Potential for Photovoltaic Solar Installation in Non-Irrigated Corners of Center Pivot Irrigation Fields in the State of Colorado

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Technical Report
NREL/TP-6A20-51330
July 2011

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NATIONAL RENEWABLE ENERGY LABORATORY

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Abstract

The State of Colorado expressed an interest in assessing the potential for photovoltaic (PV) solar installations on non-irrigated corners of center-pivot irrigation (CPI) fields throughout the state. Using aerial imagery and irrigated land data available from the Colorado Water Conservation Board, an assessment of potentially suitable sites was produced. Productivity estimates were calculated from that assessment. The total area of non-irrigated corners of CPI fields in Colorado was estimated to be 314,674 acres, which could yield 223,418 acres of installed PV panels assuming 71% coverage in triangular plots. The total potential annual electricity production for the state was estimated to be 56,821 gigawatt hours (GWH), with an average of 1.3 GWH per available plot.

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Introduction

The State of Colorado requested an analysis of unused agricultural land within the state—such as the land located in the corners of center-pivot irrigation (CPI) fields—where photovoltaic solar panels could be installed. Such installations could potentially be used to supplement the state's energy supply with renewable sources of energy and count toward the state's renewable portfolio standard (RPS).

Data

Boundary files (ESRI "shapefiles") for irrigated lands in Colorado were acquired from the Colorado Water Conservation Board (CWCB). The data consisted of boundaries, the type of crop irrigated, and the type of irrigation applied. Available data were from 2005. For legal and other reasons, only incomplete data were available for the Upper Arkansas River Basin (Upper Arkansas Basin), and no data were available for the Republican River Basin (Republican Basin). This lack of data was problematic because these basins comprise a large proportion of irrigated lands in the state. However, an older irrigated lands data set, which included these basins, was available through Colorado State University, and it was used to fill the gaps in the CWCB data. Figure 1 shows the complete irrigated lands in the state as well as the Republican and Upper Arkansas Basins.

For photovoltaic solar resource data, a data set that contains the annual average solar resource data for a tilt=latitude collector was used. The data are a 10-km satellite modeled data set representing data from 1998 to 2005 for the contiguous United States.[1]

Analysis

Identifying CPI Fields

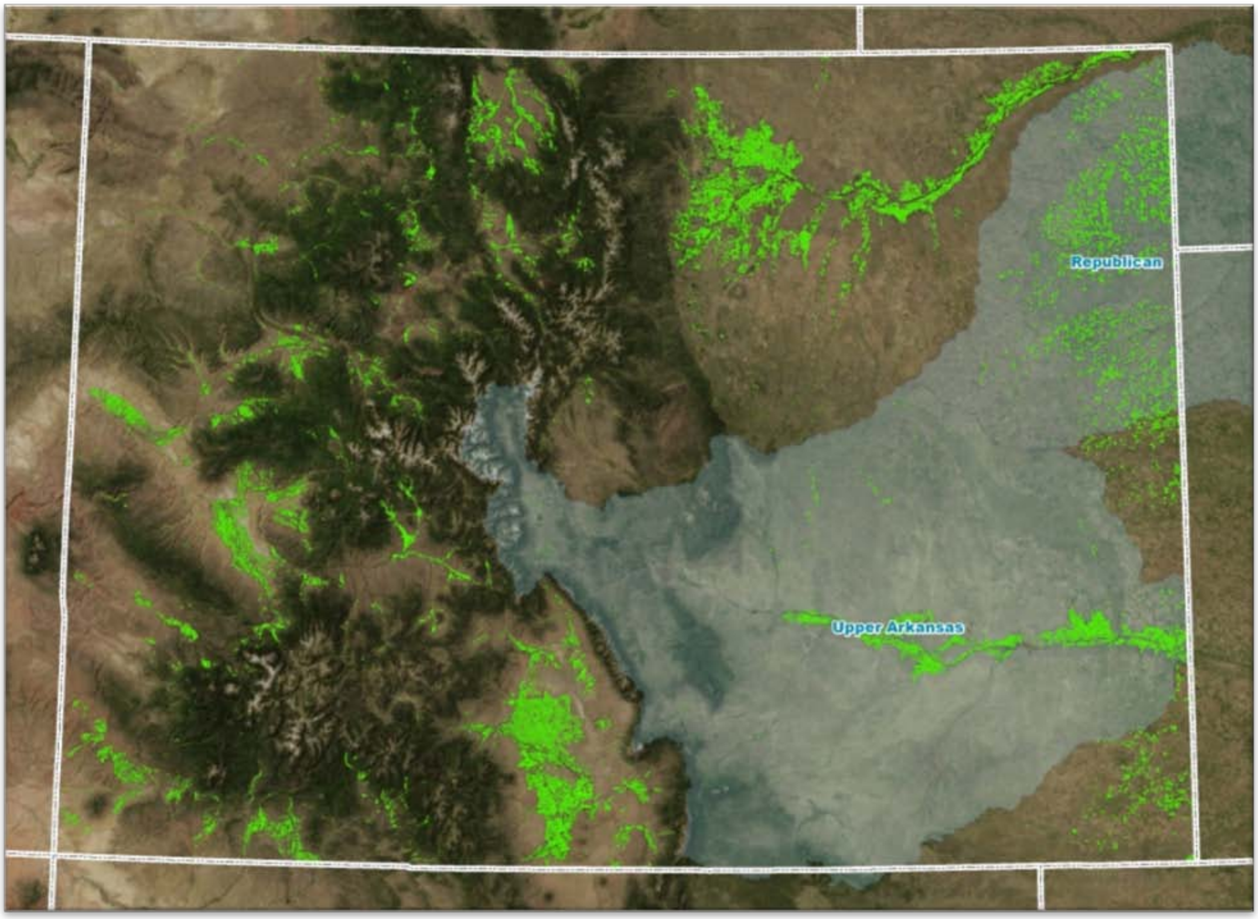
Starting with a statewide coverage of irrigated lands in Colorado, CPI fields were extracted using the data attributes (Figure 2). Plots of land containing CPI fields were assumed to be generally square with one side parallel to lines of latitude. Additionally, CPI fields were assumed to be centered on plots of land to maximize coverage by the center-pivot sprinkler. These assumptions were affirmed both in discussions with the contacts at Colorado State University who provided some of the data as well as through visual inspection of aerial imagery. A rectangular envelope was calculated around each of these circular fields, which delineated an approximate property boundary based on the assumptions.

Identifying Available Corners

To estimate available corners, all irrigated lands were extracted from the envelope areas, as were significant water bodies (Figure 3). This effectively removed the CPI field as well as corners actively being irrigated using other methods such as flood irrigation (Figure 4). Visually inspected results were compared with aerial imagery to locate anomalies and verify the assumptions. Adjacent CPI fields frequently produced corner plots with shared or nearly shared boundaries (Figure 3). Adjacent plots from different CPI fields generally were not joined, as it

[1] These data can be downloaded at http://www.nrel.gov/gis/.

was not known where property boundaries, fences, roads or other features would hinder or prevent adjacent plots from being considered as one plot. Exceptions were made for overlapping CPI fields, which were assumed to belong to the same owner and to be undivided by other features.



Source: Esri

Figure 1. Irrigated lands in the Upper Arkansas and Republican Basins

Removing Remaining Fragments

As a final step, numerous slivers were found where fragments of envelopes remained after irrigated lands were removed. For example, if an envelope was drawn around a CPI field, and all four corners were being irrigated, the removal of these corners along with the CPI field itself could leave behind thin strips or slivers of land where envelope boundaries did not quite align with known field boundaries. These slivers were not useful either because they represented land that was not actually available or because they were too narrow to be useful for installing PV. To reduce such occurrences, the isoperimetric inequality (IE) or "compactness" of the remaining polygons was calculated. A nearly circular polygon will have an IE approaching 1.0, reflecting maximum compactness as in a perfect circle. Very long, narrow polygons will have a significantly smaller IE. For this analysis, it was determined that any polygon with an IE of less than .05 and a total area less than 20 square meters were unlikely to be viable areas in the analysis and were removed, thus adequately reducing the occurrence of the slivers (Figure 5).

Determining System Size

Non-irrigated plots of land in this analysis, primarily being corners of CPI fields, were typically triangular. A NREL study by Ong[2] (forthcoming) found that approximately 71% of the area of triangular plots of land could be covered with PV infrastructure. This same study also found 6.38 acres per megawatt to be the average capacity-based area requirement or number of acres of PV panels required to generate 1 megawatt (MW) of electricity. Using these figures, the remaining area (71%) of each plot was divided by 6.38 acres/MW to estimate the system size.

Applying Solar Resource Data

The photovoltaic solar resource data for Colorado were classified into quarter kilowatt intervals (e.g., 6.0–6.25, 6.25–6.5), and available plots were associated with a resource range based on their locations. Plots were assigned the resource range they fell into based on geographic location. With the known resource range, total annual production was calculated using available acreage and NREL's System Advisor Model.[3]

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[2] When published, this study, which has the working title "Land Use Characteristics of Solar Facilities in the United States" will be made available via both http://en.openei.org/datasets/node/454 and http://www.nrel.gov/publications/.

[3] For information about the System Advisor Model (SAM), see https://www.nrel.gov/analysis/sam/.

Source: Esri

Figure 2. Circular CPI fields selected from rectangular flood-irrigated fields

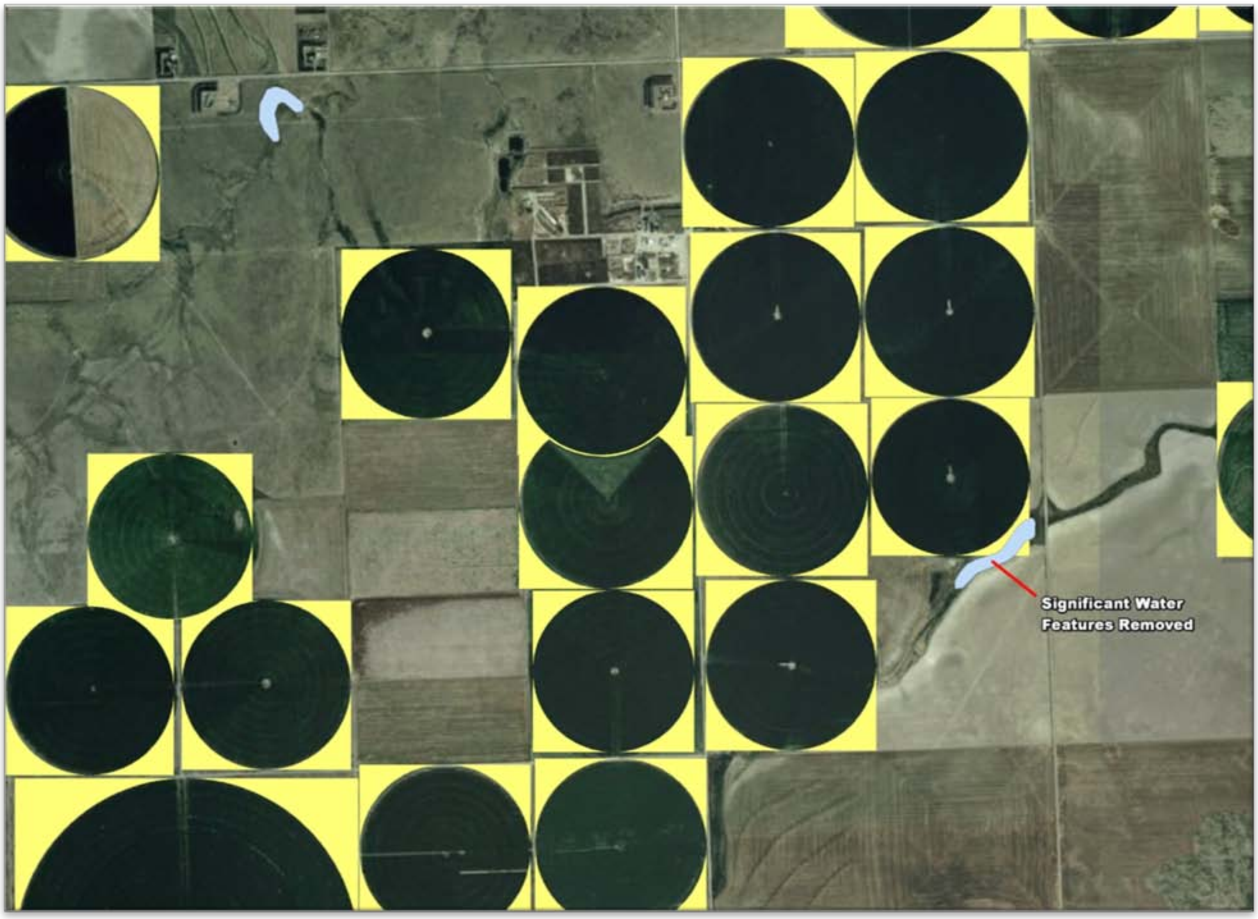

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Figure 3. Center-pivot irrigation envelopes with irrigated lands and water features removed

Adjacent plots generally remain independent.

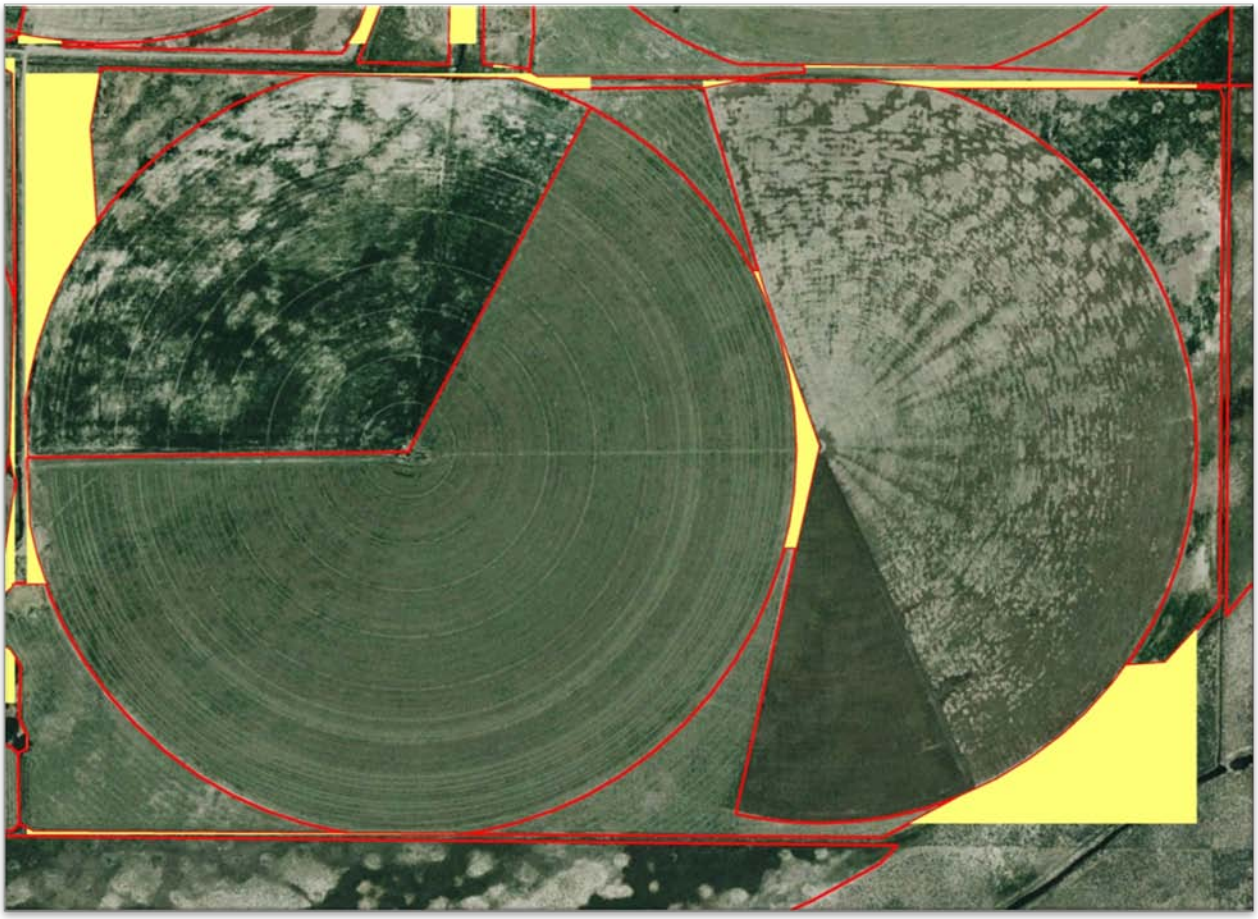

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Figure 4. Delineated irrigated areas and what remains of the envelope around the CPI after removal of irrigated fields

The red lines delineate all irrigated areas. The yellow areas represents what remains of the envelope around the CPI after all irrigated fields (CPI and flooded corners) are removed; these have potential for development.

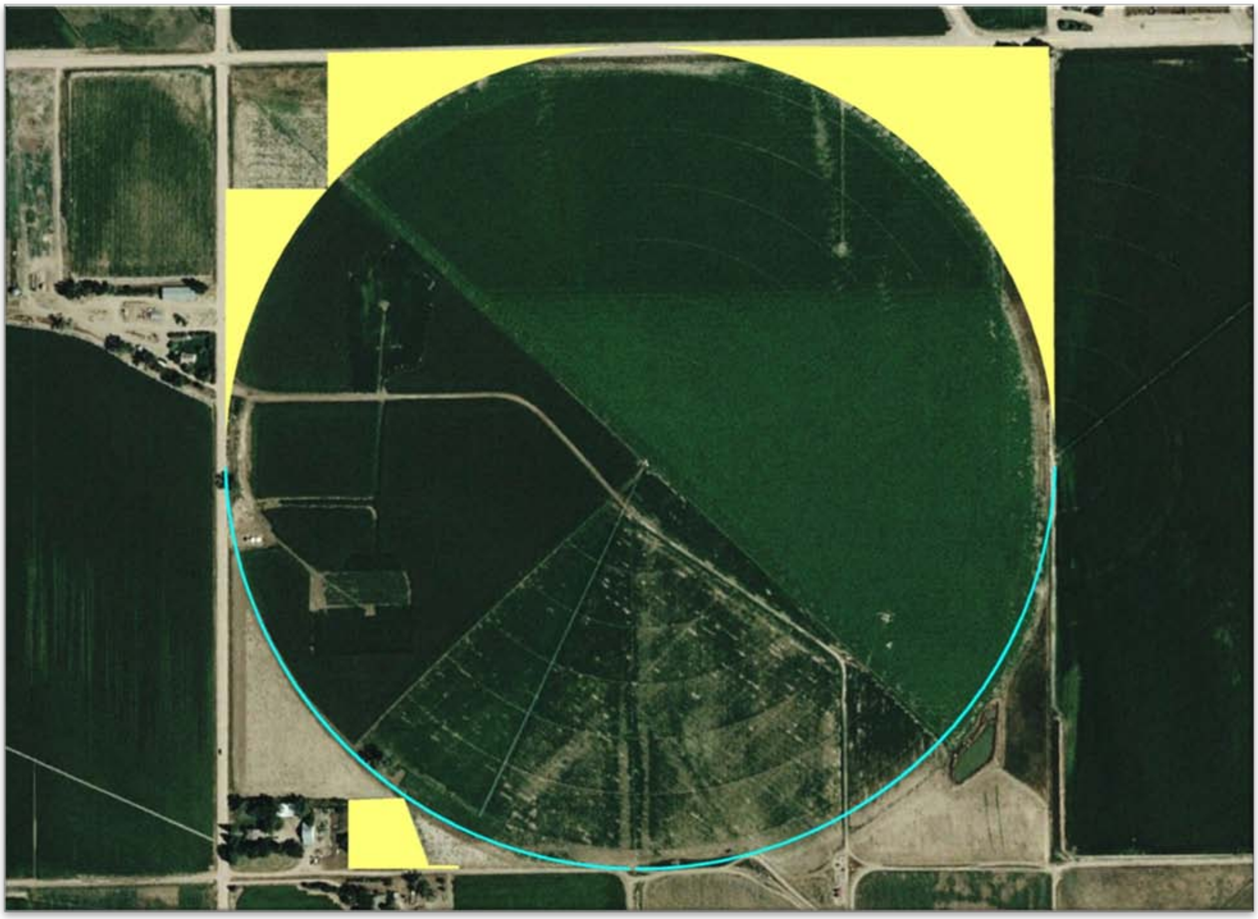

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Figure 5. Sliver of land resulting from removal of the CPI and the irrigated (southern) corners from the calculated envelope

Having both an IE of less than .05 and an area of less than 20 square meters, the sliver was removed from the data set.

Results

The total area of non-irrigated corners of CPI fields in Colorado was estimated to be 314,674 acres, which could yield 223,418 acres of installed PV panels assuming 71% coverage in triangular plots. The total potential annual electricity production for the state was estimated to be 56,821 gigawatt hours (GWH). Table 1 shows approximate acreage and capacity by county. Note that the county summary includes total acreage and capacity for all available plots that occur within the county, even if a plot crosses the county border into a neighboring county. Such plots were not split at county boundaries, and the full acreage and capacity was summed for every county within which it occurs. This double counting of some plots was applied only to county summaries to prevent the splitting of plots that might not have a geographic division. State area and electricity production estimates counted each plot only once.

Table 1. Potential Available Acreage (Approximate) and Capacity by County

County	Acres	GWH	County	Acres	GWH	County	Acres	GWH
Adams	2,667	667	Fremont	101	25	Morgan	11,585	2,871
Alamosa	10,518	2,933	Garfield	75	18	Otero	84	21
Arapahoe	402	101	Gilpin	0	0	Ouray	1	0
Archuleta	0	0	Grand	14	3	Park	0	0
Baca	14,717	3,729	Gunnison	14	3	Phillips	12,424	3,081
Bent	150	38	Hinsdale	0	0	Pitkin	0	0
Boulder	128	32	Huerfano	263	71	Prowers	4,849	1,222
Broomfield	0	0	Jackson	0	0	Pueblo	478	122
Chaffee	497	131	Jefferson	0	0	Rio Blanco	68	17
Cheyenne	4,932	1,232	Kiowa	913	230	Rio Grande	11,386	3,112
Clear Creek	0	0	Kit Carson	29,329	7,281	Routt	58	14
Conejos	4,529	1,261	La Plata	239	64	Saguache	12,636	3,480
Costilla	5,187	1,415	Lake	0	0	San Juan	0	0
Crowley	30	7	Larimer	1,692	421	San Miguel	55	14
Custer	0	0	Las Animas	13	3	Sedgwick	5,523	1,374
Delta	97	24	Lincoln	1,190	300	Summit	0	0
Denver	0	0	Logan	8,836	2,190	Teller	0	0
Dolores	412	104	Mesa	35	9	Washington	8,193	2,031
Douglas	46	11	Mineral	0	0	Weld	16,421	4,073
Eagle	100	25	Moffat	166	41	Yuma	49,880	12,363
El Paso	1,253	316	Montezuma	2,107	563			
Elbert	590	149	Montrose	298	74			

Discussion

A visual inspection of the data revealed that CPI envelopes align very well with presumed property boundaries apparent from aerial photography. In some cases, CPI fields were apparent in the aerial photography but were not included in the CWDB data and vice versa. A new analysis is advised when the 2010 updates, along with the full data set, are made available from the CWDB. These are anticipated to be available by the end of 2011.

In some cases, structures such as houses, barns, and other manufactured features occur in areas determined to be within an envelope and might be unsuitable for PV installation. These areas are not easily excluded and would likely need to be evaluated on a case-by-case basis. However, upon visual inspection, these structures did not appear to consume an appreciable amount of space.

Potentially available non-irrigated CPI corner plots are distributed statewide, though most of them are concentrated in the northeastern and south central areas of the state as seen highlighted in the final data set of potential development areas (Figure 6). Figure 7 provides a detailed view of the typical plot distribution in the final data set.

This analysis did not consider adjacency between plots, as in situations where a single landowner may own multiple CPI fields and, thus, multiple adjacent corners. In some cases this could merge very small plots that were excluded from the analysis making them viable as single, larger plots. Additionally, this analysis did not consider distance to transmission lines or demand centers or other economic factors and may warrant future study.

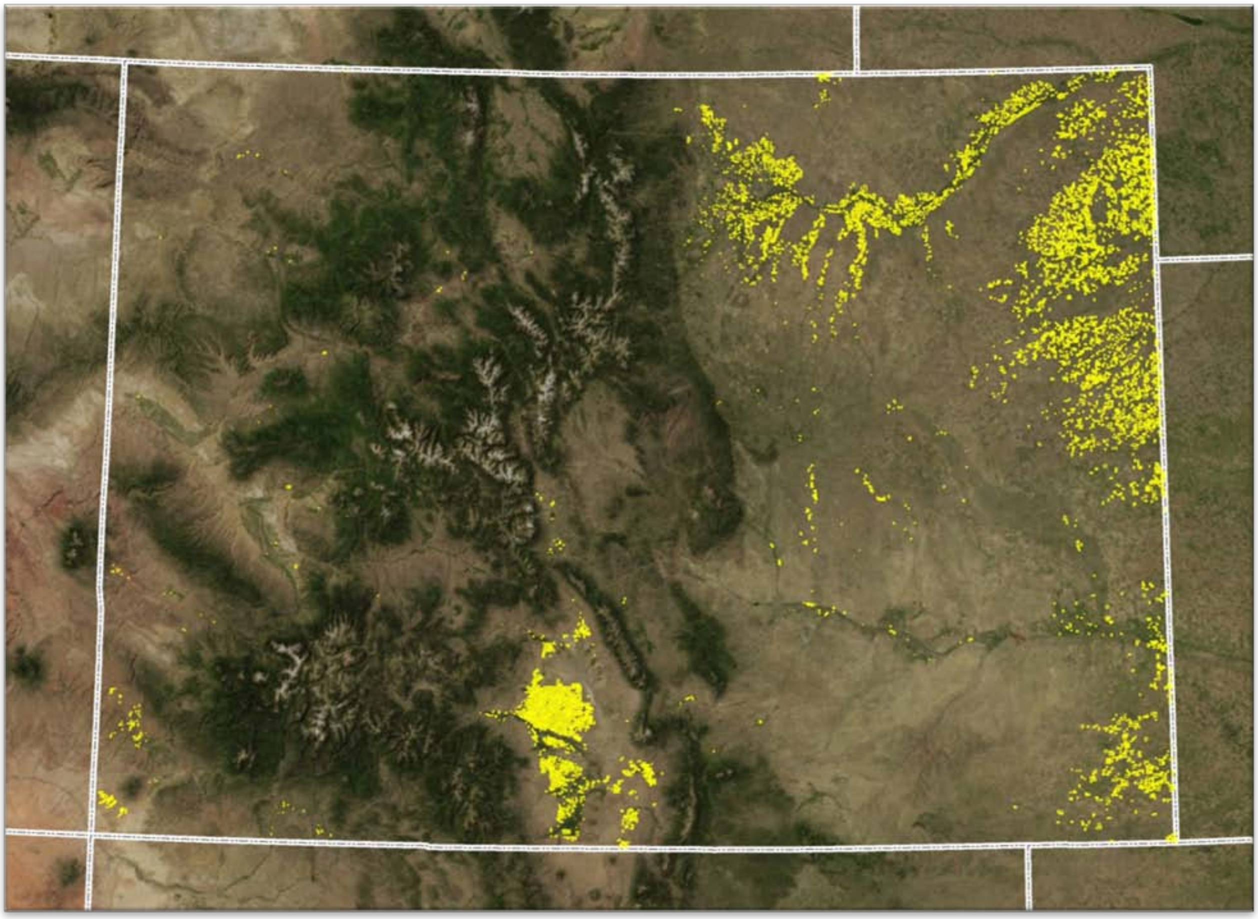

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Figure 6. Distribution of available non-irrigated CPI corners in Colorado.

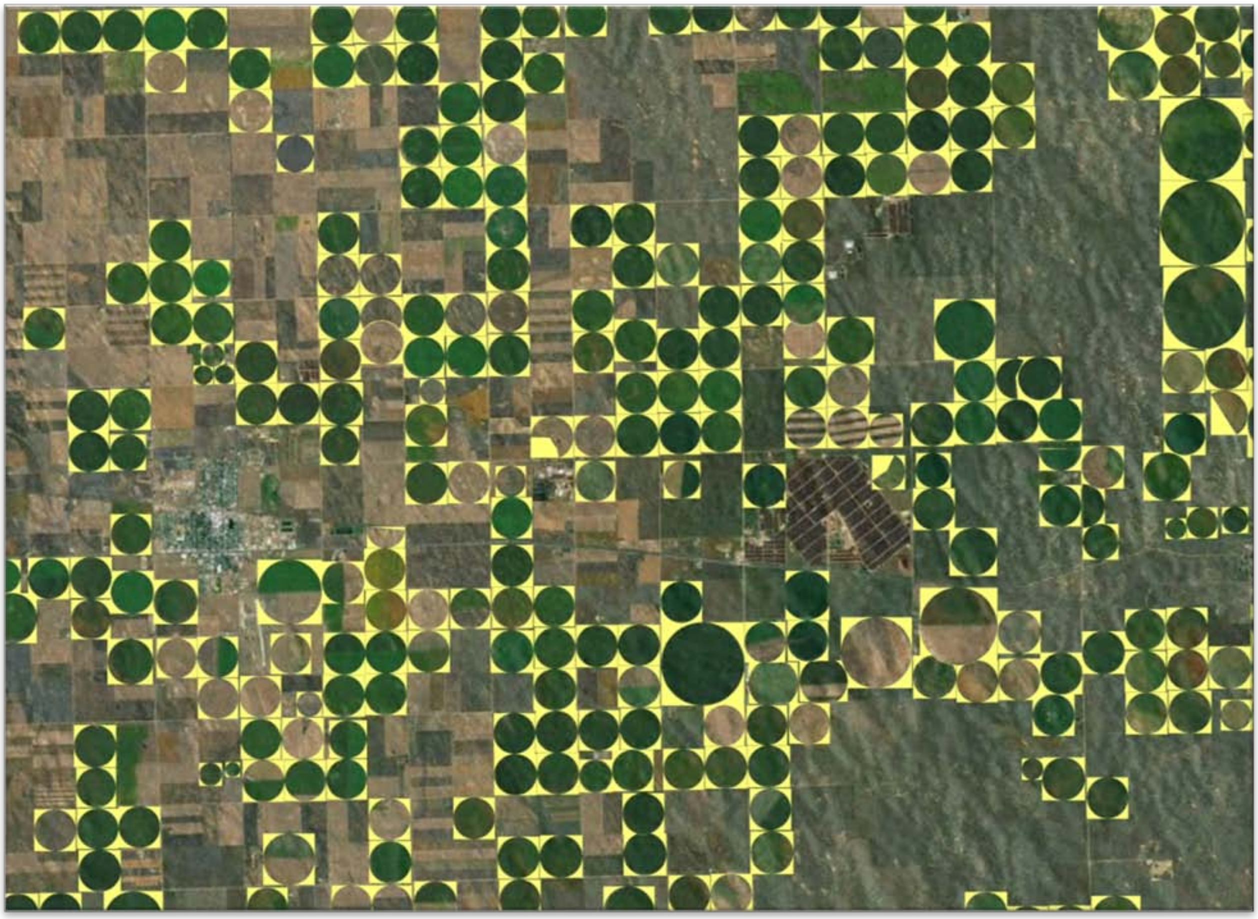

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Figure 7. Typical non-irrigated corners potentially available for development

Conclusion

Colorado potentially has a large untapped resource for generating renewable energy through PV installations on non-irrigated farmland. Analysis of irrigated cropland data suggests that PV installations on even a fraction of the non-irrigated corners of CPI fields on Colorado's farmlands could contribute significantly to Colorado's RPS goals.