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Introduction

In 2017, the Swiss population adopted the Energy Strategy 2050, which aims at increasing energy efficiency and expanding the use of renewable energies, including the phasing out of nuclear power (Lemm et al., 2020). Following the future electricity scenarios, in Canton of Berne, the nuclear power plant Mühleberg is planned to be shut down. To cover its annual energy production, estimated as around 3100 GWh/year (Swiss Nuclear 2020), we select 2 renewable energy sources to generate the missing electricity. The existing available alternatives to produce renewable energy in Switzerland are solar, wind, hydropower, biomass or geothermal energy. Hydropower has long been a major source of renewable energy for Switzerland (BFE, 2020b) and its production has remained very stable for years since the 1990s (BFE, 2020c), in this research, this source will not be further considered. As for geothermal energy, no electricity is currently being produced from geothermal sources in Switzerland (BFE, 2020a), partly due to its high technological barrier and massive amount of inputs at the initial stage, so it will neither be considered here. Among other renewable energy sources, solar- and wind energies have relatively lower price than the others (Schröder et al., 2013) and play increasingly important roles in the supply of electricity; especially solar energy, which increased rapidly, from less than 500 TJ/a in 2010 to almost 8000 TJ/a in 2018 and became the most predominant renewable energy source, excluding hydropower (BFE, 2020c). Thus, in this research, we selected solar energy and wind energy as the renewable sources to explore to cover the electricity production of Mühleberg.
Although the general public attitude towards renewable energy is high, e.g. the widely adopted Energy Strategy 2050, the social acceptance of their plants is relatively low at the local level. The reasons behind local opposition of renewable energy projects can be explained by the logic “not in my backyard”, which states that “people have positive attitudes toward something (wind power) until they are actually confronted with it, at which point they oppose it for selfish reasons” (Walter, 2014). Therefore, to increase the local acceptance of projects of solar and wind energy and to reduce the potential risks at later stages, in addition to the natural- and other social-economic criteria, we also emphasize the proximity of the plants to settlements as a factor when finding optimal locations. Hereby we derive the research question of this research as:

What is the impact of social acceptance on selecting optimal locations of solar- and wind energy plants in the Canton of Berne?

We will first define the more relevant criteria that need to be taken in consideration when modelling the suitable areas for plants of those two energy sources; while also defining the thresholds and parameters for the tools used to operationalize and implement those criteria. The proximity of the plants to the settlement will work as a proxy for acceptance or the possible remonstrances of the population with the new built plant. The resulting model of suitable areas will be analyzed and the potential energy produced in the area calculated. Finally a critical discussion of the maps as well of the quality of data and processes will be carried out, in order to assess uncertainties and possible improvements of the model.

Methods

In order to create the maps of the suitable areas for solar and wind energy, we decided to perform a multi-criteria analysis based on the relevant criteria for those energy forms, retrieved them from current studies about optimal site selection and adapted to the given conditions and limitations of the Canton of Berne. The evaluation criteria will be then weighted with help of an Analytical Hierarchy Process (AHP) and then summed up with *Raster calculator*, while the exclusion criteria, after being all converted to rasters, will be merged together in an exclusion layer, that will be finally multiplied with the results of the AHP to obtain the final map of the suitable regions. The scale of importance of a factor in relation to the others for the AHP is explained in Table 2 in the Appendix, while the pairwise comparisons for each energy type are shown in Tables 3 and 4. For all the criteria we worked to obtain rasters with a spatial resolution of 25m in order to achieve a detailed model and have sharper subdivision suitability regions.

Solar criteria

Referring from the current literature (Kereush & Perovych, 2017; Koc et al., 2019; Arán Carrión et al., 2008), we defined as important factors the slope and aspect of the surface, the elevation, the irradiation, the proximity to road networks and power lines, as well as the proximity to settlements (residential areas).

Slope (S1). Flat surfaces or with slight inclination are to be preferred, however the interval of tolerance is still debated, ranging from 3% to 15%, with 15% being considered the technical limit for a feasible installation (Kereush & Perovych). In context of this work we will accept slopes of 0-10% as a good compromise. From the *dhm25_025m_elevation_clip* with the *slope* tool, we obtain the slope in %. After with *Rescale by Function* we rescale with value 1 for 0%, then linear decreasing to 0 for 10 %. With selection by attribute we select the slope steeper than 10% and create a layer for the later exclusion.

Aspect (S2). To efficiently obtain energy from the sun the south, southeast, southwest, (with east/east) are preferred and the northern directions avoided (Koc et al., 2019). From *dhm25_025m_elevation_clip* with the *Aspect* tool, we obtain the aspect. With *Reclassify* we divide the cardinal point to three classes (flat and the souths have 2, west/east 1, other direction 0).

Irradiation (S3). Is one of the most important factors, as the higher the irradiance the higher the electricity production. Kereush & Perovych (2017) state that to be economically viable a minimum of 1100 kWh/m^2 per year is required. With the use of *Area Solar Radiation*, with default parameters, we obtain the irradiation map. The tool generates an irradiation map from the DEM. As the insulation condition over the Canton of Bern may be very different, as it ranges from mountains to plains, we decided to use the standard parameters as mean approximation of the reality, as otherwise would be needed to divide the Canton in regions and determine the specific insulation conditions. The obtained irradiation layer is rescaled with *Rescale by Function* from 1 to 0 (0 if lower than 1100 kWh/m^2, then up to 1 for the maximal irradiation).

Proximity to road network (S4). As roads are expensive to build (have also environmental costs), the selected sites should be closer to roads, of about 3 meters wide to help for maintenance (Kereush & Perovych). We consider here roads of class 1 and 2 in the VEC25 layer and maintain a security distance of 100m. After extracting the roads (*Select by Attribute*), a *Buffer* of 100 m is made and rasterized (*Feature to raster*) for the exclusion criterium. Then with *Euclidean Distance* is calculated the distance from the roads and the result again scaled from 1 (nearest points) to 0 (furthest points) with *Rescale by Function* for the evaluation criterium.

Proximity to power lines (S5). Is also an economically important factor, the nearer to existing power lines, the less are the cost of installation and the loss of energy (Koc et al., 2019). Also here for security reasons we apply a 100m-buffer. After merging (*Merge*) and clipping (*Clip*) the power lines , a *Buffer* of 100 m is made and rasterized (*Feature to raster*). Then with *Euclidean Distance* is calculated the distance from the power lines and the result scaled from 1 (nearest points) to 0 (furthest points) with *Rescale by Function*.

Proximity to residential areas (S6). While a certain distance from residential area has to be maintained to avoid impediments to urban growth (Shorabed et al, 2019; Kereush & Perovych, 2017), is also an advantage to have the plant not to much distant from the settlements as reduce electricity loss due to travel (Kerush & Perovych, 2017). We also intend to use the distance as a proxy of the social acceptance, we therefore make a *Buffer* of 500m (exclusion criteria, also rasterized) as a way to improve the acceptance, and then from there a decreasing linear scale to consider the economical aspect (evaluation criteria).

Elevation (S7). While a higher elevation is beneficial for the performance of solar (Koc et al., 2019), too high elevation (above 1500) should be avoided because of transport costs (Kerush & Perovych, 2017). We define three classes, below 1000m, between 1000-1500 m and above 1500 m. We obtain the layer with *Reclassify* of the DEM in the three classes.

Natural and protected surfaces. Based on the spatial planning principles of the federal government,we avoid protected areas, such as cantonal/national protected areas (federal inventories, natural parks, UNESCO world natural heritage), forest areas (BFE 2008). According to law a 200m *Buffer* is made protected areas, and 50m *Buffer* for forest areas, protected botany and geology. We also consider a *Buffer* of 500 from lakes, rivers and glaciers. Those layers are part of the exclusion criteria.

Weighting

Factors have been weighted according to the AHP method. The factors S3 is the more important, as determine the production of the plants. For economical reasons we weighted S4 as the second more important and then S6 is the third relevant factor, to include the social acceptance as an important factor. Below are S1 and S2, that still giocano a relevant role for the production and finally, considered less important are S5 and S7. Table 3 and 5 in Appendix summarize the factors, their weighting and their scaling.

Wind criteria

Regarding current research (Díaz Cuevas et al., 2018; Kereush & Perovych, 2017; Noorollahi et al., 2015; Pamucar et al., 2017) and restrictions in Canton Berne (Amt für Umweltkoordination und Energie des Kantons Bern 2012; BFE 2008), important factors for the selection of locations for wind energy plants are wind speed, the proximity to road networks, power lines and residential areas. Areas close to airports, protected areas and objects, water bodies, forests or having high slope or elevation are not suitable.

Wind speed (W1). This is the most important economic factor to consider when building a wind power plant. Locations with an average wind speed of more than 3 m/s are required (Pamucar et al., 2017). Functions *IDW interpolation* and *Rescale by function* (linear scaling, lower threshold '3') are applied to generate a layer `Rescale_wind_all_be`, which indicates the suitability between 0 to 1. A layer showing wind speed lower than 3 m/s is generated.

Proximity to road network (W2). In order to reduce the cost of transport it is desirable that the distance from the roads outside the safety zone of 200 m, is as small as possible. This is to maximize the use of the existing road network for the installation, transportation, and maintenance of the wind farm (Pamucar et al., 2017). The road network in our research includes railways and roads which are at least 4m wide. *Merge* was used to aggregate different networks, *Euclidean distance* calculated the proximity, and *Rescale by function* (linear scaling) indicates the degree of it between 0 to 1 (see `Rescale_RoadRail25_Be`). A layer showing area within the distance of 200m is generated for the exclusion.

Proximity to power lines (W3). Although reducing costs for the construction of energy transmission infrastructure will reduce the cost of building wind farms, the minimum distance of 100 m should be provided with adequate space from power lines (Pamucar et al., 2017). Except the distance, same operations as above (Output: `Rescale_EucD_electricityNet`). A layer showing area within the distance of 100m is generated.

Proximity to residential areas (W4). Suitable areas around residential areas are defined as those that are more than 300m (BFE, 2008), since in our research we focus more on social acceptance, the distance is increased to 500m (Díaz Cuevas et al., 2018). It is also an advantage to have the plant not too far distant from the settlements as it reduces electricity loss due to travel (Kereush & Perovych, 2017). Except the distance, same operations as above. Output see `Rescale_EucD_VEC25_pri_a_Sied_BE`. A layer showing area within the distance of 500m to the residential areas is also generated.

As discussed in the beginning, some areas are considered as unsuitable for wind power plants. Below are exclusive criteria. Layer `Available Area` shows the area after excluding unsuitable area.

Proximity to airports (Wa). Less than 2500m to commercial airports is considered as unsuitable (Noorollahi et al., 2015). *Buffer* is applied to indicate the areas within a distance of 2500m to airports.

Slope (Wb). To make the construction of a wind turbine feasible, the slope must not exceed 20% (AUE, 2012) to minimize risk such as landslides. *Slope* and *Reclassify* are used to show the area within the range of suitable slope. **Elevation (Wc)**. The wind speed starts to decrease as air density decreases at higher elevations, 2000 m was selected as the cut-off criteria (Noorollahi et al., 2015). *Reclassify* is used to show areas under 2000m.

Distance to national inventories and protected areas (Wd). A distance of at least 200 m is required (BFE 2008) to be kept. *Buffer* of 200m is used to visualize it. **Distance to water bodies (We)**. The distance should be kept to avoid intrusion on hydrodynamic systems and can help to protect wildlife, 50m is the suggested distance (Díaz Cuevas et al., 2018). **Distance to forest areas (Wf).** The minimum distance to the edge of the forest is 50 m (BFE, 2008). **Distance to protected botany and geologic objects (Wg).** No exact minimum distance required by the regulations (BFE, 2008; AUE, 2012), however, to reduce the difficulties of construction at the later stage, a minimal distance of 50m is kept. For We, Wf and Wg, *Buffer* of 50m is applied.

Weighting

AHP will be applied, where W1 is the most important economic factor to consider. Since social acceptance is one of the main barriers in the implementation in Switzerland, W4 is given the second highest attention. W2 and W3 are considered as equally important, whereas W2 is slightly more important than W3 (Giamalaki & Tsoutsos, 2019; Maan & Asaad, 2020). Table 6 in Appendix summarize the factors, their weighting and their scaling.

Results

Solar map

From Figure 1, representing the suitable areas for the solar energy, as well as their grade of suitability, can be seen how they are mostly concentrated in the northern part of the Canton of Bern, mostly in plain regions, due to the fact that the solar plants require a low slope to be feasible. In the mountains are to be spotted just a few scattered points where the slope of the surface will be suitable. Particularly rich in very suitable areas is the region of the Seeland and the northern plain of Mittelland and Emmental-Oberaargau . As will be discussed in the Discussion part, it is already evident the conflict that could rise with agriculture, as the same regions with elevated suitability are also regions of elevated agricultural production.

Assuming the same module efficiency (which represents the efficiency of the photovoltaic module) and plant efficiency (which accounts the energy losses of the plants) as in the report of Energieberatung Bern-Mittelland (2013) a mean solar irradiation of 1150 kWh/m^2 per year; and considering the great extension of the area defined as “More” and “Most suitable” (about 118537 cells of 25x25 m), then the energy potentially generated from those region could be:

Irradiation * module efficiency * plant efficiency * area = 1150 kWh/m^2 * 0.16 * 0.85 * (118537*25m*25m) = 11586991750 kWh = 11586 GWh

This is clearly not a realistic and reachable energy outcome, as in general not all the surface could actually be covered with panels, secondly because not all the potential area could be converted from its precedent use to solar energy farm. The result above gives however an idea of the amount of energy that is constantly to the Earth from the sun that could be if an extensive area would be totally dedicated to exploit this resource.

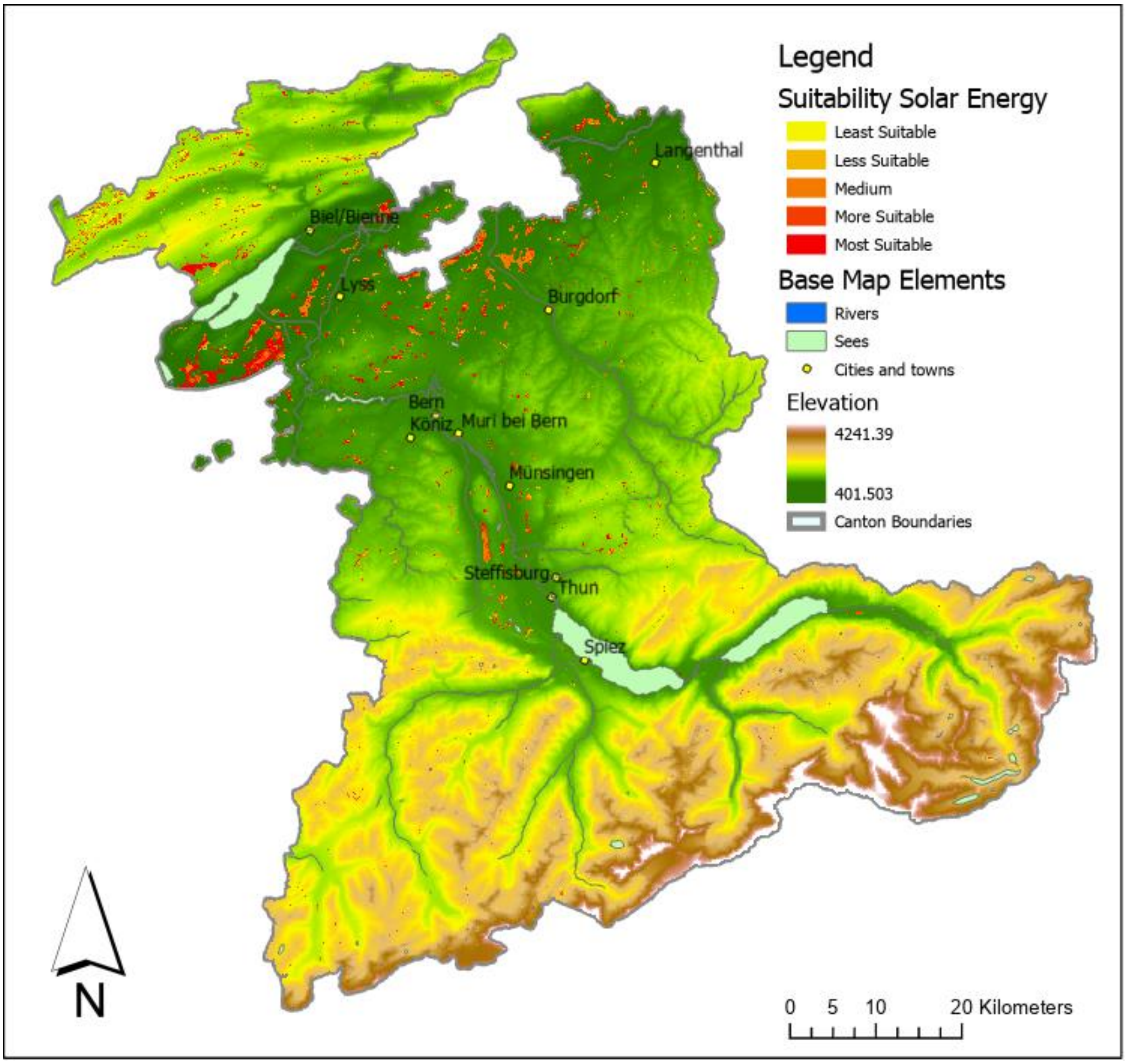

Figure 1: Map of the potential locations for solar energy plants.

Wind map

As shown in Figure 2, north-western regions are most suitable, this is also where the current wind power plant Mont Crosin is located. In this region, the suitability is at least above medium (higher than the suitability score of 0.36) and has continuous large areas to generate electricity which is able to catch up with the amount produced by Muehlenberg. And the wind speed here is around 4m/s to 8m/s. Although south-eastern regions are also areas with high wind speed, the elevation is much higher than 2000m.

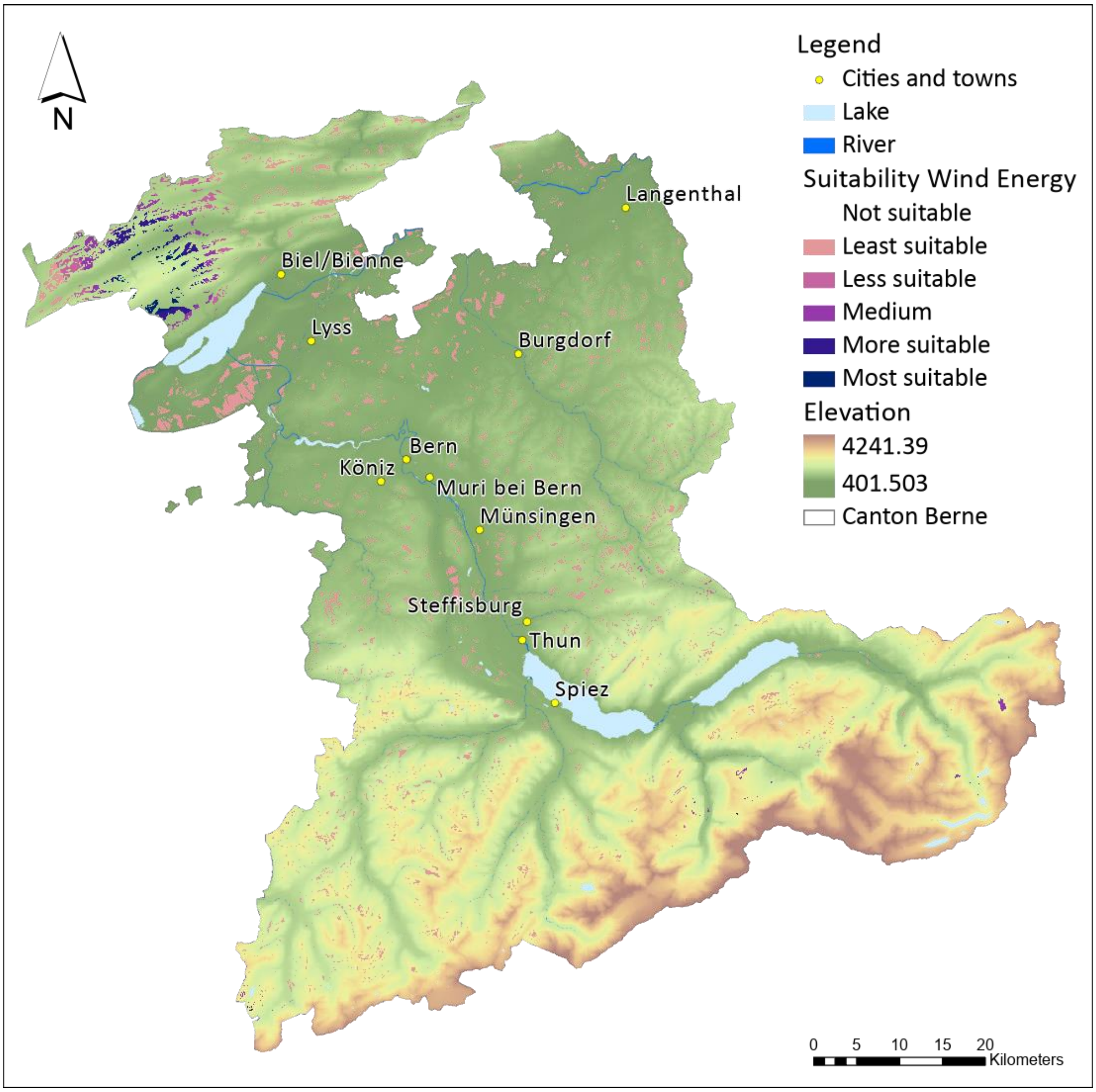

Figure 2: Map of potential locations for wind energy plant

To estimate the electricity, wind turbine Vestas V112/3000 is taken as an example. Its height is 119m and its diameter is 112m, it is currently functioning in wind power plant Haldenstein and produced 4639000 kWh in 2019 (The Swiss Wind Power Data, 2019). The wind speed in Haldenstein is from 1.8m/s to 9.4m/s (MeteoSwiss, 2020), which is similar to the optimal regions here. To avoid the turbulence caused by turbines, it is suggested to keep a distance of 7 rotor diameters between each turbine (Sciencing, 2017). Therefore, each turbine should have a buffer zone around it, at a distance of 3.5 times the rotor diameter around it. Given the motor diameter of Vestas V112/3000, each turbine requires an area of approximately 482750m². In this research, only areas in which suitability levels are not lower than “medium” are considered. The results for each level are shown in the Table 1 below.

Class	Pixel count	Area [m²]	Wind turbines	Annual Production [kWh]
Medium	24851	15531875	32	148448000
More suitable	18502	11563750	23	106697000
Most suitable	7796	4872500	10	51029000

Table 1: the potential electricity production of wind energy plants in Canton Berne.

With only considering the “more suitable” and “most suitable” levels the optimal location, in north-western regions, have the potential electricity production of 157.726 GWh/year. If “medium” is included, the potential production is expected to increase 148.448 GWh/year. However, the wind speed in this class is also lower.

Discussion and Conclusions

Solar map discussion

Our resulting map is subject to various sources of error and uncertainty, due to the uncertainty of the data, as well as the choices made for the implementation of the evaluation factors. The layers of slope, aspect, elevation and solar irradiation are all derived from the DEM, therefore are influenced from the errors in the model, which correspond to about 1 to 2m in the plains and up to 2 to 8m in the mountains (Swisstopo, 2005). Another aspect that needs to be taken in consideration for the solar irradiation layer, is that it has been generated using the standard parameters of the ArcGIS tool. To have a more accurate representation of the irradiation in the canton would be necessary to determine for all of the parameters the actual situation in Canton Bern, or even, as the weather and climatic conditions between the plains and the mountains may differ consistently to consider to evaluate the solar irradiation differently for the different regions of the Canton.

The selection of criteria to define suitable areas has been made through the analysis of the literature about the topic and from there has been chosen the criteria that most often were used. Therefore other aspects that were less discussed, such as the temperature, that according to (Koc et al., 2019) still has an influence on the performance of a solar. An improvement to our potential of solar energy would be to also consider this factor and other factors that were mentioned only in a smaller amount of studies. Also for factors as the roads and the power lines proximity has been defined a security distance of 100m, which reduces therefore the suitable area, even though it is not directly mentioned in the literature. However, we considered it wise to create a security buffer, to avoid problems with overcrowding of sensible infrastructures.

The weighting of the factors constitute too an element of uncertainty for the model. As in our work we wanted to enhance the aspect of social acceptance, the weighting of factor proximity to residential areas has been weighted more, to better represent the social response to the construction of new plants. Further, as mentioned before, the potential areas for solar energy often overlap the agricultural land, especially for example the potential areas founded in the region of the Grosses Moos. It could be argued that in a further development of the model should also be considered the aspect of the land cover and define whether and to which degree an agricultural land could be embodied in the analysis of potential, or if it should be considered as the forests and water surfaces as an exclusion zone.

Wind map discussion

To have a continuous map of wind speed, Inverse Distance Weighting is used for the interpolation, with k=2 and 12 neighbors. To estimate the accuracy, cross-validation is used in the data preparation. The mean error is around 0.87 and the root mean squared error is around 1.12. To improve the performance, after the testing, all points are used for the interpolation. Since the dataset only contains records from 2009 to 2010, a dataset covering more years can reduce the uncertainty. In addition, elevation and the height of wind turbines have an influence on the wind speed. Therefore, results can be improved by including them in the interpolation process.

We used Vector25 dataset to identify different feature classes. The inaccuracy of this dataset is 3 to 8 meters (Swisstopo 2007). Since all the buffer zones created here are at least 50m wide, the uncertainty in the dataset is compensated by the mapping.

To evaluate the weighting of 4 different soft criteria, 2 scenarios are used to conduct the sensitivity test. The first one is a social acceptance scenario by giving the same weights to W1 (wind speed) and W2 (proximity to residential area), the details of weighting see Table 7 in the Appendix . The second is an equal-weighted scenario, the weight of each criterion is 0.25. The suitability scores of this research ranging from 0 to around 0.68. If all weights equal 0.25, the range of the score is from 0 to around 0.69, which is higher. When changing weights by giving W1 (wind speed) and W2 (proximity to residential area) the same weights, suitability score is ranging from 0 to 0.58, which is the lowest among these 3.

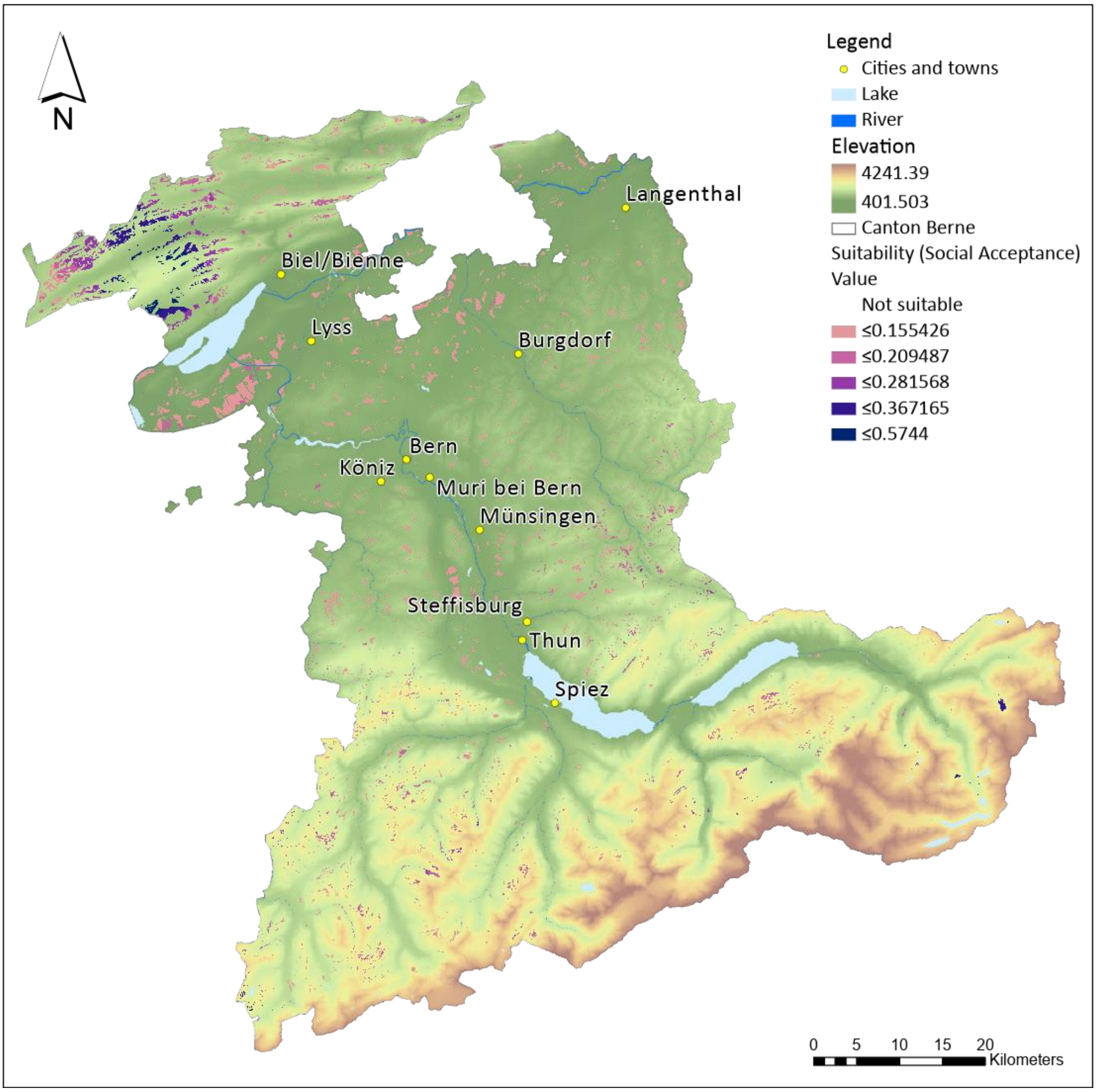

Figure 3: Map of potential locations for wind energy plants (social acceptance scenario).

Comparing Figure 3 with Figure 2, although the range of the suitability score is slightly different, we can see that by giving the same weight to W1 and W2, the optimal locations for wind energy plants in Canton Berne are still in the north-western regions. A possible way to improve the weighting is to conduct a local survey and find out more factors regarding social acceptance and residents' opinions regarding these factors.

A limitation of this research is that the agricultural land is not excluded in the mapping process, the reason behind is if excluding it, there is no enough land left since the north-western areas have also agricultural land. Moreover, no exact minimal distance to between wind farms and agricultural land written in the regulations. In addition, compared to solar energy plants, wind turbines do not require large continuous land.

Conclusion

In conclusion, our two maps of the potential areas to exploit the renewable energies of wind and sun show that the Canton Bern especially in the northern part, around the Lake of Bienne, disposes of large territories with elevated potential for those energies. However, as remarked in the discussion, there is often a conflict with the agricultural land. Also the issue of social acceptance of the plants influences the extension of the suitable area, as a greater distance from residential areas has to be kept in order to have more acceptable compromises.

Appendix

Intensity of Importance	**Definition**	**Explanation**
1	Equal importance in a pair	Two criteria contribute equally to the objective
3	Moderate importance	Slightly favor one criterion over another
5	Strong importance	Strongly favor one criterion over another
7	Very strong importance	Very strongly favor one criterion over another
9	Extreme importance	The evidence favoring one criterion over another is of highest possible validity
2, 4, 6, 8	Intermediate values	When compromise is needed
Reciprocals	Values for inverse comparison	If criterion *i* had one of the above numbers assigned to it when compared with criterion *j* , then *j* has the reciprocal value when compared with *i*

Table 2: Scales for the pairwise comparisons (Al-Shabeeb et al. 2016).

	S1 (slope)	S2 (asp.)	S3 (irr.)	S4 (road)	S5 (power)	S6 (res.)	S7 (elev.)
S1 (slope)	1	1	1/3	1	2	1/2	1
S2 (asp.)	1	1	3	1/2	1/3	1/2	4
S3 (irr.)	3	1/3	1	3	3	3	5
S4 (road)	1	2	1/3	1	5	1	4
S5 (power)	0.5	3	1/3	1/5	1	2	4
S6 (res.)	2	2	1/3	1	1/2	1	4
S7 (elev.)	1	1/4	1/5	1/4	1/4	1/4	1
Weights	0.105	0.104	0.181	0.144	0.083	0.121	0.043

Table 3:The pairwise comparison matrix of criteria weights for solar power plants.

	W1 (wind)	W2 (road)	W3 (power line)	W4 (residential)
W1 (wind)	1	6	7	3
W2 (road)	1/6	1	2	1/2
W3 (powerline)	1/7	1/2	1	1/3
W4 (residential)	1/3	2	3	1
Weights	0.609	0.105	0.077	0.207

Table 4: The pairwise comparison matrix of criteria weights for wind power plants.

Evaluation factor	Classes	Relevance
Slope (S1) 0.105	0 % 0 - 10 % >10 %	1 Linear 1-0 0
Aspect (S2) 0.104	Flat,South,Southeast/-west East/West North/Northeast/Northwest	2 1 0
Solar irradiation (S3) 0.181	> 1907 kWh/m^2 1907 - 1100 kWh/m^2 <1100 kWh/m^2	1 Linear 1-0 0
Proximity roads (S4) 0.144	100 m 100 - 12974 m >12974 m	1 Linear 1-0 0
Proximity power lines (S5) 0.083	100 m 100-21359 m >21359 m	1 Linear 1-0 0
Proximity residential areas (S6) 0.121	500 m 500-12744 m >12744 m	1 Linear 1-0 0
Elevation (S7) 0.043	<1000 m 1000-1500 m >1500 m	2 1 0

Table 5: solar evaluation factor, with weight and scaling.

Evaluation factor	Criteria rate	Operation & implementation
Inclusion criteria and weights		
Wind speed (W1): 0.609	0 - 3m/s 3 - 8 m/s > 8 m/s	0 Linear 0-1 1
Proximity to road network (W2): 0.105	0 - 200m > 200	0 Linear 1-0
Proximity to power lines (W3): 0.077	0 - 100m 100 to border of Canton Berne	0 Linear 1-0
Proximity to residential areas/cities (W4): 0.207	0–500m 500–the border of Berne	0 Linear 0-1
Exclusion Criteria		
Proximity to airport (Wa)	0 to 2500m > 2500m	0 1

Slope (Wb)	0 - 20%(approx. 11.31 degree) > 20% equal to 0	1 0
Elevation (Wc)	0 - 2000m > 2000m	1 0
Distance to forest nature reserves, nature reserves, UNESCO world natural heritage (Wd)	0 - 200m > 200m equal 1	0 1
Distance to water bodies (We)	0 - 50m > 50m	0 1
Distance to forest areas (Wf), protected botany and geologic objects (Wg)	0 - 50m > 50m	0 1

Table 6: wind energy evaluation factors, with weight and operations.

	W1(wind)	W2(road)	W3(power line)	W4(residential)
W1(wind)	1	6	7	1
W2(road)	1/6	1	2	1/6
W3(powerline)	1/7	1/2	1	1/7
W4(residential)	1	6	7	1
Weights	0.433	0.074	0.059	0.433

Table 7: The pairwise comparison matrix of criteria weights for wind power plants - social acceptance scenario.

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