Energy Research & Social Science 99 (2023) 103073

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Perspective

Rural opposition to landscape change from solar energy: Explaining the diffusion of setback restrictions on solar farms across South Korean counties

Inhwan Ko

Department of Political Science, University of Washington, Seattle, United States of America

ARTICLE INFO

Keywords:
Renewable energy opposition
Solar farms
Rural landscape
Social acceptability
Interview research
Event history analysis

ABSTRACT

While the number of utility-scale solar farms in South Korea has increased in the past decade, more than half of county governments have adopted setback restrictions on solar farms. These restrictions reduce available lands for the siting of solar farms, undermining national-level decarbonization outcomes. This study shows that rural opposition to landscape change from solar farms was a key driver for South Korean county governments to adopt the restriction. The event history analysis across 225 counties from 2012 to 2020 shows that rural counties with a higher chance of landscape change from solar farms, measured with solar farm density, faced a higher risk of adopting the restriction. Interview research further suggests that rural opposition to landscape change has motivated government officials to adopt the setback restriction on solar farms. The finding of this study implies that a national renewable energy development may confront local policy barriers if the government fails to mitigate the negative impacts of renewable facilities on local communities.

1. Introduction

Achieving net-zero emissions requires low carbon energy transition, which means renewable energy facilities should expand rapidly to replace high-carbon energy sources such as fossil fuels [1–4]. These facilities populate rural areas with low population density because of their land availability and affordability [5,6]. However, rural communities are increasingly opposing renewable energy projects [7–12]. Since 2015, the Renewable Rejection Database has reported over 450 cases of rejections or restrictions to wind and solar energy projects in the U.S. [13]. These local oppositions often translate into anti-renewable political and policy outcomes [14,15]. For instance, 729 U.S. counties have implemented policies that block or restrict the siting of renewable energy facilities until 2022 [16,17].

This study documents and analyzes a recent case in South Korea where more than half of county governments[1] have adopted setback restrictions on solar farms.[2] These restrictions refer to land-use regulations that restrict the siting of solar farms within specific distances from property lines, roads, structures, and natural features [18]. Since 2015, 129 out of 229 county governments have amended their land-use ordinances to include setback restrictions on solar farms. Fig. 1 illustrates this trend. This is surprising given that the South Korean government introduced a renewable energy policy in 2017 that aims to produce 20 % of its total electricity from renewable energy. As county governments have the final authority to issue permits to renewable energy projects, their setback restrictions vastly reduce available lands for solar energy projects. Why did local governments in South Korea enact policy barriers against solar energy development?

Utility-scale renewable facilities may face local opposition when they have negative impacts on local communities [19,20]. This study focuses on the disruptive impact of utility-scale solar farms on the surrounding landscape [21,22]. Solar farms significantly change the landscapes of where they locate as they grow in number, but differently in urban and rural areas. Solar farms are more visually alien to rural landscapes as they are manufactured facilities consisting of ceramic and metallic subcomponents. Their visual impact on rural landscapes can be magnified when they replace forests and farmlands in rural areas. Moreover, various studies document that the value of landscape is both

E-mail address: inhwanko@uw.edu.

[1] South Korea has three-tier local governance systems: Tier 1 (province-level or state-level) includes 8 provinces and 7 metropolitan cities, including Seoul. Tier 2 (county-level) includes 226 counties and cities affiliated with the Tier 1 governments, and 2 autonomous jurisdictions (Sejong city and Jeju Island) excluded from the analysis. Lastly, Tier 3 (town-level) governments are affiliated with the Tier 2 governments. The unit of analysis of this study is a county-level (Tier 2) government. I will generally refer to these tier 2 governments as "counties," even though some county-level governments are titled "cities." Ulleung county is also excluded in the event history analysis to follow since it is an island and therefore cannot account for spatial frailties (N = 225).

[2] In this study, I use the term "solar farms" to refer to utility-scale photovoltaic (PV) energy facilities.

https://doi.org/10.1016/j.erss.2023.103073
Received 26 October 2022; Received in revised form 24 March 2023; Accepted 28 March 2023
Available online 7 April 2023
2214-6296/Published by Elsevier Ltd.

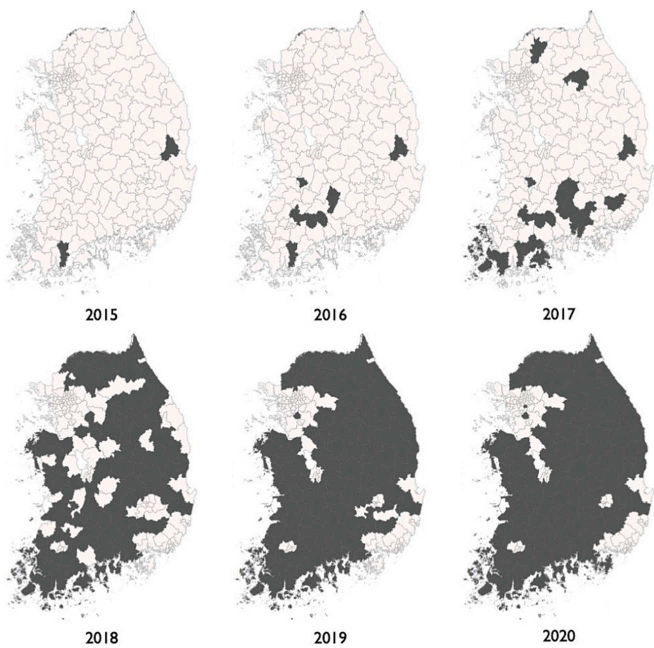

Fig. 1. The diffusion of setback restrictions on solar farms across South Korean counties, 2015–2020 (counties with restrictions colored black).

economically and psychologically crucial for rural communities [23,24]. Therefore, solar farms are more likely to face opposition from rural residents than urban residents if they populate the area and are highly visible.

This study explores whether rural opposition to landscape change from solar farms motivated county governments to adopt the restriction. Section 2 theorizes how solar farms have different implications for landscape disruption in rural and urban areas. Section 3 summarizes results from an event history analysis to see whether counties with high chances of landscape change from solar farms, measured with solar farm density, have faced a higher risk of adopting the restriction, particularly in rural areas. Section 4 presents evidence from interview research with rural residents and local public officials that rural opposition to landscape change from solar farms was a key driver for county governments to adopt the restriction. Section 5 concludes by discussing the findings and limits of this study and provides policy implications.

2. Rural landscape change as a driver for opposition to solar farms in rural areas

A landscape is a geographical area characterized by its content of observable, both natural and manufactured features, which both have physical-aesthetic and cultural-psychological values to human beings and their activities [25,26]. Therefore, a change in the landscape is primarily driven by changes in observable features, be they natural or manufactured. According to this definition, solar farms can cause landscape change as they are observable and manufactured features added to the landscape, bringing industrial transformation.

Studies have identified the visual impact of renewable facilities on the landscape as a critical factor that conditions their social acceptability [27,28]. Solar farms impact their surrounding landscapes in rural and urban areas differently. First, solar farms are more visually alien to rural landscapes than urban ones [29]. Rural landscapes are typically characterized by natural features such as forests, agricultural vegetation, snow-capped mountains, and streams. In contrast, manufactured features dominate urban landscapes, such as highroads, skyscrapers, bridges, and commercial and industrial complexes [30]. Since solar farms mainly comprise ceramic and metallic sub-components, they are more visually alien to rural landscapes than urban ones. Also, like any other construction project, solar farms require a massive land-use change [31]. They need various components other than photovoltaic panels to be installed on-site, such as support fixtures and pillars, which require developers to build a new road for their transportation from outside areas. As the number of utility-scale solar farms rises, the more likely they will change their surrounding landscapes. If they replace existing natural features, their visual impact on rural landscapes can be magnified [32].

Furthermore, to achieve cost-efficiency, utility-scale solar farms are sited at a high altitude to garner as much radiation as possible (e.g., on rooftops or hills with less shadowy areas) [33]. If they are placed on rooftops, since the average height of the buildings is lower in rural areas, one can detect solar farms more often in rural areas than urban ones. Urban rooftops are hardly visible when human beings stand on ground level. Or, if they are ground-mount, they should be sited in areas with lower land prices, translating into lower set-up costs (if they purchase lands) or production costs (if they rent them). Areas with lower land prices in rural areas are typically less developed, preserving pristine natural features that provide economic benefits for rural communities [34–36]. For instance, the rural natural landscape provides amenities that attract new migrants, facilitating local economic activities and employment opportunities [37]. Therefore, replacing or distracting these landscapes with solar farms may provoke resistance by rural residents fearing the loss of their economic value. Drawing on local house price data of the Netherlands from 1985 to 2019, Dröes and Koster [38] find that house prices within 1 km of solar farms decrease by around 2.6 % due to visual pollution.

Studies have documented various cases of rural opposition to landscape disruption from manufactured features, including energy facilities and infrastructures. Hess et al. [39] show that among 78 cases of rural opposition to proposed electricity power lines they documented in the U. S. and Canada, 31 cases were motivated by residents' concerns over their effect on landscape disruption. Bessette and Mills [40] also show that wind farm projects in rural communities with higher natural amenities were more likely contentious. In the South Korean context, both solar [41] and wind farms [42], as well as natural gas pipelines [43] have confronted rural opposition driven by landscape change in their construction process.

These studies highlight that proposed renewable projects may be delayed or even canceled when residents have concerns over their disruptive impacts on their surrounding landscapes. However, they overlook the possibility that opposition to existing renewable energy facilities may deter future projects. Local opposition can translate into local regulations or zoning laws that limit available lands for future renewable energy projects to be submitted [15]. When such restrictions are in effect, future renewable energy projects may face challenges even if they incorporate plans to harmonize energy facilities with their surrounding landscapes better. Drawing on the South Korean case, I show how rural residents' opposition to solar farms due to their disruptive impacts on their surrounding landscapes leads to local policy decisions that limit future renewable energy project proposals.

3. Event history analysis

To investigate the relationship between local setback restrictions on solar farms and their disruptive impact on the landscape, I analyze the data of 225 South Korean county-level governments from 2012 to 2020 with their restriction adoption records. The analysis covers from 2012 since county-level data on solar energy capacity is available only after 2012. The data includes county governments that have adopted restrictions (i.e., "adopters") and that have not (i.e., "non-adopters").

I use the event history analysis to analyze the data to examine what explains the timing of the adoption of setback restrictions. It is important to note that all county governments with setback restrictions have not lifted them as of March 2023. This means that adopters have left the risk set when they have adopted the restrictions, and non-adopters are right-censored (i.e., they have not adopted restrictions until the end of the study period, which is 2020). The dependent variable is a binary indicator whose value is one if a county year has the restriction and zero otherwise. Since observations are annual, we can pool them by yearly intervals. Therefore, I use a piecewise event history model[3] [44].

I set up two main explanatory variables. The first is solar farm density (number of solar farms per hectare) which captures how much solar farms affect the landscape of each county. As their number grows within a specific area, their impact on landscape change should also increase. The second explanatory variable is population density (population per square km), logged to account for the nonlinearity across counties, which should capture whether rural or urban landscapes characterize each county. Consistent with the main argument, I add an interaction term with these two explanatory variables. I hypothesize that solar farm density should increase the likelihood of county governments adopting the restriction on solar farms more highly in rural areas than in urban areas.

The model includes several additional control variables. First, I include the average capacity of solar farms (average kW per solar farm). As solar farms' capacity and physical size go hand in hand, the average capacity of solar farms in a county may proxy for how large solar farms are on average and therefore how intrusive they are for their surrounding landscapes. I also add an interaction term with the average size of a solar farm and population density. Second, I include the share of farmlands in each county year. Areas with a higher share of farmlands are more characterized by rural areas and therefore are more available for solar farms to be sited. Third, whether local governments are responsive to constituents' needs is important, typically measured by mayors' or governors' winning margin [45]. If county government leaders have won the previous election by a smaller margin, they will be more responsive to the opposition when it occurs. Therefore, I include the winning margin variable of mayors' or governors' previous elections. Lastly, I include the average global horizontal irradiation (GHI) between 2007 and 2018, largely unvarying over time. GHI is the total amount of shortwave radiation from above by a surface horizontal to the ground (kWh per square meter), retrieved from Global Solar Atlas 2.0. In counties with higher GHI, solar farms may penetrate more, and local governments may be more unwilling to adopt the restriction, given that solar farms' productivity may be higher.

The model results appear in the first column of the table (Model 4) in Appendix A. Hazard ratios are calculated by exponentiating the coefficient estimates. First, an increase in solar farm density by one per hectare, for instance, is associated with a 1.13 times increase ($e^{0.119\times1}$) in the risk of adopting the restriction on average. Also, a decrease in population density by 1 % is associated with a 1.69 times increase ($e^{-0.528\times-1}$) in the risk. Note that the coefficient for the interaction term between these two factors is statistically significant and negative. This means that an increase in population density dilutes the effect of solar farm density on increasing the likelihood of adopting the restriction. This result supports the argument that rural counties, relative to urban ones, are more likely to adopt the restriction when facing high solar farm density.

I created five counterfactual scenarios with varying solar farm and population density levels for a better interpretation of the results. These scenarios help us examine how they differ in the expected likelihood of adopting the restriction from a hypothetical county with all variables held average (i.e., a "baseline county"). The first scenario is when a county has one more solar farm per hectare than the average of all counties. This scenario shows the marginal effect of solar farm density on the likelihood of adopting the restriction. Residents in this counterfactual county should see more solar farms in their surrounding landscape than those in the baseline county. The second and third scenarios assume counterfactual counties with more solar farms per hectare but are more rural than the baseline county. Specifically, the second scenario has one lower percentage, and the third scenario has two lower percentages of population density than the baseline county. I expect their ruralness should intensify the marginal effect of solar farm density. By contrast, the fourth and fifth scenarios assume counterfactual counties that are more urban than the baseline county. The fourth scenario has one higher percentage, and the fifth scenario has two higher percentages of population density than the baseline county. I expect their ruralness should attenuate the marginal effect of solar farm density. All scenario counties share the same values for the rest of the covariates with the baseline county except for solar farm and population density variables.

Fig. 2 visualizes the differences in the expected likelihood of adopting the restriction between each scenario versus the baseline county. The likelihood of the first scenario county is higher by only about 0.01 % than the baseline county, yet this difference is significantly higher than zero. Whether a solar farm is in rural or urban areas matters when we see four other scenarios. When hosting one more solar farm per hectare, a county with one lower percent of population density (scenario 2) faces a 3 % higher likelihood of adopting the restriction than the baseline county, and a county with two lower percent (scenario 3) faces a 12 % higher likelihood. A county with one higher percent of population density (scenario 4), however, faces a 1.5 % lower likelihood of adopting the restriction than the baseline county when hosting one more solar farm per hectare, and a county with two higher percent (scenario 5) faces a 2.2 % lower likelihood. Overall, five scenarios suggest that solar farm density increases the likelihood of county governments adopting the restriction when they are in more rural than urban areas.

Coefficients for other control variables are also noteworthy. First, the effect of the average size of a solar farm is not statistically significant. The interaction term between the average size of the solar farm and population density does not show a statistically significant coefficient either. This result suggests that the number of solar farms, rather than their average size, is more visually salient for residents. Second, a higher share of farmlands is associated with a lower risk of adopting the restriction: a 1 % point increase in the share of farmlands in a county year is associated with, on average, 0.9 times lower risk ($e^{-0.098\times1}$) of adopting it. This suggests that not all rural residents oppose solar farms. If rural residents own farmlands in their region, they may face incentives to sell those lands when utility firms offer higher benefits from what they gain from agricultural products. Therefore, it points to the possible heterogeneity across rural areas depending on how much they are dependent on the farming industry. Third, the winning margin is not associated with any significant change in the risk of adopting the restriction. This suggests that two main factors, high solar farm density and more ruralness of a county, were the main drivers of the restriction adoption, regardless of how responsive the government was. Lastly, GHI does not have any significant effect on the risk of adopting the restriction, indicating how much each county is endowed with solar radiation was not an important factor.

The main finding is consistent with additional evidence of landscape disruption by solar farms in South Korea, mainly through deforestation. Park et al. [46] have investigated 4450 solar farms (71.1km^2) that have gone through preliminary environmental impact assessment (EIA) from 2004 to 2018. They found that 60.9 % of these solar farm sites have replaced forest lands and 20 % have replaced farmlands, mainly in rural areas. The Member of the Parliament Yoon Han-Hong, drawing on the evidence from the Korea Forest Service Agency, has reported that the

[3] This model is also known as a discrete-time event history model, using either logit or complementary log-log (cloglog) regression. If logit link is used, this model is equivalent to the proportional odds model from which we obtain an odds ratio when exponentiating the coefficient estimates. If the cloglog link is used, we obtain a hazard ratio when we exponentiate coefficient estimates since the model is equivalent to the proportional hazards model. In this study, I use the cloglog link function based on the goodness of fit measure as discussed in Appendix A. Therefore, I report hazard ratios instead of odds ratios when interpreting the model results.

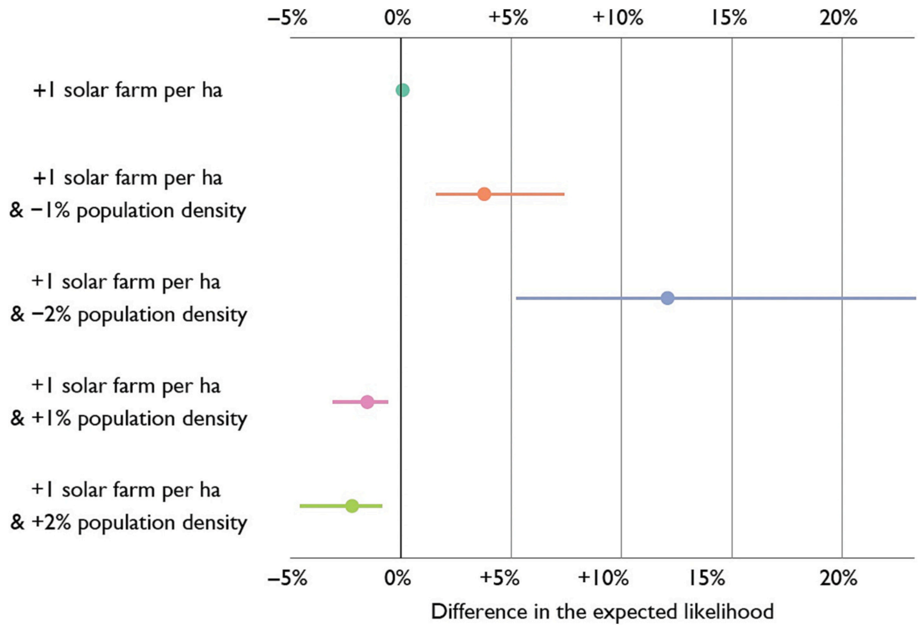

Fig. 2. Differences in the expected likelihood of adopting the restriction, each scenario vs baseline county.

size of forest lands replaced by solar farms was 6214 ha after 2014, as opposed to 289 ha before 2014.[4] Fig. 3 visualizes this replacement trend until 2019.

4. Interview research

The event history analysis demonstrates that rural counties with higher solar farm density are more likely to adopt the restriction on solar farms. But this finding alone cannot fully substantiate the claim that rural opposition to landscape change from solar farms was a key driver for the onset of setback restrictions. Therefore, I interviewed 13 residents and 14 local public officials in 10 rural and urban counties from July to September 2021. The purpose of interviews is to collect first-hand evidence of (1) whether landscape disruption from solar farms was a key motivation for rural residents to oppose them and (2) whether local opposition to landscape disruption motivated county government officials to implement setback restrictions.

I use the following coding scheme to distinguish among interviewees. All interviewees are identified with three letters, e.g., RA-1. The first alphabetic letter represents whether the interviewee is a resident (R) or a public official (P). The following letter represents the county, ranging from A to J. Finally, the number represents the ID of each interviewee arranged by order of interview dates. For instance, PF-9 indicates the 9th interview subject, a public official in F county. Residents include tenured farmers, fishers, and NGO officials. Local public officials include civil servants who are primary regulators of solar farm siting and public energy agency officials. Interview protocols received an IRB review in May 2021 (ID: STUDY00013287).

I used a snowball sampling method for the following practical but essential reasons. First, due to their increased awareness of the COVID-19 crisis, interviewees preferred in-person interviews with people they know. Therefore, I conducted an entry interview with a journalist based in Seoul, who could provide contact information for those living in rural areas. While one could arrange remote interviews to overcome this issue, most interviewees preferred talking in person as they needed more experience in video conferences. For these reasons, all interviews were in-person from July to September 2021.

Throughout the interviews, all residents agreed that solar farms drastically change their rural landscapes in an undesirable or unexpected way. When asked why they think their county needs the restriction, RC-4 and RC-5 have agreed that:

> “While most of the electricity flows to cities, solar farms are in forests and farmlands in rural areas, and they have no benefits for us. Also, we value our landscape and need to enjoy and feel nature, mountains, and the ocean. Because solar farms destroy our landscape, they do not meet our living conditions. We say no to solar farms because they are hideous objects (hyung-mul; 凶物).”

RJ-17 stated while referring to the solar farm sited alongside the road to a town:

> “Both sides of the road are all covered with PV panels. I feel suffocated. How could we live in this place? I know we cannot get any compensation for this agony, but for us (villagers living in the town), PV panels are right in front of our noses. It feels like there is a blade to our neck.”

When asked how their town started to host solar farms, RI-16 noted that:

> “When urban developers bring their solar farms, they cut down trees in mountains and fields and build fences around them. No people are left behind after they built solar farms. [...] They are not one of ours. They build solar farms here because the lands are cheap here. They do not communicate with us or seem to manage them properly. It feels like an infiltration to me.”

Residents who oppose solar farms in their vicinity did not feel they had the opportunity to meaningfully participate in the early planning process of solar energy projects. This could have precluded the possibility of revising proposals to alleviate their concerns over landscape change. Also, residents grew feelings of distrust towards solar energy developers when faced with the lack of participation in the planning process, labeling them as “urban developers” who do not belong to their community.

RD-7 pointed out that solar farms are not only visually incongruent

[4] Between 2012 and 2014, the South Korean government had granted a weight of 0.7 to renewable energy certificates (RECs) produced from solar farms sited in forest lands, disincentivizing solar energy developers to locate their solar farms in forest lands. However, in 2014, the government removed such disincentives, allowing more solar energy projects to target forest lands until 2018 when the government revived them.

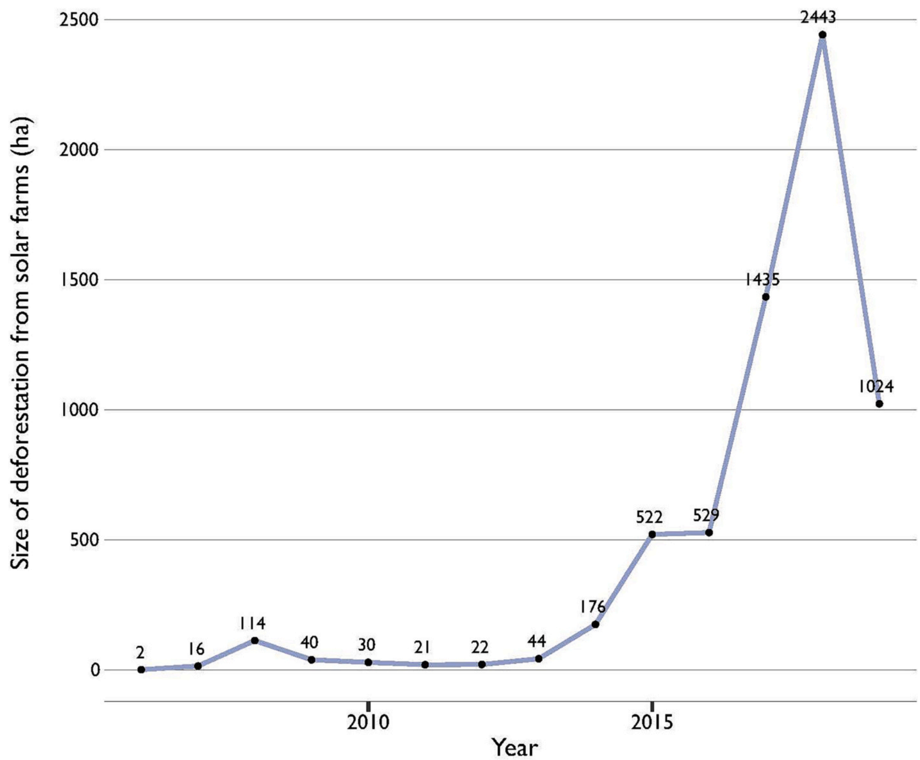

Fig. 3. Annual trend of deforestation from solar farms, 2006–2019.

with their rural landscapes but make their lives inconvenient. RD-7 shared an episode where solar farms changed local roads that villagers have shared and used together for a long time:

> "We (rural villagers) share roads because we must use ours and theirs to get to the farmland. I own some of these roads but let others use them too. We can use them together since we are a part of our community. But urban outsiders do not think about these norms. [...] They get rid of these roads after they purchase their lands."

This excerpt shows that the local road, a feature of the rural landscape which solar farms replaced, had been shared by residents for a long time to achieve the shared goal of "getting to the farmlands." Residents have perceived it was difficult to communicate the importance of these shared roads when solar farms change rural landscapes, either because their developers are outsiders or do not stay around the sites after they are built.

Interviews with public officials also confirmed that these rural oppositions to landscape change were a major concern for county governments, leading them to consider implementing setback restrictions on solar farms. All public officials in the four counties I interviewed have commonly identified that residents' opposition to solar farms was a key motivation for them to start working on the restriction. PG-11, for instance, has explained that as solar farms increased, more residents expressed visual distress from them, which gave administrative burdens for officials to mediate conflicts between residents and utility firms, along with burdens from issuing permits for their siting.

PF-9 mentioned that the setback restriction is a commonly used policy tool by county governments to deal with detested facilities, such as manure factories. When there is consistent public resistance to such facilities, county government officials might have found it useful to order them to keep distances from households or roads before careful assessment of their negative externalities. Moreover, a county government is the final authority for implementing and amending ordinances, whose autonomy is protected by the central government through the National Land Planning and Utilization Act. Therefore, county governments may stipulate setback restrictions in land-use ordinances as a cost-efficient and lawful measure to cater to local opposition to solar farms.

The interview with PH-14, however, offered an interesting point. While H County has had solar farm density higher than the average of all county governments in 2020, the county does not have the restriction up to date. Moreover, PH-14 firmly stated that they do not plan to. As of 2020, there were 47 county governments with restrictions but with fewer solar farms in their jurisdictions than H County. According to PH-14 interviewees:

> "We estimate around 20%- The fraction of total solar farms located in rural towns (affiliated to the city). The rest (80%) are built on the roofs of factories in industrial parks. Or on the roofs of individual houses. But among those in rural towns, most of them are located in industrial complexes. [...] There are almost no petitions from these solar farms."

It is important to note that H County is more characterized by urban than rural landscapes, due to its high level of industrialization with large manufacturing companies, with population density higher than the average of all counties (40-50th percentile). Therefore, the interview with PH-14 interviewee suggests that when urban landscapes characterize a county, a higher number of solar farms may not lead to higher opposition and therefore not a higher likelihood for the onset of the restriction.

In sum, interview research provides evidence that the positive association between solar farm density and the likelihood of adopting the restriction, as the event history analysis suggests, reflects the local opposition to landscape change from solar farms driving the restriction. Moreover, rural counties were more likely to face local opposition to landscape change, consistent with the earlier finding that rural counties were more likely to adopt the restriction when faced with high solar farm density.

5. Discussion and conclusion

This study is the first empirical research that explains a recent case in South Korea where local setback restrictions on solar farms have diffused across county governments. It shows that concerns around landscape disruption have shaped rural opposition to solar farms, which motivated local officials to consider setback restrictions. Specifically, the event history analysis shows that the number of solar farms has increased the likelihood of county governments adopting the restriction more greatly in rural than urban areas. Findings from interview research suggest that county governments have adopted the restrictions that restrict solar farm siting mainly as a response to these rural oppositions. I find consistent support from both qualitative and quantitative evidence to the argument that the negative impact of solar farms on the rural landscape was a key driver for the diffusion of setback restrictions on them in South Korea.

One can argue that since rural areas offer more available lands for solar farms to be sited than urban areas do, local setback restrictions are only relevant for rural areas. Yet, even urban areas can host smaller commercial solar farms that may still disrupt valuable urban landscapes, susceptible to local opposition. Take the example of Suwon City. It is home to 1.3 million population and hosts various historical sites such as the Hwaseong Fortress, built in 1796 by King Jeongjo of the Joseon Dynasty and designated as a World Heritage site by UNESCO in 1997. The city implements a setback restriction on solar farms which stipulates that "any solar energy facilities must be distanced by 100 meters from areas under the protection of Cultural Heritage Protection Act" (Suwon City Zoning Ordinance Art. 22(2)(3)). This stipulation implies that urban areas may implement setback restrictions on solar farms driven by concerns over their disruptive impacts on urban landscapes, particularly when their landscapes host historically and culturally valuable sites. It may also explain the case of H County discussed in Section 4 with over 1 million population with no setback restriction on solar farms even hosting a high level of solar farm installation, possibly because a majority of these solar farms are located on the rooftops of industrial complexes, providing a less disruptive impact on its landscape. The finding of this study, however, suggests that the landscape impact of solar farms is more salient in rural areas in South Korea, particularly because solar farms in rural areas tend to be utility-scale and therefore exhibit greater visual impacts.

This study joins a growing body of literature that focuses on how renewable energy facilities impact rural communities by changing their landscapes [47–50]. Yet, few studies examined the possible consequences of such changes and their implications for national renewable energy development. The case documented here suggests that local opposition to solar farms because of their disruptive impacts on the landscape threatens already proposed renewable energy projects and future ones. This is because local governments often do not have the capacity to effectively regulate renewable energy projects so that they protect the integrity of their surrounding landscape. When local opposition is left for local governments only to handle, they may resort to restrictive land-use policies against renewable energy projects. Therefore, a policy implication of this study is that central governments should provide active means to support local governments to mitigate the concerns of local residents over the potential negative impacts of renewable energy facilities. One possible area is implementing an a priori assessment of the landscape change from solar farms so that new projects ensure more inclusive participatory planning processes [51].

Several weaknesses of this study point to future research areas. First, due to the lack of data availability, this study could not test the direct effect of landscape change from solar farms on the likelihood of the onset of restrictions. Both interview research and event history analysis assume that solar farms have largely changed landscapes through deforestation in South Korea when they are sited in rural areas. Yet, there may be a possible variation across rural counties regarding how intrusive solar farms were to their surrounding landscapes. Future studies that link the impact of local costs from renewable facilities on local policy barriers against them should use more direct measures of such costs, such as the amount of deforestation solely attributable to solar farm siting or the loss of fish catch solely attributable to offshore wind power siting.

Because of the same issue, using variables in the event history analysis reveals some limitations. In the event history analysis, I used population density to indicate whether a county is more "rural" than "urban," which by itself does not capture the totality of "ruralness" [52]. To better capture the idea that more rural counties are likely to adopt the restrictions, one may use an indicator of ruralness constructed with various measures, such as population dynamics, industry, transportation, and distance [53]. Yet, due to the lack of county-level data for such variables, this paper only uses population density because rural areas typically have lower population density than urban areas.

Next, it fails to account for more various motivations for which rural residents oppose renewable facilities that previous studies have identified. For instance, Urpelainen [54] and Aklin et al. [55] find that rural villagers in India were largely concerned about exploitative business practices by solar energy firms, which highlights the potential effect of renewable energy injustice on rural acceptability of renewable facilities [56]. The sense of distributive injustice may also decrease rural support for renewable energy by affecting their trust in renewable facilities and their developers [57]. This implies that there are not only explicit motivations for opposing solar farms such as from landscape change but implicit ones which are difficult to examine with observational data. Therefore, future studies should benefit from individual-level or village-level survey research to explain which motivation best explains local policy outcomes against renewable facilities.

Declaration of competing interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

R code and data used in this research are publicly available on Harvard Dataverse: https://doi.org/10.7910/DVN/Z3S4EQ.

Acknowledgments

This research is funded by Peter May Graduate Research Grant from the Department of Political Science at the University of Washington, Seattle. The author wishes to thank all interview participants and Energy Transition Forum Korea for its assistance with coordinating interviews and field research. The author is grateful to the reviewers and editor of this journal for their thoughtful and constructive comments.

Appendix A

Table A1
Comparison of the discrete event history models.

	Model 1	Model 2	Model 3	Model 4
Outcome	1 if a county-year adopts the restriction; 0 if right-censored			
Solar farm density	0.123** (0.016)	0.141** (0.016)	0.095** (0.012)	**0.119** (0.013)**
Population density, logged	−0.602** (0.142)	−0.536** (0.158)	−0.615** (0.135)	**−0.530** (0.150)**
Average capacity per solar farm (kW)	0.000 (0.002)	0.000 (0.002)	0.000 (0.002)	**0.000 (0.002)**
Winning margin (%)	−0.013 (0.007)	−0.013 (0.008)	−0.012 (0.007)	**−0.013 (0.007)**
The share of farmlands (%)	−0.099** (0.022)	−0.104** (0.025)	−0.086** (0.019)	**−0.099** (0.023)**
GHI	0.001 (0.005)	−0.010 (0.008)	0.000 (0.005)	**−0.009 (0.007)**
Solar farm density × population density	−0.013** (0.002)	−0.015** (0.002)	−0.010** (0.002)	**−0.013** (0.002)**
Average capacity per solar farm × population density	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	**0.000 (0.000)**
Intercept	−0.285 (7.397)	14.105 (10.750)	0.196 (6.946)	**13.433 (10.345)**
Link function	Logit		Complementary log-log	
Spatial frailties	CAR	Matérn	CAR	Matérn
Maximum Likelihood	−289.35	−283.84	−285.12	−278.52
AIC	1197.41	1179.35	1180.48	1158.09
N (Number of events)	1776 (126)			

Note: Standard errors are reported in parentheses; **- p < .01, *- p < .05.

Another important factor for adopting restrictions is policy contagion. When residents in "A" county dislike solar farms, they may be alarmed if their neighboring counties adopt the restriction, as solar energy developers will avoid those areas and seek out other available counties, one of which may be "A" county. Therefore, there is a potential spatial autocorrelation in adopting the restrictions. One can use the dependent variable of contiguous counties (i.e. restrictions of counties that share borders) as an additional independent variable to account for this. However, spatial autocorrelation may be conditional on whether counties share borders and how close they are to each other. For instance, "A" and "B" counties may not share borders because there lies "C" county in between, but close enough to be affected by the presence of each other's restriction. Therefore, I let the model tell us how much spatial correlation varies depending on the distance between counties, not just their contiguity.

To account for this, I include Matérn random effects in the model which represent pairwise correlations calculated by the Matérn function at the scaled Euclidean distance between any paired observations. I used coordinate centroids for each county to calculate pairwise distances. Matérn random effects are easy to handle with piecewise event history analysis since it is identical to analyzing censored data with a generalized linear model where Matérn random effects have been commonly used. I show that the model that includes Matérn random effects provides consistent results with those that rely on contiguity assumption for incorporating spatial autocorrelation but shows a better fit to the data.

I compare the results of the main model (Model 4) with results from three other models (Model 1–3). Model 1 uses a logit link with conditional autoregressive (CAR) correlation to account for spatial autocorrelation, and Model 2 uses the same link with Matérn random effects. CAR correlation uses an adjacency matrix to account for the spatial autocorrelation between contiguous counties, and Matérn random effect does that using Euclidean distances between county centroids. Model 3 uses a complementary log-log (cloglog) link with CAR correlation, and Model uses the same link with Matérn random effects. All models obtain coefficient estimates of explanatory variables (fixed effects) via maximum likelihood (MLE) and random effect parameters by restricted maximum likelihood (REML). I used Akaike Information Criteria (AIC) to measure the goodness-of-fit which shows Model 4 outperforms the rest of the models (with bolded coefficients).

Fig. A1 visualizes the effect by plotting the estimated correlations against the Euclidean distance between counties. It shows that the correlation is higher when two counties are closer. This finding is consistent with the expectation that the presence of the restriction may affect the likelihood of closely located governments adopting the same.

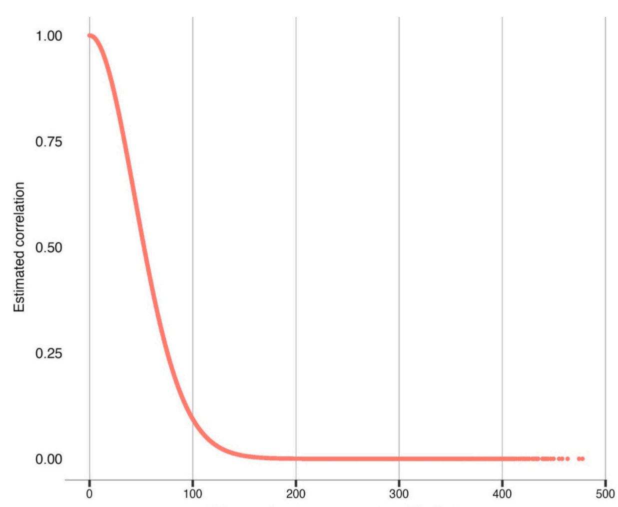

Fig. A1. Estimated spatial autocorrelation against Euclidean distance between county centroids.

References

[1] B.K. Sovacool, P. Schmid, A. Stirling, G. Walter, G. MacKerron, Differences in carbon emissions reduction between countries pursuing renewable electricity versus nuclear power, Nat. Energy 5 (2020) 928–935.

[2] B.K. Sovacool, P. Schmid, A. Stirling, G. Walter, G. MacKerron, Reply to: nuclear power and renewable energy are both associated with national decarbonization, Nat. Energy 7 (2022) 30–31.

[3] S. Khan, M. Murshed, I. Ozturk, K. Khudoykulov, The roles of energy efficiency improvement, renewable electricity production, and financial inclusion in stimulating environmental sustainability in the next eleven countries, Renew. Energy 193 (2022) 1164–1176.

[4] M. Murshed, B. Saboori, M. Madaleno, H. Wang, B. Doğan, Exploring the nexuses between nuclear energy, renewable energy, and carbon dioxide emissions: the role of economic complexity in the G7 countries, Renew. Energy 190 (2022) 664–674.

[5] E. O'Shaughnessy, R. Wier, B. Hoen, J. Rand, S. Elmallah, Drivers and energy justice implications of renewable energy project siting in the United States, J. Environ. Pol. Plan. (2022), https://doi.org/10.1080/1523908X.2022.2099365.

[6] X.S. Perez-Sindin, J. Lee, T. Nielsen, Exploring the spatial characteristics of energy injustice: a comparison of the power generation landscapes in Spain, Denmark, and South Korea, Energy Res. Soc. Sci. 91 (2022), 102682.

[7] L. Susskind, J. Chun, A. Gant, C. Hodgkins, J. Cohen, S. Lohmar, Sources of opposition to renewable energy projects in the United States, Energy Policy 165 (2022), 112922.

[8] K. Yenneti, R. Day, O. Golubchikov, Spatial justice and the land politics of renewables: dispossessing vulnerable communities through solar energy mega-projects, Geoforum 76 (2016) 90–99.

[9] E.M. Nkoana, Community acceptance challenges of renewable energy transition: a tale of two solar parks in Limpopo, South Africa, J. Energy South. Afr. 29 (1) (2018) 34–40.

[10] P. Roddis, S. Carver, M. Dallimer, P. Norman, G. Ziv, The role of community acceptance in planning outcomes for onshore wind and solar farms: an energy justice analysis, Appl. Energy 226 (15) (2018) 353–364.

[11] R. Kohsaka, S. Kohyama, Contested renewable energy sites due to landscape and socio-ecological barriers: comparison of wind and solar power installation cases in Japan, Energy Environ. (2022), https://doi.org/10.1177/0958305X221115070.

[12] D. Rudolph, J.K. Kirkegaard, Making space for wind farms: practices of territorial stigmatization in rural Denmark, Antipode 51 (2) (2019) 642–663.

[13] R. Bryce, Renewable rejection database. https://robertbryce.com/renewable-rejection-database/, 2022. (Accessed 26 October 2022).

[14] F. Reusswig, F. Braun, I. Heger, T. Ludewig, E. Eichenauer, Against the wind: local opposition to the german energiewende, Util. Policy 41 (2016) 214–227.

[15] H. Aidun, J. Elkin, R. Goyal, K. Marsh, N. McKee, M. Welch, L. Adelman, S. Finn, Opposition to Renewable Energy Facilities in the United States: March 2022 Edition, Sabin Center for Climate Change Law, 2022. https://scholarship.law.columbia.edu/sabin_climate_change/186/. (Accessed 26 October 2022).

[16] National Renewable Energy Laboratory, U.S. wind siting regulation and zoning ordinances, in: Open Energy Data Initiative, 2022, https://doi.org/10.25984/1873866.

[17] National Renewable Energy Laboratory, U.S. solar siting regulation and zoning ordinances, in: Open Energy Data Initiative, 2022, https://doi.org/10.25984/1873867.

[18] E. Peri, A. Tal, Is setback distance the best criteria for siting wind turbines under crowded conditions? An empirical analysis, Energy Policy 155 (2021), 112346.

[19] A. Prakash, N. Dolšak, Three faces of climate justice, Ann. Rev. Polit. Sci. 25 (2022), 12.1-12.19.

[20] L.C. Stokes, Electoral backlash against climate policy: a natural experiment on retrospective voting and local resistance to public policy, Am. J. Polit. Sci. 60 (4) (2016) 958–974.

[21] M. Enserink, R. Van Etteger, A. Van den Brink, S. Stremke, To support or oppose renewable energy projects? A systematic literature review on the factors influencing landscape design and social acceptance, Energy Res. Soc. Sci. 91 (2022), 102740.

[22] R. Ioannidis, D. Koutsoyiannis, A review of land use, visibility, and public perception of renewable energy in the context of landscape impact, Appl. Energy 276 (2020), 115367.

[23] M. Šťastná, A. Vaishar, Values of rural landscape: the case study chlum u Třeboně, Land Use Policy 97 (2020), 104699.

[24] M. Agnoletti, Rural landscape, nature conservation and culture: some notes on research trends and management approaches from a (southern) european perspective, Landsc. Urban Plan. 126 (2014) 66–73.

[25] A. Jorgensen, Beyond the view: future directions in landscape aesthetics research, Landsc. Urban Plan. 100 (4) (2011) 353–355.

[26] T. Simensen, R. Halvorsen, L. Erikstad, Methods for landscape characterization and mapping: a systematic review, Land Use Policy 75 (2018) 557–569.

[27] R. Wüstenhagen, M. Wolsink, M.J. Bürer, Social acceptance of renewable energy innovation: an introduction to the concept, Energy Policy 35 (2007) 2683–2691.

[28] A. Brock, B.K. Sovacool, A. Hook, Volatile photovoltaics: green industrialization, sacrifice zones, and the political ecology of solar energy in Germany, Ann. Assoc. Am. Geogr. 111 (6) (2021) 1756–1778.

[29] D. Apostol, J. Palmer, M. Pasqualetti, R. Smardon, R. Sullivan, The Renewable Energy Landscape: Preserving Scenic Values in our Sustainable Future, Routledge, New York, NY, 2017.

[30] N. Kaza, The changing urban landscape of the continental United States, Landsc. Urban Plan. 110 (2013) 74–86.

[31] D.-J. van de Ven, I. Capellan-Peréz, I. Arto, I. Cazcarro, C. de Castro, P. Patel, M. Gonzalez-Eguino, The potential land requirements and related land-use change emissions of solar energy, Sci. Rep. 11 (2907) (2021) 1–12.

[32] M. Wolsink, Co-production in distributed generation: renewable energy and creating space for fitting infrastructure within landscapes, Landsc. Res. 43 (4) (2018) 542–561.

[33] J.A. Sward, B.S. Nilson, V.V. Katkar, R.C. Stedman, D.L. Kay, J.E. Ifft, K.M. Zhang, Integrating social considerations in multicriteria decision analysis for utility-scale solar photovoltaic siting, Appl. Energy 288 (2021), 116543.

[34] K.M. Johnson, C.L. Beale, The recent revival of widespread population growth in nonmetropolitan areas of the United States, Rural. Sociol. 4 (1994) 655–667.

[35] J. Crowe, Economic development in the nonmetropolitan west: the influence of built, natural, and social capital, Community Dev. 39 (4) (2008) 51–70.

[36] G. Domon, Landscape as resource: consequences, challenges and opportunities for rural development, Landsc. Urban Plan. 100 (4) (2011) 338–340.

[37] D.A. McGranahan, Landscape influence on recent rural migration in the U.S, Landsc. Urban Plan. 85 (2008) 228–240.

[38] M.I. Dröes, H.R.A. Koster, Wind turbines, solar farms, and house prices, Energy Policy 155 (2021), 112327.

[39] D.J. Hess, R.G. McKane, C. Pietzyrk, End of the line: environmental justice, energy justice, and opposition to power lines, Environ. Polit. 31 (4) (2022) 663–683.

[40] D.L. Bessette, S.B. Mills, Farmers vs. lakers: agriculture, amenity, and community in predicting opposition to United States wind energy development, Energy Res. Soc. Sci. 72 (2021), 101873.

[41] S. Park, S.-J. Yun, Opposition to and acceptance of siting solar power facilities from the place attachment viewpoint, ECO 2 (22) (2018) 267–317.

[42] E.-S. Kim, J.-B. Chung, Y. Seo, Korean traditional beliefs and renewable energy transitions: pungsu, shamanism, and the local perception of wind turbines, Energy Res. Soc. Sci. 46 (2018) 267–273.

[43] C.Y. Park, S.H. Han, K.-W. Lee, Y.M. Lee, Analyzing drivers of conflict in energy infrastructure projects: empirical case study of natural gas pipeline sectors, Sustainability 9 (11) (2017) 2031.

[44] J.M. Box-Steffensmeier, B.S. Jones, in: Event History Modeling: A Guide for Social Scientists, Cambridge University Press, Cambridge, MA, 2004, pp. 69–83.

[45] R.E. Hogan, Policy responsiveness and incumbent reelection in state legislatures, Am. J. Polit. Sci. 52 (4) (2008) 858–873.

[46] J.Y. Park, Y.J. Lee, W.S. Lee, B.K. Lee, Status of photovoltaic power plant installation projects proceeded through EIA and its environmental discussion, Korea Environmental Institute, 2018. https://www.kei.re.kr/elibList.es?mid=a10101000000&elibName=researchreport&class_id=&act=view&c_id=721887&rn=231&nPage=24&keyField=&keyWord=. (Accessed 26 October 2022).

[47] R. Phadke, Resisting and reconciling big wind: middle landscape politics in the new american west, Antipode 43 (2011) 754–776.

[48] M. Jefferson, Safeguarding rural landscapes in the new era of energy transition to a low carbon future, Energy Res. Soc. Sci. 37 (2018) 191–197.

[49] M. Naumann, D. Rudolph, Conceptualizing rural energy transitions: energizing rural studies, ruralizing energy research, J. Rural. Stud. 73 (2020) 97–104.

[50] K. Calvert, E. Smit, D. Wassmansdorf, J. Smithers, Energy transition, rural transformation and local land-use planning: insights from Ontario, Canada, Environ. Plan. E 5 (3) (2022) 1035–1055.

[51] R. Ioannidis, N. Namassis, A. Efstratiadis, D. Koutsoyiannis, Reversing visibility analysis: towards an accelerated a priori assessment of landscape impacts of renewable energy projects, Renew. Sust. Energ. Rev. 161 (2022), 112389.

[52] M.J. Beynon, A. Crawley, M. Munday, Measuring and understanding the differences between urban and rural areas, Environ. Plan. B 43 (6) (2016) 1136–1154.

[53] B. Waldorf, A. Kim, The Index of Relative Rurality (IRR): US County Data for 2000 and 2010, Purdue University Research Repository, 2018, https://doi.org/10.4231/R7959FS8.

[54] J. Urpelainen, Energy poverty and perceptions of solar power in marginalized communities: survey evidence from Uttar Pradesh, India, Renew. Energy 85 (2016) 534–539.

[55] M. Aklin, C.-Y. Cheng, J. Urpelainen, Social acceptance of new energy technology in developing countries: a framing experiment in rural India, Energy Policy 113 (2018) 466–477.

[56] B.K. Sovacool, Who are the victims of low-carbon transitions? Towards a political ecology of climate change mitigation, Energy Res. Soc. Sci. 73 (101916) (2021) 1–16.

[57] G. Walker, P. Devine-Wright, Trust and community: exploring the meanings, contexts and dynamics of community renewable energy, Energy Policy 38 (6) (2010) 2655–2663.