, nor are they the greatest land use efficiency strategies. Unfortunately, Canada is lagging Europe, Asia and the U.S. in agrivoltaics. Other countries that make more aggressive use of agrivoltaics would be expected to generate more revenue per acre and win competitive markets. As the fifth largest agricultural exporter in the world [71], Canada has considerable revenue at stake to maintain the state-of-the-art in agricultural technology.

Land use policies and legislation have traditionally been a deterrent in wide scale PV deployment due to the apprehensions of adverse impact(s) on agriculture due to such development [72-75]. As Canada in general, and Alberta in particular, is already at a strategic disadvantage in the agricultural space without the use of agrivoltaics, this study reviews both the current policies and the policy changes necessary to capitalize on the benefits of using agrivoltaics in Alberta.

3. Alberta

3.1. Governance

Canada's national government operates as a constitutional monarchy and a federal democracy. Each province and territory have a distinct legislature that oversees local matters and controls municipalities within its jurisdiction. Alberta, the 4th largest/4th most populous province of Canada and has the 3rd highest gross domestic product, represents about 15.3% of the GDP of Canada [76-78]

D3.2. Alberta Solar Energy Potential

Alberta has a total installed power generation capacity of approximately 17,224 MW. The largest share of electricity generation comes from Cogeneration (30%) followed by coal-fired (16%) and wind plants (13%) and 4% of the total installed capacity is comprised of solar plants [79]. Agriculture sector shares approximately 4% of the total provincial electricity consumption in Alberta [80]. The province is witnessing an increasing trend of solar PV and wind power generation as investments come from the public and private sector [81].

With an approximate solar PV production portfolio of 1,276 kilowatt-hours, per kilowatt, per year (kWh/kW/yr), as can be seen in the solar energy distribution in Figure 2, Alberta has the second highest solar energy potential [82]. Solar power potential of Alberta exceeds that of Berlin, Tokyo, and Paris (Germany, France and Japan are all leading countries in agrivoltaics). With the increasing cost of electricity in Alberta, the future of solar PV appears to offer significant savings [83]. Previous studies have shown a close relationship between solar insolation and prevalence of solar PV technology in that region [84, 85], so growth of PV in Alberta appears likely.

Photovoltaic potential, annual (kWh/kWp)	0 - 500	500 - 600	600 - 700	700 - 800	800 - 900	900 - 1000	1000 - 1100	1100 - 1200	1200 - 1300	1300 - 1400
Photovoltaic potential, monthly (kWh/kWp)	0 - 20	20 - 40	40 - 60	60 - 80	80 - 100	100 - 120	120 - 140	140 - 160	160 - 180	180 - 200
Mean daily global insolation (kWh/m2)	0 - 0.8	0.8 - 1.7	1.7 - 2.5	2.5 - 3.3	3.3 - 4.2	4.2 - 5	5 - 5.8	5.8 - 6.7	6.7 - 7.5	7.5 - 8.3
Mean daily global insolation (MJ/m2)	0 - 3	3 - 6	6 - 9	9 - 12	12 - 15	15 - 18	18 - 21	21 - 24	24 - 27	27 - 30

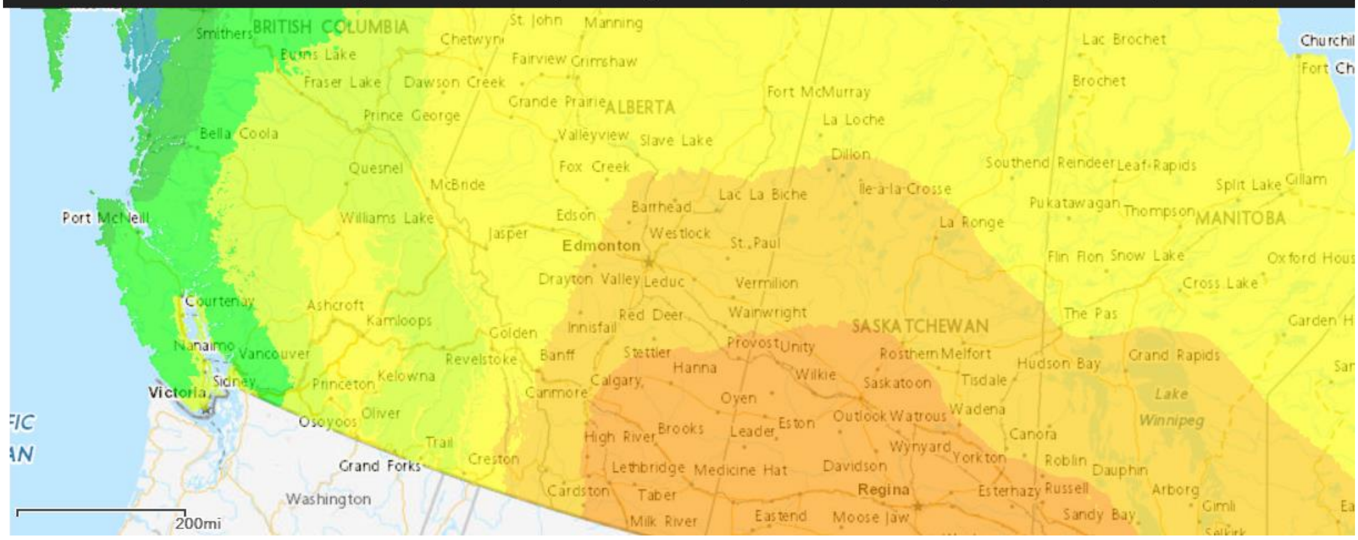

Figure 2. Annual solar photovoltaic potential in kWh/kWp facing south with a lattidtude tilt in Alberta [86].

3.3. Alberta Renewable Energy Policy

In Alberta, Clean Energy Technology was facilitated via the Renewable Electricity Program which aimed to take the province's generation capacity to 30% via renewables [87]. Through Renewable Energy Act also, province of Alberta resolves to augment renewable energy generation to 30% by 2030 [88]. To promote green electricity, it is often imperative to provide affordable financing [89-91]. One such initiative is the Clean Energy

Improvement Program, which allows individuals to make energy efficiency upgrades without initial financial burden [92]. A few other initiatives such as Small-Scale Generation Regulation under the Electric Utilities Act also promotes clean energy technology on a community scale [88].

There is also an opportunity for substantial employment in solar in Alberta [93]. Worldwide, solar PV employs the highest share of workforce in the renewable energy market – approximately 3.6 million people are associated with solar sector as of 2018. China leads the industry being the lead employer followed by U.S. [94]. A study conducted by Solar Energy Consulting foresees a potential of more approximately 10,000 jobs till 2030 in Alberta [95].

3.4. Alberta Solar PV Regulations

In Alberta, Solar Photovoltaics are regulated using the following three basic regimes [95]:

- Micro-generation Regulation
- Small-scale Generation Regulation
- Utility-scale regulatory frameworks and exchange through the power pool

3.4.1 Micro Generation Regulations

According to Alberta Energy, "Micro Generation" refers to electricity generation on a limited scale (normally ranging from 150 kW to 5 MW) using renewable energy means such as wind, solar, etc. [96]. It is normally employed in residential setups or small offices to provide their day-to-day power requirements. It allows people of the province to compensate their electricity needs via clean energy technology.

The generation units falling under this category receive credits for excess electricity generated which they feed to the grid thus forming a net billing system. Small setups receive credits for electricity fed to the grid on a monthly basis at retail rates, while large micro-generators receive credits for sending energy to the grid at an hourly wholesale market price [83]. Small generation units may also receive the credits on hourly basis at wholesale market prices provided they install a suitable meter. This would be appropriate for small to medium sized farms using agrivoltaic systems.

3.4.2 Small Scale Generation Regulation

The regulation tackles the gap which has previously existed between micro generation and large-scale utility projects. Although not specifically mentioned, size of the projects falling under this category is limited to the distribution system capacity thus curtailing them typically to 25 MW [95]. The regulation provides special opportunities for certain groups such as schools, universities, and agricultural societies. It also simplifies the procedures of connection. This size of system would be appropriate for medium to large farms targeting agrivoltaics. Payment mechanism for small scale units connected to the grid involves metering the energy credit on an hourly basis. Distribution owner then calculates the revenue on the basis of spot market rate and payments are made monthly to the owner.

3.4.2 Utility Scale Generation Regulation

Utility-scale solar farms are large-scale solar projects consisting of large-scale solar arrays and supply power to the transmission grid. These are regulated through Electric Utilities Act in a manner similar to other large power generation installations. Compensation of electricity costs are carried out by application of tariff to Electric Utilities Commission as established under the Alberta's Utilities Act Commission. Once the tariff is approved and the utility forms part of the Power Pool, which is operated by Alberta Electric System Operator (AESO) for setting out financial settlement in exchange of electrical energy, then, subsequently, finances are settled through the pool price established. Alternatively, a direct sale agreement may be established following the ISO rules for sale/purchase of electricity between the parties to account for compensation [97].

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According to Renewable Electricity Act, the independent system operator (ISO) has the authority to establish a renewable electricity support agreement with the selected renewable facility or participant which is done by running a competitive process. This agreement outlines the regulations regarding operation of the facility as well as the payment mechanism. Renewable generating unit above 5 MW is designated as large-scale utility scale generation according to Renewable Electricity Act [98].

3.5. Opportunities for Agrivoltaics in Alberta

The number of Canadian farms reporting use of renewable energy has more than doubled in the last five years according to the latest data in the 2021 Statistics Canada Agricultural Census. Of the total 205,000 farms approximately, more than 22,500 farms nationally reported having renewable energy production on their operations, up from a little more than 10,000 in 2016 [100]. Much like businesses in general, farmers in Canada are increasingly using solar power as a source of energy generation more commonly for small size applications like feed in tariff program in Ontario and heating water for cattle in Alberta. PV is the largest source of renewable energy being used by Canadian farmers. The integration of solar energy in agriculture witnessed a steep rise with the number of farms with solar increasing more than 66% as cited in the latest 2021 Census results [99].

This increase in interest may in part be a result of agrivoltaic operations. One such example is in central Alberta where Innisfail [100] leased municipal land to a solar production company, which is also used as a sheep ranch. Solar is also increasingly used to power irrigation pumps, as well as over open canals to help stem evaporation, while producing electricity [100]. Statistics Canada credits government programs for the growth of on-farm renewable energy production, however, these programs appear to have subsided. Programs such as the joint federal-provincial Growing Forward program for on-farm solar was extremely successful in addition to an Alberta program funded by the provincial carbon tax on large CO_2 emitters, which has not been renewed [100].

3.6. Alberta Federation of Agriculture (AFA)

Alberta Federation of Agriculture (AFA) is an organization comprised of farmers and people associated with farming who intend to contribute to the future of agricultural operations in Alberta [101]. The resolutions of this society align with the concept of agrivoltaics and can serve as an opportunity to build a case for agrivoltaics in Alberta while also introducing agrivoltaics to the wider agricultural community.

As per the AFA 2020 resolution [102], farmers of Alberta take advantage of the Conservation Cropping Protocol that allows them to sell carbon offsets. Though the advantage is capped once 40% of the farmland, which makes up 8.76 million acres of land, is compliant with the Protocol. Currently, 39.5% (8.67 million acres) of the farmland has registered to Conservation Cropping Protocol [102]. The resolution suggests that AFA approaches Government to remove the capping so that farmers may participate for 100% compliance. Agrivoltaics provide an excellent opportunity to Albertan farmers to play their part in carbon sequestration, gain carbon offsets and achieve Canada's target of net zero greenhouse gas emissions by Canadian Agriculture till 2050. In addition, several recent studies [103, 104] have indicated that wood-based PV racking is economically viable and can be used for agrivoltaics, which would further improve a farm's carbon footprints as it represents a long-term carbon storage in sustainably harvested wood over the life of the agrivoltaic system (25 years).

One of the conclusions of Canada Food Policy [105] is sustainable food practices and AFA through its resolution on Food Awareness, suggests raising awareness among the masses as well as within the government that Canada Food Policy must align with sustainability. Agrivoltaics provides an innovative methodology of ensuring food sustainability/security as it circumvents usage of agricultural land for pure urban development and the associated problems that come with such a conversion [106, 107, 108]. With placement of solar PV on agricultural land for use in agrivoltaics, industrial energy generation

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or urban expansion could be avoided as the same piece of land is used for electric power generation at an increased revenue per acre point.

3.7. Climate Smart Agriculture

The government of Canada has imposed taxation on carbon emissions [109]. To meet the targets on the Paris Accord [102], one approach is to use carbon sequestration in agriculture. Therefore, AFA through its 2020 resolution, demanded that a national program be established where carbon credits can be traded for carbon emitters/sequesters and carbon tax may be offset using the carbon credits earned [102]. Agrivoltaics is an innovative way of using renewable energy for agricultural operation, which may help farmers economically as well as aid Canadian government meeting the target of the Paris Agreement. "Climate Smart Agriculture" refers to the practices and operations that result in alleviating greenhouse gas emissions, hence, contributing positively to changing climates while also maintaining food security [110]. Farmers, using innovative agricultural techniques like agrivoltaics, can seek advantages of such practices contributing to lower carbon footprints and better climate resilience. On-farm energy usage contributed to approximately 13% of Alberta's greenhouse gas emissions [110]. Electrification combined with onsite agrivoltaic solar electric generation provides a path to reducing this value beyond zero as farms become net exporters of green electricity while still providing food.

Farmers often suffer the worst of the negative impacts of climate change with increased flooding [111], droughts [112, 113], and heat waves [114] that all adversely impact agricultural operations. Hence, there is a long-term incentive for farmers to adopt sustainable practices and farmers, by adopting agrivoltaic technology, can contribute to lower carbon emissions and play their part in conserving the environment as well as help alleviate climate change impacts. Southern Alberta is one of the most conducive regions for PV installations. The electricity produced via solar PV on agricultural land may be sold to the Alberta Electric System Operator [115], thus also providing an alternate revenue stream for farmers.

4. Policy Review for Agrivoltaics in Alberta

4.1 Land Use Framework (LUF) for Alberta

Alberta's Land Use Framework is a top-level document that aims to ensure sustainable growth and development without compromising Albertan's social and environmental goals.

4.1.1. Land Use Decision Making According to LUF

Land-use decision making in Alberta considers the government's 1948 decision to categorize land as Green and White Areas as shown in Figure 3 [116]:

- Green Area lands are defined as lands consisting of forested land and covers almost two-thirds of Alberta's land [116]. Nearly all public land, mainly in Northern Alberta, fall under the Green Area classification. Main utilization of Green Area includes timber production, oil and gas fields, tourism, fish and wildlife habitat etc. Regulatory and decision-making authority lies with provincial government for public land. Currently, no renewable energy development is allowed on Crown Land in Alberta neither it is permitted on massive grazing lease area in southern Alberta. This puts PV development pressure on deeded agricultural land for clean energy projects as that is the only buildable area aside from parking lots, urban green spaces or on buildings. The preferred approach from a climate/sustainability perspective would allow renewable development on Crown Land, thus, taking away pressure from cultivated soils. Now, with agrivoltaics, however, large-scale PV deployment can be done on cultivated soils. Having agrivoltaics access Crown Land is clearly beneficial following Figure 1. It should be noted that

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the map does not show the exclusion zones for Crown Land administered by Special Areas or through public grazing leases.

- White Area lands consist of settled land and cover almost one-thirds of Alberta's land [116]. Approximately three-quarters is privately-owned land, mainly central, southern and Peace River area fall under White Area. Main utilization of White Area includes urban settlements, agriculture, oil and gas fields, tourism, fish and wildlife habitat. Regulatory and decision-making authority in these areas lies with municipal government for private land and provincial government for public land.

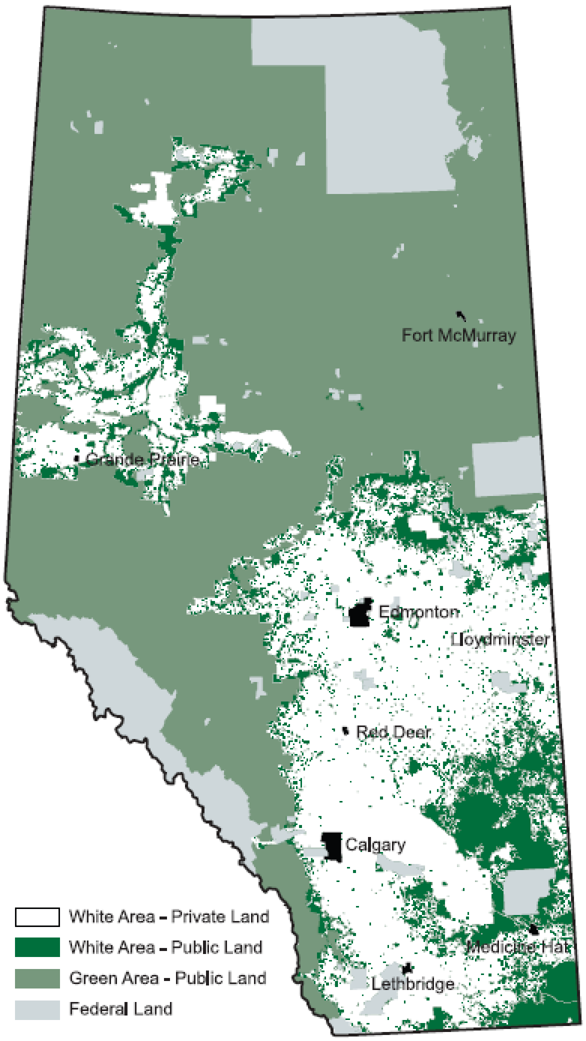

Figure 3. Alberta's Land segregated as Green Area, White Area (Public and Private) and Federal Land in Land-use Framework [116]

The framework entails seven different strategies which will define the utilization of land in the province [116]. Here, only those strategies (1,2,3, and 5) which may have a connection with agrivoltaics are discussed:

- Strategy 1 – Develop seven regional land-use plans based on seven new land-use regions.

Alberta's provincial government have chalked out various regulations and frameworks (including Alberta Land Stewardship Act, Municipal Government Act, Soil Conservation Act, Agricultural Operations Protection Act, Special Areas Disposition Regulation) that may impact land use. Authority to final decision and enforcement, however, lies either with the provincial government, municipal governments, multi-stakeholder groups, industry, or a combination of all four [116]. Although the processes worked to come up with plans intended for a definite purpose, there is some ambiguity when

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implementing these processes to a particular geographical region [116]. The Province of Alberta also lacks a formal planning mechanism on the regional level [116]. In order to address this, the Government of Alberta intended to create seven land-use regions for which individual land-use plans will be developed. The objective of these regional plan will be four-fold [116]:

1. Integration of provincial policies at a regional level
2. Identify land-use objective at a regional level
3. Provide background and context of land-use decision making in the region
4. Reflect uniqueness of the landscape/geography and set regional priorities

- Strategy 2 – Create a Land-use Secretariat and establish a Regional Advisory Council for each region.

For efficient land-use planning and better resource management, it is imperative to have a strong leadership and clear direction. For implementation of this LUF, a governance structure which will form the Land-use Secretariat is needed which will be responsible for the development of regional plans in collaboration with other government bodies [116].

- Strategy 3 – Cumulative effects management will be used at the regional level to manage the impacts of development on land, water and air.

In Alberta, environmental impacts assessment was usually carried out for individual projects and developments. The methodology did not consider the overall effects of multiple developments taking place at different times. Hence, LUF through this strategy, ensures that the regional plan will incorporate the cumulative effects approach for determining the environmental impacts. This will help better the understanding of associated environmental risks posed by these new developments as well as identify environmental objectives and its management to remain within those objectives.

- Strategy 5 – Promote efficient use of land to reduce the footprint of human activities on Alberta's landscape.

Land is a limited resource, and its efficient utilization is extremely important. The idea should be to alleviate the impacts of human activity on Alberta's landscape. Hence, all land-use decision making must consider this objective whether its residential or urban development related, transportation or industrial related, or agriculture related.

4.1.2. Departmental Responsibilities for Land Use

There are several departments and ministries that impact land use in Alberta including:

1. Alberta Agriculture and Food
2. Alberta Energy
3. Alberta Environment and Parks
4. Ministry of Municipal Affairs

Alberta Agriculture and Food works in an advisory role and in collaboration with other provincial ministries, municipal governments, landowners, and industries/companies to ensure sustainability of agriculture business as well as its expansion via policies, legislation and strategies [116]. It is responsible for the legislation and policies of more than 52 million acres of agricultural land.

Alberta Energy works for the development of Alberta's energy and mineral resources by selling oil, gas and mineral rights [116]. It also carries out evaluation and collects revenue from nonrenewable resources in the form of royalties, and freehold mineral taxes. The ministry primarily deals with oil and gas, petrochemicals, electricity, coal and minerals as well as renewable energy resources (wind, bioenergy, solar, hydro, and geothermal).

Alberta Environment and Parks oversees the legislation and policies that impact air quality, water and waste management, land use and climate change [116]. It is responsible for environmental reviews and promotes environmental conservation and education. It

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serves as a monitoring body and ensures enforcement of the provincial environmental laws and policies.

The Ministry of Municipal Affairs serves as advisory body to municipalities for planning and development [116]. The Municipal Government Act allows municipalities to undertake strategies and develop land-use bylaws to ensure the best utilization of land within their region.

The Department of Sustainable Resource Development is responsible for the managing the province's public land, forest, fish and wildlife resources.

4.1.3. Alberta's Future and Guiding Principles

Several guiding principles define Alberta's vision for the future and its key ingredients going forward into the future [116]. Only those which are related to agrivoltaic technology are reviewed including sustainability, knowledge-based decisions and responsiveness:

One of the guiding principles that Alberta's LUF mentions is sustainability [116]. All technological progress and development should be able to meet the present needs without costing or adversely affecting the requirements of future generations. The principle which drives intergenerational responsibility covers all forms of human land use including agricultural. Without considering sustainability in Alberta's future land use decision making, the consequences are likely to be negative for future generations.

Another aspect of the guideline is to ensure that all government decision-making and choices are based on science and evidence.

One of the guiding principles suggests that the land-use decision making will address the changing socio-economic and environmental conditions through regular assessments. In case of any unwanted results, the Cabinet will reconsider the policies and regulations for improvement. Provincial outcomes desired from land use planning include:

- healthy economy that is supported by province's land and natural resources,
- healthy ecosystems and environment, and
- people-friendly communities with sufficient leisure and cultural opportunities.

Agrivoltaics could play a role in achieving these three desired outcomes in Alberta.

4.1.4. Conservation and Stewardship in LUF

The Government of Alberta is keen to implement stewardship tools that could help protect provincial landscapes while continuing sustainable growth [116]. In the context of agrivoltaic technology, the applicable measures on private land are:

- Transfer of Development Credits: A tool which promotes development away from certain geographical locations and ensure protection of open landscapes and agricultural land.
- Land Trusts and Conservation Easements: Land Trust [116], a non-profit organization acquires land or interests in land (i.e., conservation easements) to safeguard it from human interventions/activities.

In the context of agrivoltaic technology, the applicable measure(s) on both public and private land are:

- Land conservation offsets refers to compensation for the loss or damage to biodiversity or landscape or environment due to development on either public or private land. Compensation may take any form including replacement, restoration or monetary compensation.

Another characteristic of LUF is the efficient use of land, which suggests utilizing "green" technology in new development that alleviates the impact on ecosystem and natural landscape [116]. Agrivoltaic aligns well with this postulate of LUF and provides opportunity to Albertans to lead a green and sustainable technological revolution.

4.2 Maintaining Agricultural Land

Alleviating the conversion of agricultural land for other development purposes is a cornerstone of an efficient LUF [116]. Alberta's economy largely benefits from agriculture

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and conservation of agricultural land is thus imperative. As part of addressing this concern, the LUF indicates that the Government of Alberta may develop mechanisms and approaches such as market-based incentives, transfer of development credits, agricultural and conservation easements, and smart growth planning tools designed to reduce the fragmentation and conversion of agricultural lands as part of Alberta Land Stewardship Act (ALSA). The purpose of the ALSA is to implement the LUF and has direct control of planning and protection of agricultural lands [117].

4.2.1. Regional Planning

In terms of land use planning, the ALSA holds promise for conservation of agricultural lands via regional plan zoning and conservation directives. Alberta is divided into following seven regions for regional planning purposes as shown in Figure 4:

1. Lower Athabasca Region;
2. North Saskatchewan Region;
3. South Saskatchewan Region;
4. Upper Peace Region;
5. Lower Peace Region;
6. Red Deer Region; and
7. Upper Athabasca Region.

Figure 4. Alberta's seven regions for land use planning [118].

A regional plan, once implemented, must be followed by those in power at the provincial and municipal level. With regards to agricultural land especially, a regional plan may conserve, protect, manage and enhance agricultural values by declaring a conservation directive in a regional plan. Regional plan zoning could thus serve as a tool to limit development, or other uses of land within a region. This could be used to establish an agricultural zone in which only agricultural activities are permitted (as a kind of agricultural reserve/greenbelt). Despite over a decade since realization of ALSA, only two regional plans have yet been completed while work on third (the North Saskatchewan

Regional Plan) is in progress. In the two regional plans (the Lower Athabasca Regional Plan or LARP and the South Saskatchewan Regional Plan or SSRP) completed, however, there have not been any restrictions imposed [117]. Both the plans demand municipalities to prioritize location for agricultural activities, however, there are no explicit directives to protect such regions [117]. It is left at the will and discretion of municipality to take measures for conservation of agricultural land. Permits for installation of solar PV on agricultural land are governed by Local Municipal Development Board via "discretionary use permit". A Provincial Review Board oversees the approval process for installation of solar systems and once a conditional permit is approved, there is a 45-day appeal period.

The LARP's purpose is to maintain, preserve and diversify the region's agricultural industry. The indicator selected to monitor this objective is the fragmentation and conversion of agricultural land. There are no targeted zoning restrictions or conservation directives regarding agricultural land in the LARP [117]. Therefore, it can be said that LARP lacks the relevant regulatory authority for its implementation, although it does provide limited guidance and direction for agricultural land usage.

Agriculture plays a significant role in the SSRP as it is the primary renewable and sustainable resource in the area. The SSRP indicates that agricultural activity on public land in the Green Area is limited to grazing that is compatible with other uses [117]. Public Land in the White Area is also classified as agricultural land. The aim of the SSRP is to diversify and maintain agricultural industry and agricultural land conversion. The Pekisko Heritage Rangeland represents the only specific zoning restriction in the SSRP for agricultural land and there are no conservation directives regarding agricultural land in the SSRP [117]. Hence, quite similar to the LARP, the SSRP only provides some guidance and direction concerning agricultural landscape, but not the authority required for its implementation.

Furthermore, the guidelines in the LARP and the SSRP seem to lack conclusiveness and the details. Regional planning is an excellent avenue which if used properly provides a gateway for evaluation of agricultural land within the province, determining priority regions for protection and development of a framework to minimize fragmentation.

4.2.2. Conservation Directives

One of the land use planning tools referred to in the ALSA is conservation directives. From the act, the purpose of conservation directive is to "permanently protect, conserve, manage and enhance environmental, natural scenic, esthetic or agricultural values" [119]. No conservation directives, however, have been issued to date [120]. Contrary to other tools available in ALSA, compliance with conservation directive becomes mandatory once enforced, however, negotiations could be carried out with the government thus practically making it compliance voluntary.

4.2.3. Conservation Easements for Agricultural Lands

A conservation easement is a contract between a private landowner and a government agency or a qualified private land conservation organization in which the landowner consents to certain limitations to be enforced on the land for protection [121]. It is the only tool in use under ALSA. The following limitations may be pressed on conservation easement lands:

- no use or set aside: generally used to safeguard an environmental feature and permit only existing use to continue;
- restricted agricultural/ forestry use: permit usage of land in accordance with certain standards of practice considered favorable to the environmental state of the property and restrict activities that minimize environmental benefits or ecological functions; or
- restricted development: generally, the most flexible and permits most forms of agricultural or renewable resource use. This, however, is not always the case. For example, currently, one of the largest and most active conservancies in Alberta is the Nature Conservancy, which has a blanket limitation against all renewable

energy projects on conservancy bond lands including agricultural land. This again, pulls land out of the farmland inventory for potential applications for agrivoltaic use. As agrivoltaic development maintains the farmland for use during operation, it comes with a host of attributes that are in line with conservation and environmental protection goals and does not permanently cause damage to the land for other uses. It may be time for the Nature Conservancy to reconsider its position against PV.

4.2.4. Conservation Offsets

Conservation offsets suggest that conversion of an agricultural land for other usages and purposes would be offset to make up for the loss/damage.

4.2.5. Transfer of Development of Credit Schemes (TDC)

The idea underlying transfer of development credit (TDC) schemes [119] is to utilize transferable units which will lead development away from conservation areas (sending areas) and ensure development takes place in other regions (receiving areas). TDC schemes are basically an offsetting tool which require to be used along with other tools that conserve land. Although TDC schemes are allowed under ALSA, there are no pertinent guidelines for their practical realization [119]. Protection of agricultural land can be promoted in urban outskirts through a TDC scheme. Via TDC, an agricultural landowner in the sending area can earn stewardship units in return of not allowing the agricultural land for development and those stewardship units can be exchanged with a developer. It allows developers more liberty for development.

4.2.6. Stewardship Units and Exchange

ALSA allows for stewardship units and the possibility for an exchange. There are no reinforcing regulations or framework to make use of stewardship units in Alberta, neither is there any formal exchange established. The definite role for stewardship units and the exchange is presently ambiguous due to limited guidelines and directions available in the ALSA.

4.3 Municipal Government Act (MGA)

The MGA serve as the main legislative document oversighting municipalities in the region [117]. Hence, it becomes relevant to conservation, conversion, protection and fragmentation of agricultural lands. A municipality has the authority to pass bylaws for health, safety, protection and welfare of people, property, and environment [117]. Bylaws for betterment and well-being of environment including programs for conservation, stewardship and protection of biodiversity have been extended in Edmonton and Calgary.

A part of MGA deals with planning and development matters whereby its purpose is to “achieve orderly, economical and beneficial development, use of land and patterns of human settlement, and to maintain and improve the quality of the physical environment within which patterns of human settlement are situated in Alberta” [122]. The following planning documents (to be prepared by a municipality) are required by MGA:

- Intermunicipal development plans (IDPs) address future land use and environmental matters relevant to those lands within the municipal boundaries
- Municipal development plans (MDPs) are related to future land use within the municipality; coordination of land use, future growth patterns and other infrastructure with adjacent municipalities; and future development in the municipality.
- Area structure plans (ASPs) serve as a framework for subsequent subdivision and development of an area of land.
- Area redevelopment plans (ARPs) are used to designate areas within a municipality as redevelopment areas for different purposes including preserving or improving land and buildings within the area.

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It is evident that literature related to municipal planning does not conserve or protect agricultural land, however, municipal planning could be structured in a manner which conserves or protects agricultural lands. Furthermore, the current approach is decentralized, resulting in municipal and regional autonomy to manage development with little provincial oversight [117].

MGA also requires each municipality to pass a land use bylaw that segregates municipality into districts and defines/designates allowable land uses for each district, also referred to as "zoning". However, it may be easily amended to accommodate for any development [117].

In addition, MGA enables the establishment of Growth Management Boards. Until now, two Growth Management Boards have been set up: the Edmonton Metropolitan Region Board (EMRB) and the Calgary Metropolitan Region Board (CMRB) [117]. Efforts are now underway at regional level for multiple counties boards to work together on land use and some areas like the Battle River Economic Alliance is attempting to attract business through land use strategies [123]. The mandate of both Boards includes ensuring environmentally responsible land-use planning, growth management and efficient use of land. Each Board is tasked with the development of a Growth Plan which must, among other things, identify agricultural lands and provide policies regarding the conservation of agricultural lands.

With their extensive planning and development powers, municipalities have the authority and legal arm that can enforce significant control over urban development on agricultural lands. Within the jurisdiction of a municipality, zoning and other planning decisions can be made that have direct implications on agricultural lands.

4.4 *Laws and Policies Related to Agricultural Operations and Practices*

Agricultural operations and practices, in essence, fall under provincial jurisdiction [117]. The relevant legislation in Alberta with regards to agricultural operations and activities are the Soil Conservation Act [124] and the Agricultural Operation Practices Act (AOPA) [125]. The Soil Conservation Act makes it the duty of every landholder to prevent soil loss or deterioration while the AOPA protects agricultural operations from nuisance actions. Any agricultural activity carried out on agricultural land for the purpose of gain or benefit may be referred to as an agricultural operation [125]. This includes farming on land; breeding and maintaining livestock; crops production; production of dairy products such as eggs and milk; production of fruit, vegetables, sod, trees, shrubs and other horticultural crops; production of honey, and other similar activities. A generally accepted agricultural practice may be referred to as an activity carried out in a manner coherent with the accepted norms and standards, developed and followed by similar agricultural operations under analogous situations and occurrences. A generally accepted agricultural practice can include the use of innovative technology used with advanced management practices. This is prime opportunity to integrate agrivoltaics into existing law. All development, however, must align with the guidelines of environmental and decommissioning guidelines set out by AEP. This also requires preparation of a Referral Report for each site after a year's study of a project's impacts to develop steps required to manage soil and native species throughout the life of project [126].

4.5 *Bill 22*

The newly introduced Bill 22 [127] made some amendments to Alberta's Electricity Utilities Act (EUA) [128], Hydro and Electric Energy Act (HEEA) [129] and Alberta Utilities Commission Act (AUCA) [130]. The most relevant legislative change which may impact agrivoltaics is the amendment unlocking provision for self-supply and export of electricity. Through the changes proposed in Bill 22, a path is described to acquire the status of Industrial System Designation (ISD) [131]. According to HEEA an ""industrial system" means the whole or any part of an electric system primarily intended to serve one or more industrial operations of which the system forms a part and designated by the Commission as an industrial system" [129]. HEEA, EUA and other regulations generally forbid self-supply

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and export of electricity. Any facility marked as ISD, however, is exempted from such prohibition. In summary, through Hydro and Electric Energy Act, Alberta Utilities Commission (AUC) grants any generating facility Industrial System Designation if construction of on-site electric generation is an element of an efficient, highly integrated industrial process where on-site generation is the least expensive source of generation for on-site operations [129]. Although current legislation permits generation units to provide electricity for its own consumption, a series of AUC rulings (E.L. Smith Decisions) disallowed self-supply and export of electrical energy without a particular statutory exemption [131].

With the amendments proposed in Bill 22, new projects intending to self-supply and export electrical energy may take aid from the exemption clause of Electric Utilities Act in case they do not meet the requirements of being granted ISD. By new exemption regulations introduced into EUA, self-supply and export will be dependent on Independent System Operator (ISO) tariff rate [131]. ISO tariff rate is not concluded yet [131]. Moreover, AUC may also demand from the concerned generating facility to pay part of the transmission costs. It should be noted, that no such charges to date have been imposed on any ISD seeking approval. Moreover, since AUC itself acknowledged that although it had approved self-supply and export facility requests, through E.L. Smith Decisions, those decisions made earlier (AUC's approval decision for self supply and export of electricity) would stand void. Bill 22, however, addresses the ambiguity and provides a grandfather clause through which all such plants operating on or before the January 1, 2022, may apply for ISD and be granted the same for continued operation. With the introduction of Bill 22, farmers now have the opportunity to install larger solar PV systems (greater than 5 MW, which historically was only to cover the farm's load), export electricity, and thus, benefit from off-farm revenue stream.

4.6 Special Areas Disposition Regulation

Part 2 Grazing Dispositions [132] and part 3 Cultivation Dispositions of Special Areas Disposition Regulation [132] may have implications regarding implementation of agrivoltaic technology in Alberta.

4.6.1. Grazing Dispositions

Part 2 of Special Areas Disposition Regulation deals with the Grazing Disposition which means grazing lease or grazing permit. The Minister is authorized to grant grazing leases that allow grazing of livestock over public land. The document directs receiver of grazing disposition to utilize land granted under the disposition in line with adequate conservation practices. It also mentions that the holders of grazing license/permit may carry out constructions such as shelters, barns and other improvements on the lands but these improvements are limited to those intended for proper care and well-being of the livestock. Moreover, via this regulation, no grazing disposition holder is allowed to carry out farming or cultivation works or disturb grazing land without relevant permits. In case the aforementioned point is breached, it is the responsibility of the disposition holder to bring back the land in the condition as directed by the Minister. As for the development of renewable energy on Crown Land, currently there exists no disposition policy.

4.6.2. Cultivation Dispositions

Part 3 of Special Areas Disposition Regulation deals with Cultivation Disposition which means cultivation lease or cultivation permit. The Minister is authorized to grant cultivation leases which will allow cultivation or farming on public land. The document mentions that receiver of cultivation disposition may carry out constructions on land granted under the license/permit. Erections may include shelters, buildings and other improvements which are mandatory for purposes of disposition.

4.7 Potential use of Agrivoltaic in Transportation and Computation

The agrivoltaic potential of a typical farm far exceeds its electricity use. An area that could use excess electricity from Agrivoltaics could be vertical gardening operations.

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Another area that could use these vast quantities of agrivoltaic electricity would be to decarbonize transportation. Heavy haul and heavy farm equipment can be powered by hydrogen fuel cell vehicles (HFCV). Following a successful demonstration project, two long range fuel cell electric trucks (FCET) are operating between Edmonton and Calgary [133]. The hub and spoke collection system developed by dairy producers can be mirrored by the hub and spoke on farm hydrogen production by agrivoltaics. There is no fundamental technical hurdle preventing Alberta from developing the infrastructure for solar-powered local hydrogen production for the local population and industry [134]. Agrivoltaics could thus provide hydrogen as a transportation fuel or electricity for direct charging. Hydrogen-based transportation is still more expensive than electric-only based transportation. Electric vehicles (EVs) appear to be far more likely than hydrogen fuel cell vehicles to dominate sustainable road transport in the future [135]. The region of Southeast Alberta has the highest share of renewable energy generation, currently around 35% which is expected to augment to 60% or more with upcoming projects. Powering transport with renewable electricity from agrivoltaics is straight forward (i.e. the electricity is used to charge EVs directly) and may be one of the future's major uses of agrivoltaic electricity. Hydrogen may also serve the purpose of providing instantaneous power generation as per the requirement of electricity grid. It could aid in stabilizing the grid by ensuring power is readily available whenever needed if it can prove to be more cost effective than electric batteries. Utilizing solar-generated hydrogen for power production will result in replacement of natural gas in cogeneration system which is used for heat generation and act as a peaking source for counterbalancing traditional clean energy technology.

Southeast Alberta has a vast agricultural landscape with concentrated agricultural operations and energy requirements. Existing energy share suggests diesel to be the dominant fuel source to meet energy needs, with natural gas and electricity now attracting interest as well. Largest share of diesel utilization is attributed to crop farming due to use of farm tools/machinery required for agricultural operations. The greenhouse sector in Southeast Alberta is also a major consumer of natural gas as an energy source mainly consumed for heating, lighting and operation of fans in greenhouse areas. Work in Ontario has already demonstrated the potential for PV-integrated greenhouses [136, 137]. There is considerably more work to be done as 'greenhouse modules' require optimization (e.g., investigating density, size as well as chemical composition of nanoparticles which perform spectral shifting via fluorescence [138, 139, 140]). Livestock farming operations are also energy intensive whose current demands are being met through natural gas and electricity. These demands can be efficiently met by using hydrogen as a fuel not only for agricultural machinery, but also as a source of power generation and heating. Similarly, these needs could be met with PV-generated electricity, and a combination of heat pumps and thermal batteries and electrical battery storage.

In addition to transportation electrification, the vast quantities of electricity made available by large scale role out of agrivoltaics could be used in computing. Both crypto currency mining [141, 142] and data centers [143] can also benefit from an agrivoltaic facility. Crypto miners use powerful computing equipment to solve mathematical algorithms. These machines consume electricity and hence, electricity costs directly impact their profitability. Moreover, it has also become an environmental issue since this electricity is often provided from non-renewable resources. Similarly, data centers are reliable sources of vast quantities of electrical loads that are somewhat flexible in their geographic distribution (as long as they are accessible to an Internet trunk). Data can be viewed as a moveable load which has the potential to create another on farm revenue source from agrivoltaics. Agrivoltaics, if used for crypto mining or data centers, can provide a clean source of power to its users. In addition, using renewable means of electricity to run these computing machines would defy the general perception of crypto being a risk to environment and further its acceptance among the general public, investors and institutions alike. Similarly, major Internet companies would benefit from green branding using agrivoltaics to compensate their electricity demands.

5. Policy Recommendations

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Agrivoltaics is a technology which relates to agriculture or farming since it utilizes land for both cultivation as well as generation of electricity via installation of solar PV panels. Considering the various advantages of agrivoltaics (see Figure 1), especially to the farmers, rejecting or discouraging the usage of large-scale solar systems on agricultural land is not recommended. Experiments throughout the world have demonstrated increased agricultural output by employing agrivoltaics, hence, efforts should be made to promote it not only in the province of Alberta, but all over Canada. The earlier the technology is diffused inside Canada, it will ultimately have a competitive edge over other nations currently working on agrivoltaics which might in turn leave farmers in Canada at an economic disadvantage. The following policy areas need to be addressed to promote agrivoltaic development in Alberta:

1. Research and development
2. Education and awareness of Community
3. Agrivoltaic Technology Regulations and Policies
4. Agrivoltaic Technology – Application Standard
5. Financial Incentives

5.1 Support Applied Agrivoltaic Research in Alberta

Previous research in Ontario has shown great promise for agrivoltaics [10]. Hence, similar work should also be carried out for Alberta as well. Alberta is a host to second largest farm area after Saskatchewan [144] and therefore, seems to be a great potential for agrivoltaic technology. As agrivoltaics has the potential for additional revenues, it may be able to support farm families and prevent the average age of farmers from continuing to climb and perhaps avoid the number of farms from declining. As of 2016, the total farmland in Alberta is approximately 50 million acres. Agrivoltaic research should be carried out on Alberta's crops such as different wheat types grown on approximately 7 million acres of land, canola grown on 6 million acres, barley grown on approximately 3 million acres, oats that covers approximately 0.8 million acres, mixed grain that covers 0.2 million acres of farmland as well as hay, fodder crops and other field crops [145]. The primary research that needs to be done for these grain and field crops is to determine optimum geometries of agrivoltaic racking systems and designs (e.g. vertical or tilt, fixed or tracking, close packed or spaced, mono or bifacial, partially transparent or opaque) for all of these crops and on farms with different equipment. This research should be made publicly openly accessible for the greatest rate of technology diffusion.

Although agrivoltaics is under large scale investigation in different parts of the world, there is still much appetite to investigate a variety of crops which have not been tested yet. Previous researches carried out on the crops include aloe vera [146], aquaponics (aquavoltaics) [147], basil and spinach [148], celeriac [149], chiltepin peppers, jalapenos, cherry tomatoes [150], corn/maize [151, 39], grapes [152], kale, chard, broccoli, peppers, tomatoes, and spinach [153], lettuce [154, 155], pasture grass [45], potato, celeriac, clover grass, winter wheat [40], sweet corn [39] and wheat [29]. These investigations demonstrated either trivial impact on crop production or increased crop yields. Enhanced agricultural output was mostly observed for shade tolerant crops or leafy vegetables such as lettuce.

To help with the design of agrivoltaic systems, Riaz et al. proposed using the light productivity factor. Light productivity factor is used to measure the efficacy of irradiance sharing considering individual crop types' effective photosynthetically active radiation (PAR) and the design of PV system [65]. Further research work is required to optimize agrivoltaic technology. Previous studies have mainly focused on a single crop and investigated a single design of PV array at a given location. Intense research is required to investigate more crops considering above 20,000 types of edible plants are produced all over the world [157] and several crops are cultivated in abundance in Alberta as noted above.

PV array design has substantial impact on agrivoltaic production. The list below summarizes these design aspects which greatly influence the technology:

1. Geometry, orientation and type of racking for PV array, spacing between rows and modules
2. Type of tilting i.e., fixed tilt (vertical and angled), single axis or dual axis tracking
3. PV module type (for instance, monofacial or bifacial, thin film module or silicon cell-based modules etc.)
4. Type of PV material used for module development (for instance single bandgap, or multiple bandgaps)
5. Module transparency (accomplished by changing cell packing densities or thin film absorber thickness)
6. Spectral transmission of PV modules considering effect of optical enhancement methodologies including anti-reflective coatings (ARCs) (research is already being carried out on partially transparent colored PV modules [158, 159] which may have application for agrivoltaic technology. Semitransparent PV modules are already in use in greenhouses [160, 161, 162, 163] while tinted semitransparent PV modules can actually yield for agricultural products [164]).
7. Using spectral shifting techniques/materials to augment greenhouse output [165, 166] or make light more beneficial for agrivoltaic technology application positively impacting plant growth [166, 167, 168, 169].

Investigating different variations of PV module design with different crops would require immense number of experimentations and therefore, needs. In addition, more research is required on testing of sub-systems such as pumping and irrigation, post-harvest processing, production of hydrogen, ammonia, and EV charging which would all present opportunities for real supplemental incomes for farmers from the use of off peak energy (i.e. outside of planting production and harvesting), Therefore, Agrivoltaic technology could reap rewards of coordination and integrated efforts of funders of energy (e.g. The Office of Energy Research and Development (OERD)) and agriculture (e.g. the Ministry of Agriculture, Forestry and Rural Economic Development Alberta, Agricultural Research and Extension Council of Alberta (ARECA)).

5.2 Education and awareness of Agrivoltaic Technology among Albertans

To address the problem related to enormous quantity of research and investigations required for agrivoltaic technology, a parametric open-source cold-frame agrivoltaic system (POSCAS) was recommended to ensure economical and efficient agrivoltaic system testing [64]. POSCAS provides great advantage to researchers as multiple setups with varying configurations could be experimented in a single attempt. Moreover, these devices could greatly enhance public knowledge in the field of agrivoltaics utilizing the approach of citizen science [170, 171]. Use of such a device would also help individuals to study numerous combinations of PV design with different crops. Farmers as well as gardeners could be provided with free POSCAS setup to experiment and report the impact of agrivoltaic technology on local crops.

The majority of North Americans are unfamiliar with the concept of agrivoltaics, but when introduced to the technology, they generally look at it favorably and may even become proponents of it [172, 173, 174]. Although the approach of citizen science discussed may be helpful in educating the masses, as publicly showing the results of agrivoltaics where they could witness (and even participate in finding) the results would put a stamp of approval on its viability. It will create awareness among lawmakers and legislators as well as build public trust. Initial studies on agrivoltaic technology in other parts of Canada (Ontario) have demonstrated encouraging results, however, open pilot experimentation should be performed allowing farmers and citizen to witness results. Allowing agricultural lands for agrivoltaics research can also circumvent other proposed construction in such demographics while also enhance awareness on agrivoltaic technology in the region.

5.3 Agrivoltaic Technology Regulations and Policies

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Considering limited deployment of agrivoltaics in Canada, apart from further research and population awareness, it is imperative to clearly define and categorize agrivoltaic technology. Unlike conventional PV systems, agrivoltaic technology allows continued use of land beneath the arrays for farming and agriculture. Agrivoltaics technology is therefore distinctively placed to enable betterment of farmers and diversify their economic portfolio from dual income sources i.e., from agricultural products as well as from clean electricity generation. It is imperative to conclude a proper definition of agrivoltaic signifying no disruption to continued use of agricultural land for farming, while potentially increasing yields, reducing costs and providing energy independence for farmers. It is also important to prevent misuse of agrivoltaic friendly regulations. One way of ensuring it could be to introduce a tier system for categorization of agrivoltaic technology on the basis of land utilization as given below in Table 1. Different tiers of agrivoltaics systems could be incentivized differently. For instance, Tier 1 agrivoltaic solutions could be provided with more benefits than Tier 2 systems. Food production on agricultural land should be prioritized. Such a tier system could serve as a major obstacle to entities who may install a conventional solar power plant and seed wildflowers beneath it just for the sake of accessing agricultural land. Similarly, although PV production can outcompete tobacco for profit per acre even in North Carolina [175], agrivoltaics benefits should not accrue to farmers growing tobacco and other drugs that have a detrimental impact on public health [176] instead of food. Alberta can also study other regions to develop programs and regulations which incentivize agrivoltaic deployment such as in the U.S., where the Massachusetts Department of Energy Resources established the Solar Massachusetts Renewable Target (SMART) program [177-179].

Table 1. Proposed potential tiers of agrivoltaic systems to favor systems with greater land-use efficiency and greater potential for GHG emissions reductions.

Tier/ Allowed Land Use	Agrivoltaic Type	Comments
1. Prime agriculture	Crop	See Section 5.1 for crops investigated to date
2. Pasture	Grazing	Sheep [180, 181], and rabbits [182]
3. Marginal	Apiculture (beekeeping)	Honey production [183]
4. Non-restricted	Insect Habitat	Pollinators like butterflies that provide secondary services

A legal realization of agrivoltaics as an agriculture-related use by the province of Alberta and other relevant provincial/municipal authorities could help diffuse the technology. Using the tier-based approach, agrivoltaic deployment on agricultural land would open doors of new development possibilities while preventing misuse. Hence, agrivoltaic advancement in Alberta would help ensure socio-economic as well as environmental well-being of the province without adversely impacting agricultural land for food production for generations to come. The food-energy-water nexus is already an issue in water-stressed Alberta and is likely to be exacerbated by climate change as less water is available for traditional farming and without changes the province will loose productive acres. Agrivoltaics has the ability to deliver additional water to acres not yet irrigated by integrating technologies including vertical growing (coupled to field based agrivoltaics to reach net zero), soil drip irrigation, and providing solar canopies over crops similar to the work already shown in heat stressed areas of the U.S.

As studied in the existing regulations/frameworks discussed above, the subject of solar PV farms installation on agricultural land seems unaddressed. Current legislation

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and its language, however, may pose significant restrictions to deployment of agrivoltaic technology. For instance, municipal planning does not conserve agricultural land today, however, zoning and other planning decisions can have consequences for usage of agricultural lands in the future. Similarly, postulates such as conservation easement and conservation directives may hinder development of agrivoltaic technology. Similarly, Special Areas Disposition Regulations can potentially act as a barrier to agrivoltaic diffusion. It should also be noted that regulations for net metering and line connection should be made simpler and easy for farmers to move towards this technology.

To promote agrivoltaic deployment in Alberta, alignment of provincial and regional policies is imperative. Regional plans as advised in LUF should provide robust regulations that encourage agrivoltaic technology development. Any apprehensions regarding preservation of agricultural land should be tackled by clearly addressing the integration of energy development without compromising current land use. Although, it is understandable since agrivoltaics is a relatively new concept, provincial as well as municipal/regional policies should incentivize agrivoltaic development considering its advantages for meeting energy, climate and food goals. Legal frameworks and policies focusing on assisting development of agrivoltaics as well as harmonizing laws on energy systems, land utilization and agriculture require more attention for maximizing the benefits that agrivoltaics provides.

5.4 Agrivoltaic Technology – Application Standard:

A standard could be devised to define a specific methodology for design, installation and testing of agrivoltaic technology. Criteria for land usage could be included addressing installation requirements of PV systems on farmland. Similarly, the standard may cite minimum requirements of agriculture land loss due to agrivoltaic construction, minimum requirements of crop production/yield post agrivoltaic deployment as well as water and soil preservation. Moreover, technical, installation, operational and maintenance guidelines could also be provided. Such a standard would minimize the risk of major stakeholder including farmers, financers as well as government bodies as it will provide a framework for acceptance of agrivoltaic systems. Moreover, such a standard would prove to be fruitful in improving the quality of agrivoltaic systems. Finally, the standard could be used by testing and certification bodies ensuring the minimum installation, operational and maintenance requirements are being complied.

5.5 Financial Incentives:

New financial models for both agrivoltaic developers and farmers and new sources of investment capital to provide project financing must be identified and developed for Alberta to reach its full agrivoltaic potential. To promote development of agrivoltaic technology, the Government of Alberta could provide financial incentives, which would attract people and businesses associated with the agriculture towards agrivoltaics. These incentives could take the form of tax relaxations for farmers willing to install agrivoltaic technology on their farmland, although historically this has been challenging with the Canada Revenue Agency. For instance, farmers purchasing solar panels and other associated accessories could be exempted from sales tax or have reduced property taxes. Agrivoltaics would have access to Class 43.1 and 43.2, which allow for accelerated depreciation. Up to 94% of qualifying expenses can be depreciated in a straight line or accelerated depreciation up to 100% of qualifying expenses in year 1 of the PV installations [184]. The agrivoltaic owner, however, would have to be making money to use this tax credit as unlike the U.S. this tax credit is not transferrable.

Since initial capital for installation of PV systems on farmland could be a challenge, governments at all levels could provide farmers with easy and low or no interest loans for the purpose of agrivoltaic development. Also, governments could reimburse a certain portion of initial capital to individuals installing solar farms on their agricultural land in the form tax relaxation. Moreover, users of agrivoltaic technology could be given benefits for carbon sequestration, particularly if wood-based racking is used. Electricity generation from solar technology that displaces fossil fuel combustion contributes in reduction of carbon emissions. Moreover, a comprehensive financial model needs to be developed for all stakeholders including identifying new sources for projects' capital investment. Hence, farmers should benefit for their contribution.

5. Conclusions

With rapid decline in cost of PV systems, solar technology is becoming increasingly affordable but requires large surface areas. This study indicates significant potential for agrivoltaic deployment in Alberta, Canada. Land-use legislations, however, generally hinders development of solar power citing land-use conflicts. In this paper, frameworks, acts, bills including the Land Use Framework (LUF), Alberta Land Stewardship Act (ALSA), Municipal Government Act (MGA), Special Disposition Act (SDA)and Bill 22 were reviewed which are relevant to on agrivoltaics technology. LUF details land-use conservation and stewardship tools in the form of transfer of development credits, land trusts and conservation easements and land conservation off sets. LUF also discusses sustainability as well as utilization of "green" technology which aligns well with wide-scale use of agrivoltaic technology. ALSA acts as implementation tool for LUF and suggests categorizing land into zones for conservation purposes where only agricultural activities are permitted. Other tools detailed in ALSA include conservation directives, conservation easements, conservation offsets, transfer of development credit schemes and stewardship units. Apart from conservation easement, other tools lack the supporting regulations/policy for their effective implementation. MGA overlooks municipalities within the region of Alberta. Although municipalities have significant authority to control development on agricultural land, there seems to be no clauses currently which conflict with deployment of agrivoltaic technology. Other laws examined here include Soil Conservation Act, Agricultural Operation Practice Act and Special Disposition Act. In addition, a new legislative document "Bill 22" was recently introduced which have direct implications on agrivoltaic development in the province. The bill provides a pathway which will allow self-supply and export of electricity to the grid.

This study further identifies five important policy avenues to promote agrivoltaics in Alberta: 1) research and development, 2) education and awareness of community, 3) agrivoltaic regulations, 4) agrivoltaic standards, and 5) agrivoltaic financial incentives. It is imperative that further research on agrivoltaics is carried out in Alberta on existing major crops that demonstrate effectiveness to the general public. It is recommended that funding for such research is all tied to open access requirements to ensure the public and farmers can make informed decisions. This is also expected to galvanize social acceptability of large-scale PV deployment in the region. Moreover, certain policy mechanisms are recommended to support agrivoltaic development including a) clearly defining and categorizing agrivoltaic technology, b) developing of programs and policies to incentivize agrivoltaic deployment over simple large-scale PV deployment, c) developing agrivoltaic technology-friendly regulations and frameworks. Moreover, development of application standard for agrivoltaic technology for its design, installation, and testing purposes is also important for technology's wide-scale adoption. Lastly, providing financial incentives such as tax deductions and low interest rate loans would also encourage diffusion of technology. Through these measures, Alberta can achieve conservation and sustainability in food and energy sector while simultaneously addressing the renewable energy and climate-related goals.

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