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Integrating Land-Use and Renewable Energy Planning Decisions: A Technical Mapping Guide for Local Government

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Abstract: Land-based, utility-scale renewable energy (RE) systems using wind or solar resources to generate electricity is becoming a decisive solution to meet long-term carbon emission reduction goals. Local governments are responding in kind, by adopting their own goals and/or establishing policies to facilitate successful implementations of RE in their jurisdiction. One factor to successful RE development is to locate the most suitable lands, while continuing to sustain land-based economies and ecosystem services. Local governments often have limited resources; and this is especially true for small, land-constrained local governments. In this paper, we illustrate how a standardized RE technical mapping framework can be used by local governments to advance the implementation of RE in land-constrained areas, through a case study in the Town of Canmore, Alberta. Canmore has a limited municipal area surrounded by the Canadian Rockies, along with complex land-use bylaw and environmentally sensitive habitats. This mapping framework accounts for these conditions as it considers theoretical resources, technically recoverable lands, legally accessible lands, and the spatial capital cost of connecting new RE facilities. Different land-use planning scenarios are considered including changing setback buffers and expanding restrictions on development to all environmentally sensitive districts. The total RE potentials are then estimated based on the least-conflict lands. Technically speaking, even under restrictive land suitability scenarios, Canmore holds enough land to achieve ambitious RE targets, but opportunities and challenges to implementation remain. To eventually succeed in its long-term emission reduction goal, the most decisive step for Canmore is to balance the growth of energy demands, land-use changes, and practicable RE development. Mapping systems that can study the influence of land-use planning decisions on RE potential are critical to achieving this balance.

Keywords: land suitability; GIS; scenario mapping; wind energy; solar energy

1. Introduction

As the global demands of energy and related services are constantly increasing to satisfy the social and economic growth, anthropogenic greenhouse gas (GHG) emissions and resultant atmospheric concentration have reached their historical high compared to the pre-industrial level [1]. The transition to renewable energy (RE) can lower GHG emissions and mitigate climate change, while still meeting global energy demands [2]. However, the availability of RE varies regionally, and spatial patterns and spatial concentrations of RE potential do not always match the spatial patterns and spatial concentrations of energy demand. The successful implementation of RE projects is subject to a set of factors including regulations, physical and engineering limits, markets, and social/public acceptance [3–5]. As a result, many regions continue to be reliant on fossil-based resources despite high access to RE resources.

Canada, for instance, holds abundant landscapes and natural resources that can, in theory, supply the entire country's power consumption [6]. Currently, RE resources, including hydropower, solar, wind, biomass, and geothermal, account for over 60% of Canada's total primary energy supply [7,8]. Despite this, the sources of power generation vary hugely in different provinces. The Canadian province of Alberta has one of the highest annual carbon dioxide (CO_2) emissions per-capita at 62.4 tonnes compared to the national average of 19.4 tonnes [9]. Meanwhile, Alberta has some of the most promising and significant utility-scale RE resources in the country including on-shore wind, solar, and biomass resources [6,10–13]. Alberta is also one of the largest oil-producing jurisdictions in the world [14] and approximately 83% of its electricity generating capacity is coal- and natural-gas-fired generated [15].

This carbon-intensive power system is being reconsidered by provincial and municipal governments in Alberta. With the passing of the Renewable Electricity Act in 2017, the government of Alberta has committed to have 30% of its electricity generated from renewable resources (including solar, wind, and biomass), while phasing out coal-burning power plants by 2030, and at the same time is capping emissions from its oil sands operations at 100 megatons per year [16]. These provincial declarations are being matched and, in some cases, exceeded by declarations from local government. The Town of Canmore, for instance, set carbon reduction plans for its corporate emissions (town-owned non-residential facilities, fleets, lights, wastewater treatment) and community emissions (residential, commercial, and institutional buildings) by 80% from its 2015 levels by 2050 [17]. Currently, two-thirds of Canmore's GHG emissions are sourced from the carbon-intensive electricity grid in Alberta [18]. As such, Canmore's Climate Action Plan identifies " ... local renewable energy production within town limits" as one of the essential approaches to meet targets [17]. This includes utility-scale RE systems (i.e., greater than 1-megawatt capacity [19]).

Indeed, the global energy transition will need to translate and decentralize into local actions. Those actions result in fundamental changes to landscapes and land-use systems as wind turbines and solar panels pop up and as land is used to grow energy crops rather than, or in addition to, food crops. At first glance and in theory, there is more than enough land available to recover renewable energy at the rate society requires. The challenge, however, is that the vast majority of land is already being used to provide economic functions (e.g., agriculture) and ecosystem services (e.g., habitat). In other words, the area of land that can actually be used for RE recovery without compromising these existing economic and ecosystem services is very limited. One primary barrier to implementation at the local level is a deficiency of comprehensive planning tools to locate the "least-conflict lands"; i.e., land that can support RE systems with least regulatory, technical, economical, or social conflicts. There are few standardized RE planning frameworks that can foresee potential regulatory obstacles, encourage the implementation, or engage with the local communities and stakeholders [20].

With these global and local opportunities and challenges in mind, this paper aims to (1) develop a standardized RE planning and deployment framework that considers the feasibility of local RE generation based on constraints related to resource access, economic cost, and land-use policies; (2) apply the framework in the town of Canmore, Alberta, Canada; and (3) estimate the approximate RE potentials for the town based on its availability of technical and legally accessible lands. The research focuses on wind and solar technologies since these have the most significant implications on local land-use changes and landscape impacts. Furthermore, we focus on electricity generation under the assumption that many heating systems and transport systems will be electrified and will demand more clean sources of electricity. Overall, by demonstrating the technical RE mapping experiences of a small, land-constrained jurisdiction, we hope this standardized RE planning framework can be replicated by local governments with similar ambitions and similar constraints related to RE development.

2. Background

2.1. Unused Potential Abound

Many local governments across southern Alberta experience a relatively high level of solar insolation compared with other international jurisdictions [21]. For instance, the town of Okotoks in southern Alberta has higher solar energy potential than Miami in Florida from July to October [22]. Solar energy can be classified into solar photovoltaic (PV) systems that include the rooftop level PV system and ground-mounted systems, along with solar thermal collectors that are particularly used to pre-heat water [6]. The town of Canmore commissioned a study to evaluate its rooftop solar potential at the neighbourhood level [23]. The result shows that even Canmore's least productive neighbourhoods still have relatively higher solar insolation (W/m^2) than capital cities of Germany and China (the two countries with the most installed solar capacity worldwide) [24]. In addition to the existing study, the research on utility-scale solar opportunities in Canmore will be helpful for knowing the overall RE potentials that are underutilized for the town.

Wind power potential is estimated to be 64,000 MW in Alberta, and it is considered to be one of the most accessible land-based wind resources in Canada [10]. Despite this potential, the installed capacity of wind turbine in Alberta was still less than 1500 MW in 2018 [25]. Due to the unique structure of Alberta's electricity market, wind power supported by the issuance of renewable energy credits can be a particularly striking force to the traditional coal-fired generator after the deregulation of Alberta's electricity market [15] and the release of Climate Leadership Plan [16]. The unit cost of wind power generation is considered as the lowest-cost option for electricity generation in Canada [26]. In December 2017, the competitive RE procurement for wind energy fell to 3.7 Canadian cents per kWh in Alberta [27]. As better technologies will be used, the unit cost will continue to drop. For example, the cost of on-shore wind has declined by 30% from 2010 to 2015 [16]. Furthermore, the wind power system has already become a significant source of reliable revenue and employment for many local jurisdictions in Alberta including Pincher Creek and Vulcan [28]. With the low-unit cost, unused potentials, and socioeconomic benefit, possible wind energy development should never be ignored by local jurisdictions, especially when their wind energy potentials may be underestimated.

2.2. Multi-Criteria Decision Analysis and RE Planning

Typically, land-based suitability studies for utility-scale RE planning often use multi-criteria constraint mapping [29–33] and GIS-based multi-criteria decision making analysis (MCDA) methods [34–42]. In addition to the presence/absence or relative strength of the resource itself, analysts consider a range of technical/geographical, legal, and economic constraints on resource access. Conceptual frameworks to organize all of the relevant factors and constraints for mapping RE resources date as far back as 1998 [43–45]. Calvert [20] notes the lack of standardization in these conceptual frameworks, especially in terms of the factors/constraints considered—e.g., some studies incorporate regulatory constrains on resource access while others do not; some studies mix regulated and non-regulated constraints making it difficult to understand the influence of policies and regulations on their results. A lack of a standardized approach to organizing criteria results in poor communication of realizable RE potential. In addition, there are usually inconsistencies in the constraints and factors included in the study and unclear reasons for assigning scores and weightings when MCDA methods are adopted. The problems associated with this lack of standardization may be the overestimation of recoverable lands for RE developments when it is based on a large jurisdiction and geographic extent [46]. For a small jurisdiction, the process of estimating recoverable lands should follow a different approach since the "available" lands are presumably limited. In the conventional energy industries (e.g., oil, natural gas, and coal), the extractive planning is quite explicit; "resources" are the total amount of estimated fuels or minerals contained in Earth's crust, while "reserves" are technically and economically recoverable resources [47]. Energy transition values the lands as an important resource but requires moving from the vertical extraction of underground resources (fossil fuels) to the horizontal capture of energy flex on the surface (RE) [48]. Comparatively, we could follow the similar "bottom-up" logic as oil and gas industries to locate those exploitable and renewable "reserves" on the land [49,50], although we tend to call it RE "potential" in this paper.

It is especially important to note that the policies and regulations that are controlling access to RE resources evolve over time and across space. One jurisdiction, for example, may require that wind turbines be located 500 meters away from the nearest dwelling/residence, while another may require a 1000-meter setback distance. This has significant implications on the total area of land from which wind energy can be recovered. Similarly, a jurisdiction may change its regulation—from 1000 meters to 500 meters—which opens up more land and therefore more resources for possible development. Although recent work has incorporated local regulations into the constraints and factors considered in RE resource assessments, for the most part, the influence of policy change is rarely assessed [46,51]

3. Methods

3.1. Study Site

The Town of Canmore is located in the Bow River valley in the very eastern gate of the Canadian Rockies with less than 70 km^2 of land area [52] (Figure 1). Many lands in Canmore are characterized by steep slopes and restricted land-use bylaw. The distinct topography of the town also brings drastic spatial variations in solar and wind resources within its boundary. However, Canmore is well known for its leadership in climate actions, including a commitment to the Global Covenant of Mayors (COM) and regular support for local climate change mitigation and adaptation [17]. The town has very ambitious long-term targets of reducing carbon emission to meet the provincial and national goals of sustainable growth. Apart from the long-term emission reduction goals (80% less than 2015 level) mentioned previously, by 2030, Canmore's community aims to reduce its GHG emissions by 30% below 2015 levels (about 275,000 tons of CO_2 equivalent) [17].

3.2. A Framework to Standardize RE Mapping

This study adopts a framework developed as a part of the Accelerating Implementation of Renewable Energy (AI-RE) initiative [53], which is designed to support local governments in advancing their energy-related economic development and emission-reduction goals. The scope of this initiative is to develop protocols that can support more rapid implementation of renewable energy resources. As part of that initiative, a framework has been developed to enable municipalities and regional governments to have consistent nomenclature for RE planning and development, in turn fostering more productive conversations between decision makers, stakeholders, and residents. The framework is illustrated below in Figure 2. The framework was initially developed for larger jurisdictions with more homogenous lands. In this project, we focus on adopting and applying the technical mapping model to a significantly smaller and mountainous jurisdiction in Canmore, Alberta.

The technical mapping framework is best conceptualized and visualized as an inverted triangle. A data table is used to summarize the available data in Canmore to fit this framework (Table 1). First, *theoretical* resources are mapped; in this study, we include wind and solar energy. Due to the coarse resolution of the resource data, we use the Focal Statistics tool in ArcGIS [54] to smooth the *theoretical* potentials.

Second, *recoverable resources* are mapped based on filtering out technical constraints such as slope and aspect requirements. We will focus on the derived product of the digital elevation model (DEM) including slopes and aspects of the study area. Lands with a slope less than 35°, or a slope less than 10° when it is north-facing (clock-wised degree from 337.5° to 22.5°) are considered as *recoverable*. Those areas are both technically unrecoverable for building RE facilities and inaccessible in a regulatory manner according to Canmore's land-use bylaw.

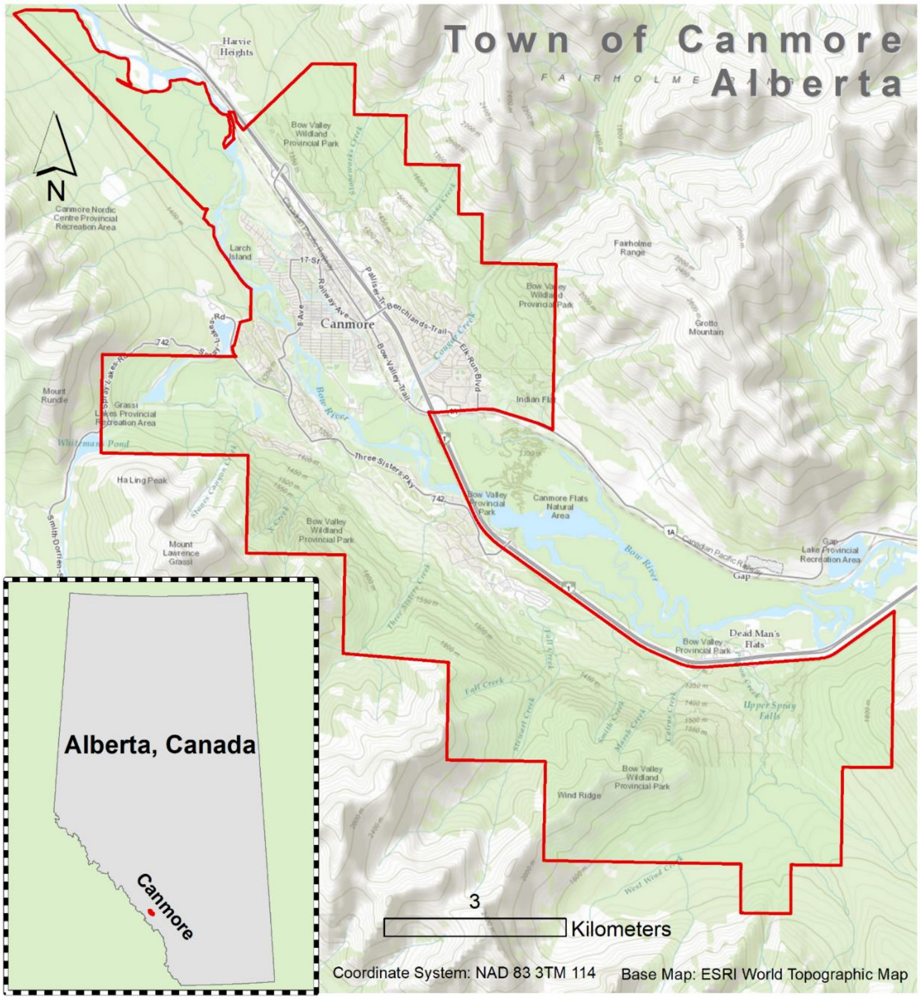

Figure 1. Town of Canmore.

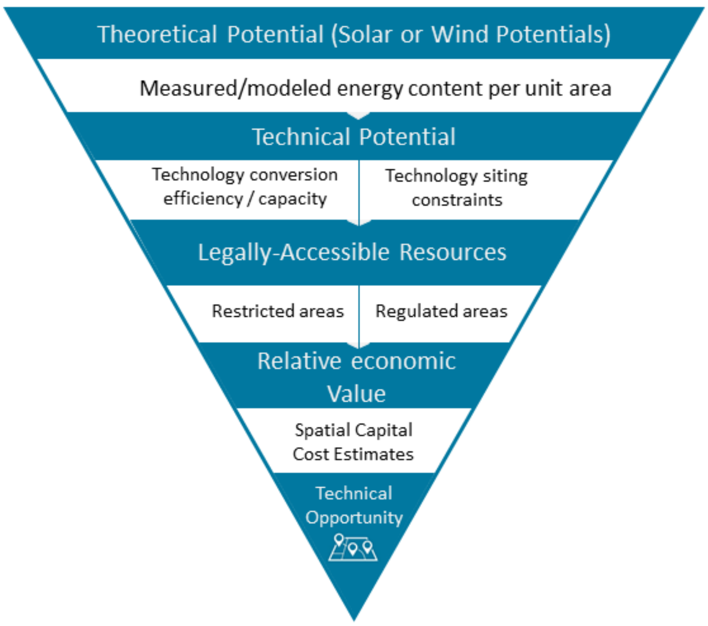

Figure 2. Framework used in this study to conduct detailed technical mapping for local energy planning. Modified from Calvert [20].

Third, *legally accessible resources* are mapped based on filters that respect provincial and local land-use regulations and bylaws [55]. The land-use bylaw data includes a detailed classification of the lands in Canmore [55]. Many of the constraint levels (especially for those in the *legally accessible* category) will be based on the land-use report [55]. To define what land-use types are *legally accessible* requires a dynamic comprehension of local environments. Therefore, the determination of legally accessible lands is a consultant work with Canmore's local officials. Indeed, such consulting promotes a positive reasoning on where is preferable (such as municipal parking lots) instead of only considering unsuitable lands. We classify the roads, railway and water bodies as *legally accessible* resources in the mapping process. Due to the massive overlays of provincial parks and environmentally sensitive lands within Canmore's boundary, we use a binary filter for *legally accessible* resources: semi-permissive areas with some restrictive conditions applied, and non-permissive areas prohibited for RE developments. We assume that at least 4 ha of land is required per MW of installed ground-mount PV capacity [19]. This minimum land requirement ensures the future solar energy development to be built with enough space for electrical substations. According to observation-based or simulated studies, the energy density of a wind turbine could range from 2.5 [56] to 10 MW/km^2 [57]. Therefore, instead of setting a minimum area filter for wind turbine, we would count all the (semi-) permissive lands as possible locations. Spacing between turbines will be considered in the theoretical installation capacity estimation.

Last, the relative *economic value* of resources is assessed based on the spatial capital costs of building new fundamental facilities (roads and power lines) that connect to the resources. The estimation of cost for connecting RE facilities to transportation and transmission lines depends on local road design [58] and the unit construction prices of both the road and power transmission lines [59,60]. A more detailed description of this framework can be found in Calvert [53]. In the sections that follow, we describe the study area, data, and techniques used for this analysis. For *economic* factors, we estimated the costs for a per meter road with a width of 12m to be about CAD 680 [59], the per meter high voltage power line will cost about CAD 530 [60]. Seemingly, the most economical zones of building new RE facilities are, in general, along the conductor lines. There is no "ideal" cut-off value for theoretical potentials or relative capital costs estimation due to the ongoing progress in RE technologies and fluctuations of market construction costs. Therefore, a normalized cost of building new roads and power lines that will be connected to the potential RE facilities is considered.

Table 1. Accelerating Implementation of Renewable Energy (AI-RE) data table for 4 different categories.

Categories	Layers		Constraints	Resolution	Data source
1. *Theoretical*	Solar PV input			1 km	Global Solar Atlas [61]
	Wind speed at 100 m level			200 m	Global Wind Atlas [62]
2. *Recoverable*	Slope		<35°	10 m	Derived from digital elevation model [63]
	Aspect		No north facing when slope > 10°	10 m	
3. *Legally accessible* (according to LUB)	Water bodies	Bow River	60 m setback distance	Vector	Town of Canmore [64]
		Other Rivers	20 m setback distance		
		Floodway	6 m setback distance		
	Roads	Arterial	9 m setback distance		
		Highways	27.5 m setback distance		
		Other roads	5 m setback distance		
	Railway		27.5 m setback distance		

Table 1. *Cont.*

Categories	Layers		Constraints	Resolution	Data source
	Environmental	Natural parks	Non-permissive		
		Wildlife corridor			
		Provincial parks			Altalis [63]
		Flood fringe	Semi-permissive		
		Environmental district			Town of Canmore [6]
		Wildland conservation			
	Administrative	Public use districts			
		Urban reserved district			
		Restricted urban reserve district			
		Industrial areas			
		Municipal parking lots			
		Commercial zones	Non-permissive		
		Residential zones			
		Direct Control (DC) districts	Non- or semi-permissive depending on DC types		
4. ***Economic***	Transmission line cost			10 m	AESO [60]
	Road cost				Alberta Municipal Affairs [59]

3.3. Regulatory Scenarios

Mapping different policy scenarios helps to understand the available lands dynamically. For example, there are land-use classifications not specifically indicated by Canmore's land use bylaw (LUB) while they can still be environmentally or regulatorily sensitive. Table 2 considers 4 scenarios for both solar and wind energy developments. Solar energy scenarios consider the habitat patches (Figure 3a), steep creek hazard zones (Figure 3b), wildlife corridors (Figure 3c) [64]. Wind energy scenarios include both habitat patches and setback buffer distances from residential zones (Figure 3d) for possible wind turbine developments. As such, the scenario mapping provides an assessment of the implications of multiple land-use policies on the availability of land for solar and wind energy development.

Table 2. Scenarios for potential solar and wind energy development.

Scenarios		Solar Energy		Wind Energy	
		Excluding Wildlife Corridor	Excluding Steep Creek Hazard zones	Setback Distance	
				500 m	750 m
Including	Habitat patches	1. Only excludes the wildlife corridor that overlapped with legally accessible lands	2. Steep creek hazard zones are extracted from scenario 1	1. Excludes lands within 500 m of noise receptors (residential zones)	2. Excludes lands within 750 m of noise receptors (residential zones)
Excluding		3. Habitat patches within Canmore boundary would be excluded + scenario 1	4. Both habitat patches and steep creek hazard zones are excluded.	3. Excludes habitat patches + scenario 1	4. Excludes habitat patches + scenario 2

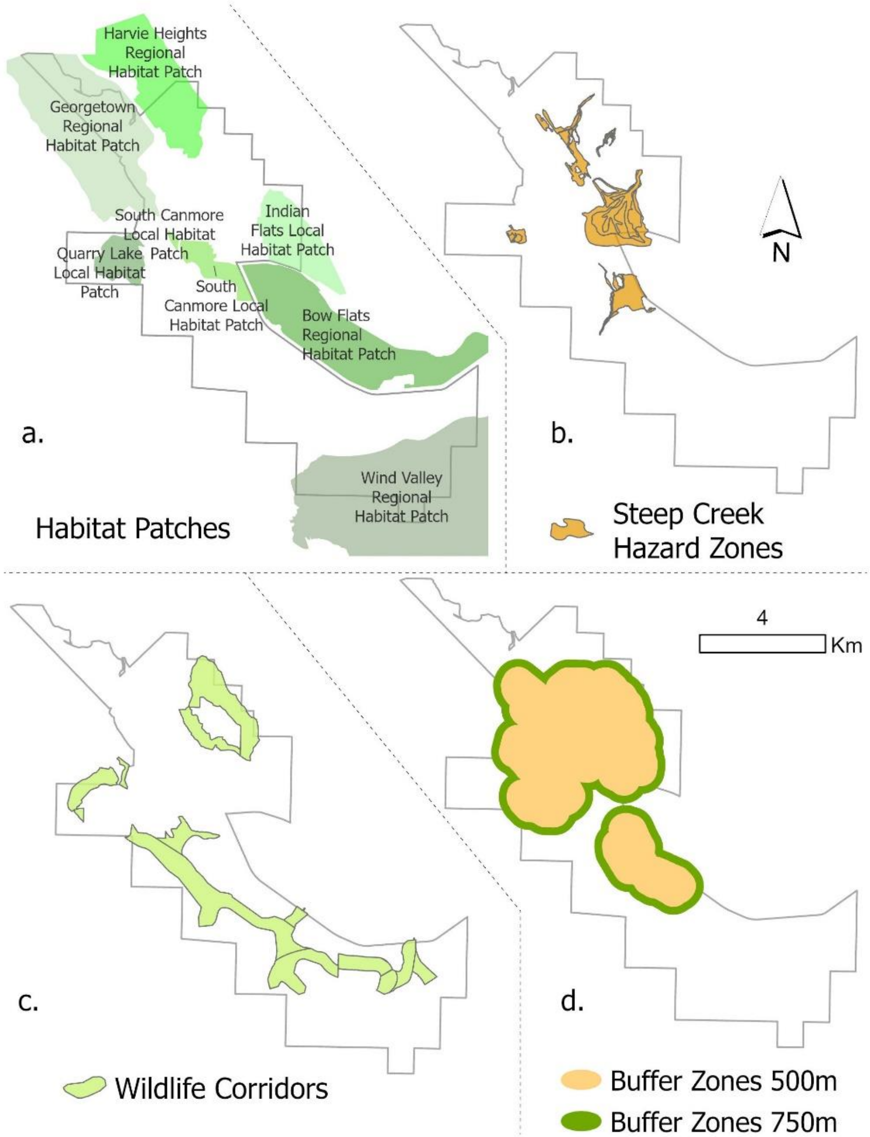

Figure 3. Four criteria are added to corresponding legally-accessible layers as scenarios including (**a**) regional habitat patches, (**b**) steep creek hazard zones that are subject to mass wasting, (**c**) the wildlife corridors and (**d**) two setback buffer zones of 500 and 750m, respectively, away from residential zones in Canmore.

There is no provincial-level regulation for wind turbine setback distance in Alberta [65]. The setback distance is, therefore, up to the local jurisdiction to decide. This study provides two setback possibilities: 500 and 750-m radius buffers from Canmore's residential zones (as defined according to LUB).

4. Results

4.1. Accessible RE Resources

Theoretical resources (wind and solar potentials) are mapped in Figure 4a,b. The general patterns of power potential for wind and solar are the opposite: the north and west of Canmore generally has more solar potential, while the south and east of Canmore have higher wind speed. The wind classification is based on the annual average wind speed (max) of IEC wind classes [66]. The technically *recoverable* lands are indicated in Figure 4c.

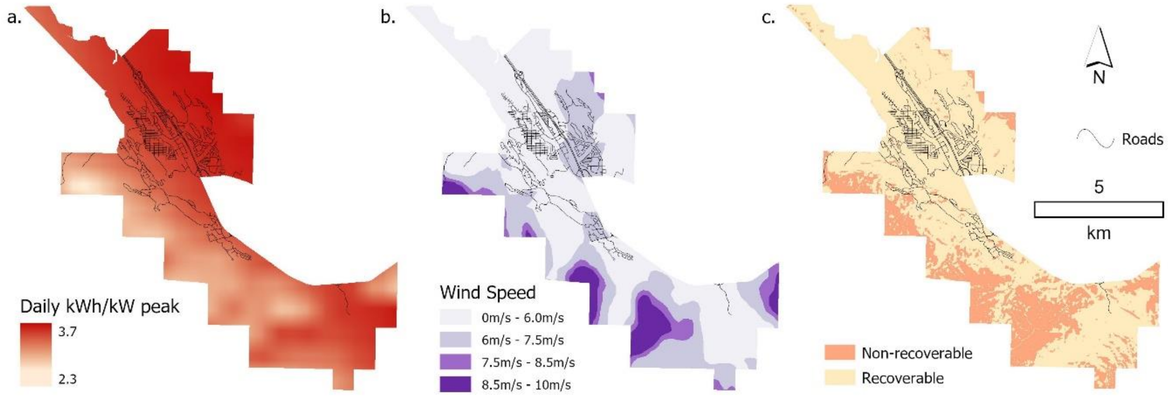

Figure 4. Theoretical resources of (**a**) solar PV input and (**b**) wind potentials; (**c**) technically recoverable potentials that consider the slopes and aspects.

Legally accessible lands (Figure 5) in Canmore are organized according to Canmore's land-use bylaw (LUB) [55]. There are two classes distinguished here: non-permissive lands, and semi-permissive lands. Under the *semi-permissive* class (darker colors in Figure 5), the land has the possibility of being developed into RE use, but only with some possible concessions between community members, stakeholders, and decision makers. The setback distances of water bodies, roads, and railways are based on LUB. Developments under lands with the *non-permissive* classification (lighter colors in Figure 5) are not actively considered for RE development. Apart from the LUB classification, additional legally accessible layers are also considered. Provincial parks are considered as *non-permissive* lands. Municipal parking lots are considered as semi-permissive lands. About 8.3% of lands (559 ha) in the town are semi-permissive for solar energy development. About 650 ha of lands are semi-permissive for wind turbine development. Due to strict land-use regulations, all lands are at least semi-permissive; none are fully permissive.

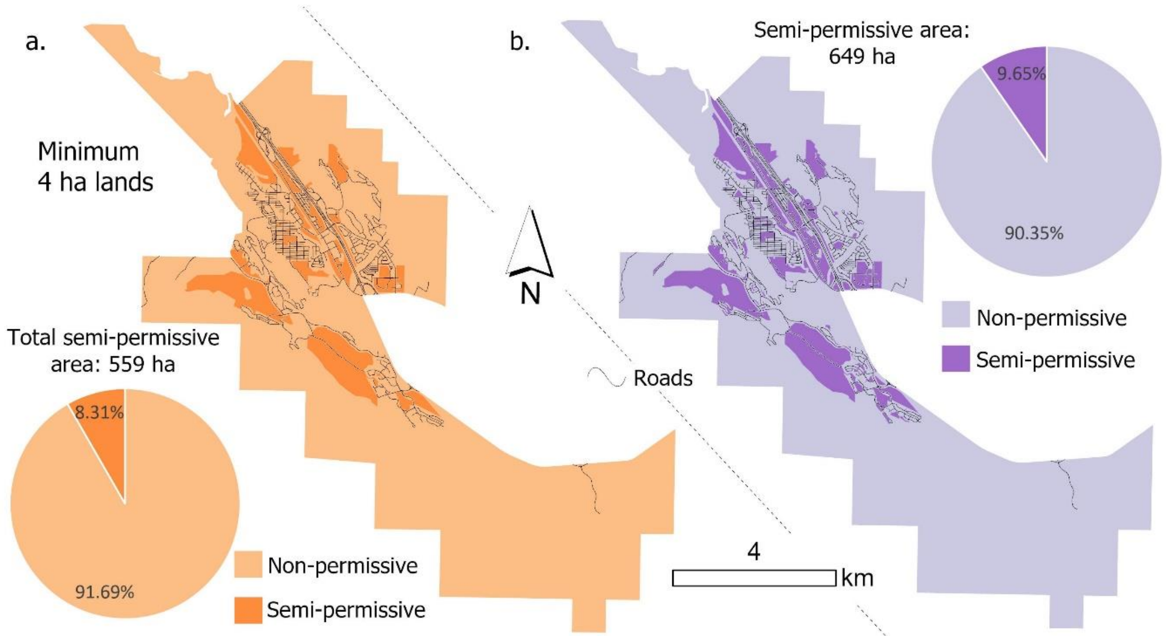

Figure 5. Legally accessible resources for solar (**a**) and wind (**b**) energies mostly based on land use bylaw (LUB).

The relative economic cost filtered by *non-recoverable* lands and *non-permissive legally accessible* resources are illustrated in Figure 6 for both solar (left) and wind (right) developments, demonstrated with relative economic cost gradients. About 625 ha of lands are left for wind energy development, while the area of semi-permissive lands suitable for developing solar power is about 537 ha. The most economically feasible lands are those regions long the power transmission and vehicle transportation lines. Many of those lands are in the northern and central Canmore along the Trans-Canada highway and Three Sister Drive.

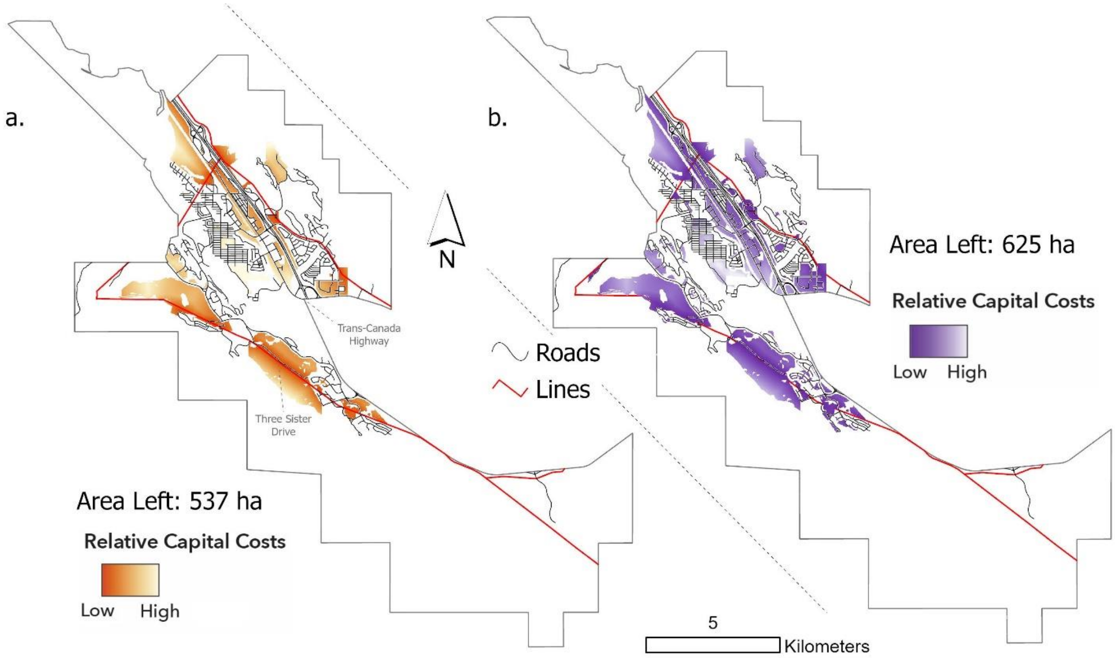

Figure 6. Relative capital cost of connecting those resources to existing roads and lines after constraint applied for (**a**) solar and (**b**) wind opportunities. Constraints include technically recoverable resources and those semi-permissive lands under legally accessible resources.

4.2. Scenario Maps

We examined four scenarios and their impacts confining available lands for both solar (Figure 7) and wind (Figure 8) energy development. Habitat patches such as the Quarry Lake Local Habitat patch, Georgetown Regional Habitat patches, South Canmore Local Habitat Patches have significant overlaying areas with existing legally accessible area. Wildlife corridors do not overlay much with existing semi-permissive lands. By applying the setback buffers for wind power development, most of the semi-permissive lands in northern Canmore are not feasible anymore. Whether the town will adopt buffer zones for wind turbines is, therefore, decisive for possible wind energy development in the future.

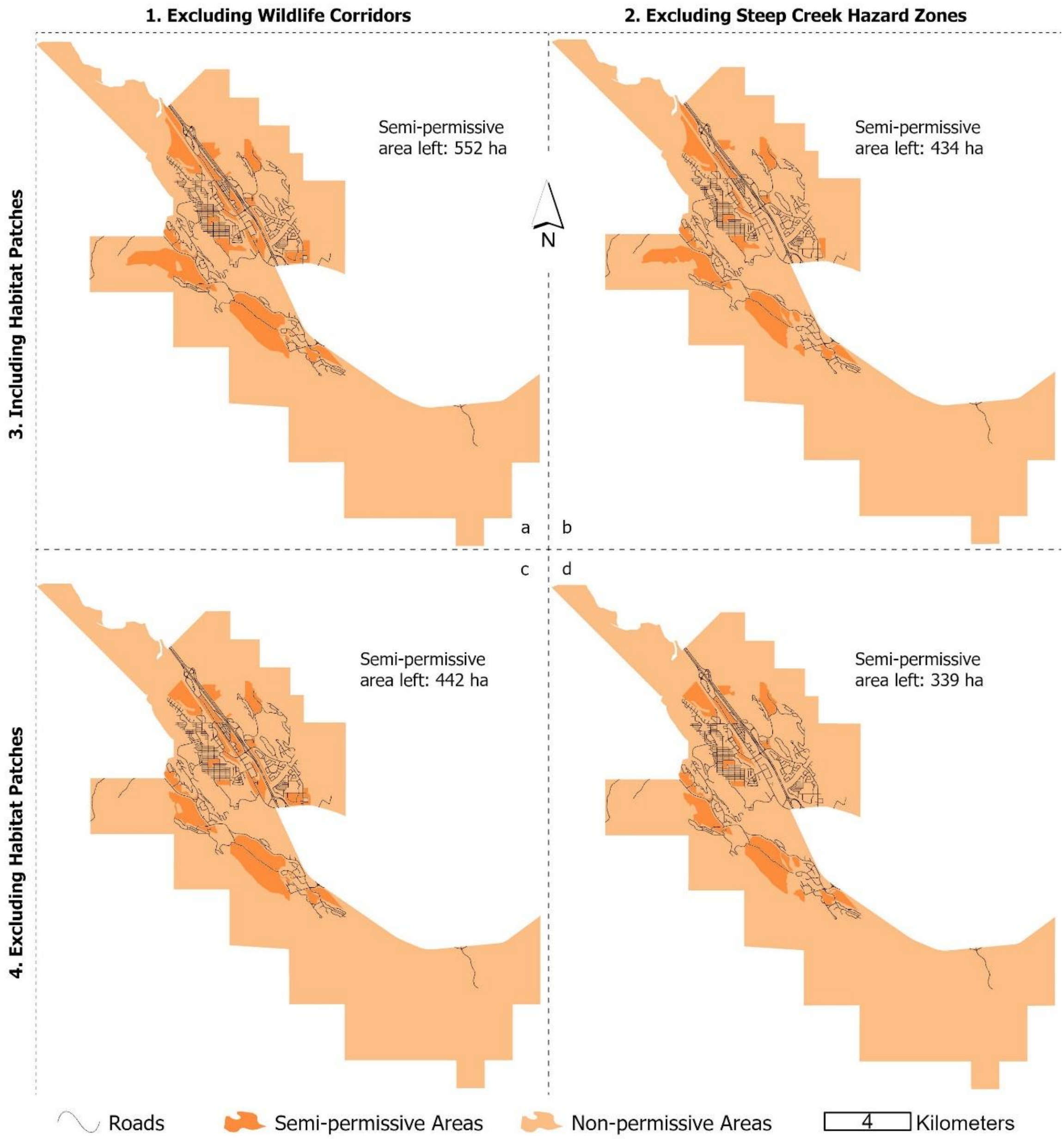

Figure 7. Four solar energy development scenarios are (**a**) excluding wildlife corridors; (**b**) excluding wildlife corridors and steep creek hazards zones; (**c**) excluding wildlife corridors and habitat patches; and (**d**) excluding habitat patches and steep creek hazard zones.

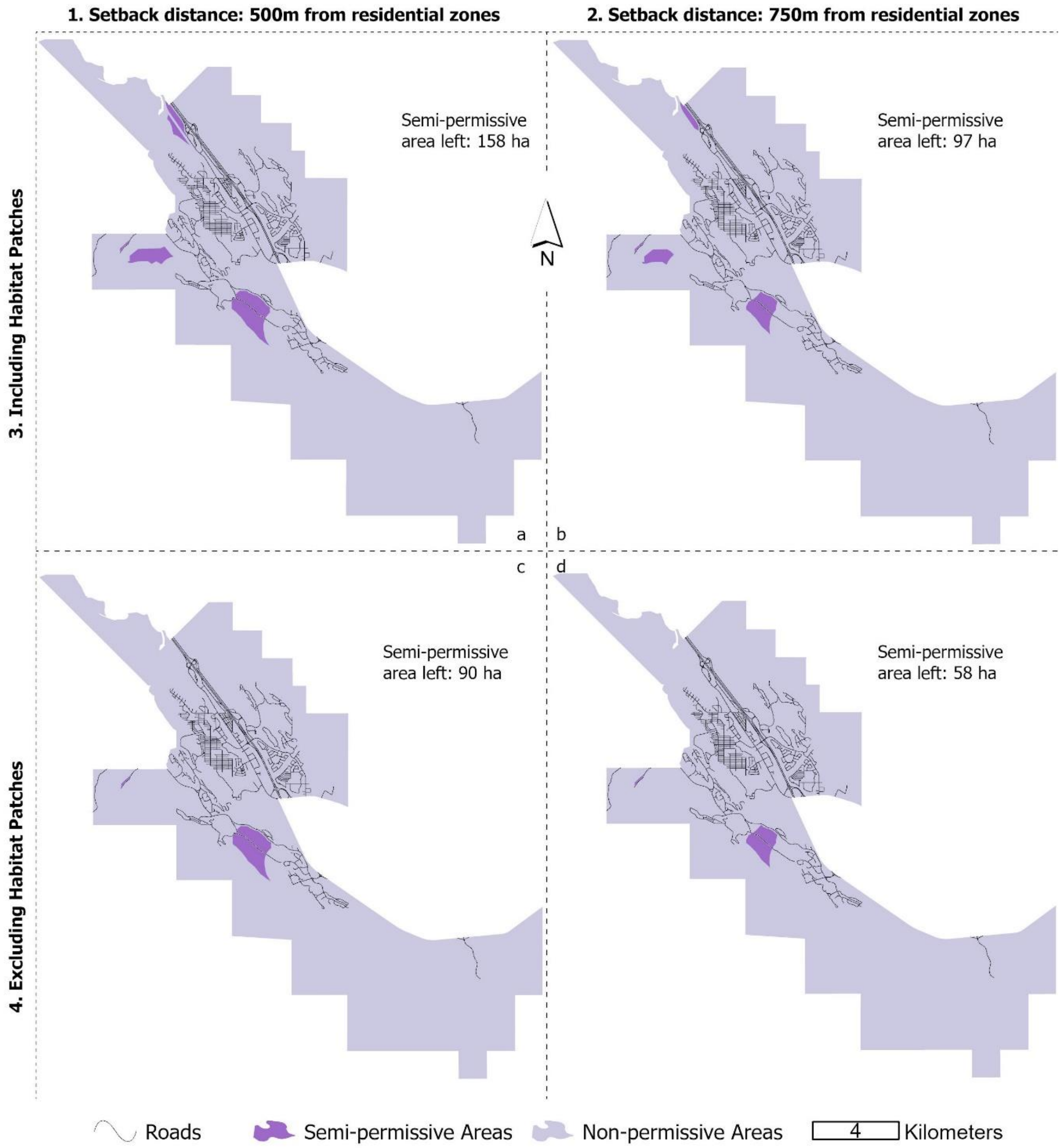

Figure 8. Four wind development scenarios are (**a**) applying 500 m setback distance from residential zones; (**b**) applying 750 m setback distance from residential zones; (**c**) applying 500 m setback distance and excluding habitat patches; and (**d**) applying 750 m setback distance and excluding habitat patches.

4.3. Estimating RE Generation

Based on the technical mapping result of available lands, land requirement and yearly production of utility-scale solar farms or wind turbines, we could estimate the corresponding energy production potential in Canmore. We compare this to the future electricity demands based on the per capita consumption and population growth projection. However, modelling energy production and future energy demands can be an infinitely complex work. The parameters to be considered are all subject to a variety of drastic changes: production changes due to solar panel or wind turbine efficiency improvement; consumption change due to different lifestyle of residents; population changes; or increases in the number of electric vehicles. To simplify the estimation, we will keep the number of variables limited to per capita emissions in the town and population growth to estimate the RE potential.

Table 3 lists the population growth [52], power consumption per capita [18], a rough estimation of power demands by 2050, as well as those required and available lands for both solar and wind opportunities based on their annual unit production [67,68]. This approximate estimation indicates that there are enough semi-permissive lands available to reach Canmore's emission-reduction goal (80% less than 2015 level by 2050) if they are to be developed into solar farms. Depending on the future scenario, wind turbines may also play a significant role in Canmore's energy transition. Overall, solar energy is more promising in Canmore due to its flexibility on land requirements.

Table 3. Power demands and land-based potential estimation.

	Population	**Population Increase Rate**	**Per Capita Consumption**	**Population Projection**	**Total Electricity Demands (MWh)**	
2000	10,517	33%	9166 kWh (2008)			
2016	13,992					
2050				>25,000	230,000	
	Required Lands (ha)	**Yearly Production (MWh)**	**Semi-Permissive Lands (ha)**		**Maximum**	
			Original	**Recoverable**	**Yearly Production (MWh)**	**Total Capacity (MW)**
A 2.5 MW wind turbine	25–100	~6000	649	625	36,000–150,000	15–225
A 1 MW solar farm	4	1300–1600	559	537	174,000–215,000	134

5. Discussion

It is noteworthy that the conceptual structure of the AI-RE framework (Figure 1) is designed to be universal and transferable, while detailed parameters and the classifications of layers must always be customized to suit the local context. In Canmore specifically, RE potential is shown to largely depend on decisions related to what are currently considered semi-permissive lands. Only 32% of these lands would secure the 180 hectares needed to be 100% powered by solar energy alone. Admittedly, this is a hypothetical scenario; achieving ambitious targets will never solely depend on only a single source of energy and much of the land considered 'semi-permissive' for RE is currently providing economic and ecosystem functions that need to be considered. Indeed, along with encouraging utility-scale RE development within the town's limit, Canmore's Climate Action Plan outlines a set of other approaches: incentivizing rooftop-level solar panel installations, retrofitting buildings with extra insulation and high-efficiency heating systems, adding electric or hybrid vehicles and charging stations, and the importing of RE or low carbon energies and fuels from regional energy sources in surrounding areas [17]. The knowledge of where the RE resources are most likely to be developed can not only support Canmore's transition to renewable energy transmission plans but also help amend and update its overall climate action strategies accordingly in the following decades.

The unique landscape of Canmore brings a lot of variations in not only the theoretical RE resources but also the regulatory restrictions, which raises further opportunities and challenges. The future RE development for Canmore is largely limited by its current LUB and land intersections with provincial parks. Its complex landscapes and provincial regulations on setback distances from a wind turbine enabled our emphasis on policy scenarios. However, above all, the small municipality provided us an opportunity to attentively address and integrate the jurisdiction's land-use bylaw; something that is hard to capture in a larger, multi-jurisdictional, regional, or national studies of RE planning.

It should be recognized that land-use regulations and clean-energy technologies will change over time. One functionality of the standardized framework is to clarify that the decision analysis of land-based RE development is a set of tradeoffs. RE-related policy changes on a provincial scale would possibly alter the track of energy transition for local jurisdictions, while local land-use policies and by-laws will influence the availability of RE resources. In this regard, the technical mapping process established in this study and its results intend to foster an "interface" connecting the public, decision makers, and stakeholders that fundamentally accelerate the implication of land-based RE planning. Using the outputs of this study, such an interface will bridge the next step of the RE planning model:

the participatory mapping by asking opinions from local residents on their favourable locations of possible RE development.

Due to the data availability in Canmore, this technical mapping model indeed has some limitations. Although Canmore's relative solar irradiance is high compared to many other places [23], the coarse resolution of solar PV input data (1km by 1km) [61] may not be representative when the filtered lands are counted in hectare unit. Besides, the daily solar PV input data does not consider the annual variations of solar irradiance and possible snow-covers in cold-climate regions [69]. Thus, the annual unit (1 MW) power generation from a solar farm may be overestimated in Table 3, and further detailed engineering studies would be required to assess production potential more accurately. Furthermore, the *economic* layer in this study uses a relative scale because it does not include the cost of substations, landcover cleaning, and removal, or the cost of RE facilities like wind turbines [30], which may lead to the underestimation of cost. Apart from those data availability situations, the scope of this framework intuitively leaves some gaps to be filled by engineering and energy studies in the future. Given the least-conflict lands, for example, it would be still challenging to integrate electricity from RE into Canmore's power distribution system when there is lack of storage system while the daily peak of power demanding and peak wind intensity (or solar irradiance) do not always overlap [21,70].

Over the course of this study, Alberta's Residential and Commercial Solar Program (RCSP) that provided PV installation incentives was suspended by the newly elected provincial government [71]; incentive programs for wind energy such as the Renewable Electricity Program (REP) [16] were cancelled simultaneously [72]. Although the dropping price of RE development may compensate for the disappearing incentive programs in the long term, the local energy transition process remains overcast without provincial support. Moreover, the carbon levy used to disincentivize GHG emissions is not high enough at the provincial level. To meet the 30% share of RE energy target by 2030, some suggests that the current carbon tax (CAD 30/ton carbon emission) in Alberta is not high enough to incentivize the wind or solar power until such tax is increased by 700% to CAD 210/ton of CO^2 emission [73]. Without a strongly carried standard on carbon levy, local jurisdictions such as Canmore may encounter longer lags on meeting the emission-reduction goal.

This highlights another consideration facing many small municipalities: even if Canmore could be 100% powered by RE by 2050, would Canmore's case be powerful enough to lead the renewable energy transition at the provincial level? Nevertheless, the future energy landscape is full of variables. The town of Canmore also recognizes its advocacy and partnerships' role to take actions like building long-term partnerships with the province and other municipalities for implementing smart electricity-grids and advocate for the province to reduce the carbon intensity of electricity [17]. One may argue that a single municipality will not make any difference when most of Alberta's energy productions come from fossil fuels. A long-term strategy of adopting RE requires patience and more, the courage to act when it is the right thing to do.

6. Conclusions

The global transition of energy to renewable sources requires careful spatial planning. Using Canmore as a case study, we demonstrate how a standardized land suitability framework for potential RE assessments can provide critical information to formalize these discussions. According to our study, even a land-limited jurisdiction such as Canmore has enough RE potential to meet its long term GHG-reduction goals and even achieve 100% electricity-powered by RE. In other words, the transition is not limited by land per se. Without environmental scenarios applied, the least-conflict and most economically accessible lands are found in central and northern Canmore along major roads and transmission lines. The next phase of the study will map out the voice from the community about where to locate potential RE facilities. Further research and consultations should be conducted on improving and expanding the input parameters of the model, as well as better understanding the bonds between RE sources, local targets, and the overall energy system.

Essentially, the energy transition process can be perceived as a land-based trade-off between energy provision, prevailing land-use functions, and social values related to those prevailing functions. To manage these trade-offs while facilitating local energy transition, we recommend that local governments and especially small municipalities assess the implications of their land-use plans on RE availability, track the market prices of different RE types, and monitor energy demands between all involved parties. Most importantly, we demonstrate how the technical mapping of a standard RE planning process can be universally and easily replicable with different measurements of resource recoverability.

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