Unintended consequence of renewable energy injustice? Local opposition to renewable energy and the diffusion of local regulations against solar panels in South Korea

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Abstract

This paper surveys one possible unintended consequence of market-based renewable energy policies that exploit and perpetuate inequalities between rural and urban areas: The diffusion of local regulations against renewable energy. I examine a puzzling case of South Korea where the central government actively promotes national renewable energy development while more than a half of local governments have implemented regulations that largely restrict siting of solar panel facilities. Using a mixed-methods approach, I argue that market-based instruments such as renewable energy portfolio encouraged market actors to penetrate into rural areas which facilitated the process of entrenchment. This fueled local oppositions to which local governments responded by blocking solar panels from being sited in their jurisdictions through local legislation. This implies that the use of market-based policy instruments needs a careful consideration for their energy justice implications especially when a rural-urban divide is deeply ingrained in a larger social context.

Keywords: energy justice, renewable energy development, entrenchment, market-based instrument, rural-urban divide, unintended consequence

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1 Introduction

The global race toward net-zero emission targets, especially after the adoption of 2018 Intergovernmental Panel on Climate Change (IPCC) report, has fueled low-carbon renewable energy development across a number of countries. This rapid turn, though applaudable, is often plagued with the lack of consideration for the energy justice implications of climate change mitigation (Banerjee et al., 2017; Sovacool, 2021). Case studies reveal that renewable energy development in a wider range of spatial locations follows a similar trajectory with an industrial growth model (Brock, Sovacool and Hook, 2021), which has disproportionately impacted local communities and politically, economically and socially marginalized groups, potentially leading to severe local conflicts. Without fully considering these dimensions of energy injustice, local conflicts may not only derail local renewable energy projects but drive renewable energy development to a bumpy road.

While much literature has examined energy justice issues in renewable energy development cases mainly in the Western world (Mulvaney, 2013; Sovacool, 2021; Levenda, Behrsin and Disano, 2021; Batel, 2020), renewable energy policies that fail to account for them are commonly observed around the globe (Yenneti and Day, 2015; Fathoni, Setyowati and Prest, 2021), and their consequences should not be ignored. This paper surveys one possible consequence of local opposition to renewable energy technology (RET) which is the diffusion of local regulations that prohibit its siting through the case of South Korea. In May 2017, newly elected South Korean president Moon Jae-in announced the nationwide renewable energy development scheme called "Renewable 3020 Action Plan (hereafter "3020 Action Plan")," which aimed to increase the share of renewable energy in total electricity production from 7.6% in 2017 to 20% by 2030. The main policy tool to achieve this is the renewable portfolio standard (RPS), which incentivizes market actors to produce electricity from renewable energy sources by allowing sales based on system marginal prices (SMP) and renewable energy certificate (REC) prices. Yet, as of 2020, more than half of local governments in South

Korea have introduced local regulations that prohibit siting solar power[1] facilities based on distances from roads, arable lands, and other facilities. These siting regulations against solar power facilities drastically diminish the available area for their installation, even to less than 1% of the total area in some jurisdictions (Kwon, Kim and Jo, 2020). Facing the diffusion of local regulations, the share of renewable energy in total electricity production has slightly decreased from 8.3% in 2018 to 8.13% in 2019.

Although the main question is why local *governments* decided to implement local siting regulations, narrowing the scope only to government actors misses a broader picture of this puzzling case. I argue the diffusion occurred due to the failure of the South Korean government in understanding and resolving local opposition to solar panels, which poses a serious challenge to its ambitious renewable energy plan. The 3020 Action Plan with market-based policy tools encouraged public and private renewable energy businesses in urban areas which largely lack knowledge of needs and desires of local communities to hastily penetrate into rural areas for available lands with lower rents to site solar power facilities. This has led to numerous conflicts between local residents and renewable energy businesses, particularly between 2017 and 2020, deepening the rural-urban divide and spatial injustices (Brock, Sovacool and Hook, 2021). Local governments, unable to find an effective mechanism from above to solve these conflicts, resorted to local siting regulations to prevent new solar energy projects from crowding into their jurisdictions. As renewable energy businesses have sought out local jurisdictions which did not have regulations to site their facilities, local governments quickly followed their neighbors to implement regulations for fear of further local conflicts (spillover effect). In other words, the diffusion of local siting regulations was an unintended consequence of the renewable energy development policy in South Korea which did not take into careful consideration on how local conflicts can be fueled by inequalities RETs can exploit and deepen. This has a serious implication on net-zero emission targets and policies recently proliferating around the world. If these targets do not consider the

[1] In this paper, I refer to the photovoltaic power as solar power, although the term "solar" includes not only photovoltaic but solar thermal power.

potential of energy injustice into policy instruments designed to achieve them, increasing local opposition can translate into actual policy barriers such as the diffusion of anti-renewable energy regulations in a local level.

I test this argument with a mixed-methods approach. First, I examine a general pattern of diffusion with a Cox proportional hazard model with data from 205 local governments from 2005 to 2019. Next, I conduct a field research and interview in rural areas to further examine the causal mechanism between local conflicts and the adoption of regulations. As the field interview is scheduled in June of this year, however, I will show the preliminary result of the former. For this end, Section 2 provides a comparative review of literature that explained why local opposition to renewable energy development takes place, and Section 3 applies the political economy framework of energy injustice (Sovacool, 2021) to the case of local renewable energy conflicts in South Korea. Section 4 concludes by discussing my preliminary findings and their implications.

2 Local renewable energy opposition: a debate

Batel (2020) explains that literature on local renewable energy opposition has followed three waves. The first approach draws from "Not-In-My-Back-Yard" (NIMBY) framework, which explains that residents living nearby renewable energy facilities oppose their situation because they are detested and divisive facilities. Scholars who found this framework useful have often emphasized that in various countries while the general public supports the expansion of RETs, local populations living near these facilities remain largely opposing to them (Devine-Wright, 2005).

Despite its wide use to date, the NIMBY framework has several flaws. First, it shares the view that renewable energy businesses and supporters of renewable energy development have toward what they call "NIMBY attitudes" of residents as "parochial" and "self-interested" (Konisky, Ansolabehere and Carley, 2020), which makes the framework fail to take into account their needs and desire under different contexts. Second, the NIMBY framework views locations where local opposition arises as "sites" or "backyards," not "places" to which residents often have strong emotional and historical attachment (Hidalgo and Heranadez, 2001; Devine-Wright, 2013). Third, it predicts local opposition to arise only if renewable energy facilities are large and intrusive enough to cause detestation and perception of hazard, which largely ignores cases where even a small-sized facility becomes a source of local opposition. Lastly, this approach tends to equate residents with renewable energy producers in terms of their political and economic leverage, which is not true in most cases of local backlash (MacArthur, 2016). Rather, local conflicts reflect pre-existing inequalities that are deeply embedded in a larger societal context.

The second wave of literature consists of studies which do not view renewable energy businesses and local communities are in a leveled playing field. These studies acknowledge that renewable energy projects have negative impacts on local communities and residents, hence focus on how to mitigate negative impacts such that they can "accept" those projects to be sited through the concept of "social acceptance" or "public acceptance" (Wüstenhagen, Wolsink and Bürer, 2007). In this literature, commonly identified negative impacts are degradation of local environmental quality and perceived potential health risks from renewable energy facilities (Upreti and Horst, 2004), which originate from the lack of political participation in the planning process (i.e., procedural justice) (Hoen et al., 2019) and unfair share of profits from projects (i.e., distributional justice) (Cowell, Bristow and Munday, 2011; Musall and Kuik, 2011).

Despite the fact that the second wave of literature takes a more nuanced approach to local opposition than its first wave, this strand of literature has offered policy suggestions that have several limits. Studies that suggest a stronger consideration for procedural justice hardly account for the fact that pre-existing political, economic and social inequalities between renewable energy businesses and local communities make it hard for residents to be as meaningful political actors (Aitken, 2010). For instance, public engagement in the planning process of renewable energy projects often starts by "information provision" to residents living near the siting areas. However, some of those efforts end up giving a one-way flow of information, which reveals that the idea to "educate" residents about highly complex technical components of the projects is a mere illusionary form of (non)participation (Arnstein, 1969). Also, the power differential between project managers (e.g., private firms or government actors) and local population (e.g., individualized citizens or community groups) prevents various forms of public engagement or deliberation in the planning process from giving residents more agency or opportunities to have their voices (Healey, 2003; Lennon, Dunphy and Sanvicente, 2019). Therefore, although local communities may be present in the planning process, they largely remain as passive actors understood as those who "should accept" the projects in the long run.

Also, studies that support a stronger incorporation of distributional justice often rely on willingness to pay (WTP) framework to set a fair but also "optimal" amount of financial compensation (Moula et al., 2013; Liu, Wang and Mol, 2013; Kim, Lee and Koo, 2020). However, they are at risk of translating these negative impacts into economic costs with which they are hardly commensurable. Moreover, local conflict financial compensation to those disproportionately impacted by renewable energy facilities can lead to their co-optation, widening the gap between impacted groups and renewable energy producers (Bell, Gray and Haggett, 2005).

The third wave of literature, which Batel (2020) calls "a critical approach to people's responses to RET," acknowledges that renewable energy projects have serious energy justice implications. This means that renewable energy projects not only mainly impact those who are politically, economically and socially marginalized in the society, but can also make them marginalized further. In other words, renewable energy projects have not only "negative" but "disproportionate" impacts on marginalized groups. The political ecology framework of energy injustice proposed by (Sovacool, 2021) effectively captures these disproportionate impacts through conceptualizing four processes of renewable energy development: *enclosure,* *exclusion, encroachment*, and *entrenchment*.

First, enclosure refers to the process where public assets are appropriated by private institutions, particularly business actors, in the process of planning and demonstrating renewable energy projects. It is intensified when private actors penetrate into rural or peripheral areas from which they can extract profits from renewable energy projects. Second, exclusion resonates with social acceptability studies that criticize the lack of procedural justice in renewable energy projects, which refers to "unfair planning, policymaking, or lack of presentation, recognition, and due process" (Sovacool, 2021). This includes not only the lack of representation of those physically included in the planning process but that of those (in)deliberately excluded. Enclosure and exclusion reinforce each other: The lack of representation by local population accelerates the exploitation of local assets by private institutions, which further marginalizes their political agency (Heynen and Robbins, 2005). Third, encroachment relates to the process in which renewable energy projects undermine environmental quality and natural ecosystems. As climate change mitigation policies often prioritize human survival, they downplay the value and the profound role of nonhuman nature (Wuerthner, Crist and Butler, 2014).

Lastly, entrenchment, which I understand as a core concept in the political ecology framework of energy injustice, refers to the process in which renewable energy projects deepen and perpetuate various inequalities ingrained in the society. As the term suggests, entrenchment refers to the case where all three processes discussed earlier can be "entrenched" or fortified: Enclosure deepens the gap between urban renewable capitalists and rural agricultural workers; exclusion deepens the gap between political elites and underrepresented groups; and encroachment deepens the gap between human and nonhuman actors.

I contend that the process of entrenchment is accelerated when the government uses market-based policies to expand renewable energy projects in the context of the serious rural-urban divide (Brock, Sovacool and Hook, 2021). Market-based policies encourages private institutions to take the lead in renewable energy development who seek out lands with "cheaper" rents to maximize their profits from renewable energy projects. This incentivizes their penetration from urban into rural areas (enclosure). Residents in rural areas face with lower political agency, along with the lack of expertise, than these market actors empowered by market-based policies (exclusion). Also, renewable energy facilities like solar panel plants require larger areas than traditional fossil fuel power plants to be installed, which lead to more dispersed transformation of local wild landscapes (encroachment). These processes are not only exploiting the rural-urban inequality but perpetuating it (entrenchment).

3 Identifying entrenchment in renewable energy development in South Korea

I apply the political economy framework of energy injustice to analyze how entrenchment occurred in the process of renewable energy development in South Korea. The expansion of renewable energy projects since 2010 demonstrates the pattern of entrenchment by market-based renewable energy policies under the rural-urban divide. I discuss the various dimensions of rural-urban divide in South Korea and how it was further entrenched by its renewable energy policy, which faced its unintended consequence of the diffusion of local siting regulations.

3.1 Two dimensions of the rural-urban divide in South Korea: inter-class and inter-generational inequalities

The rural-urban divide entails not only inter-class but also inter-generational inequalities. First, in the eyes of Marxist ecologists, renewable energy development unveils uneven power relations between urban capitalists and rural agricultural workers (Newell and Cousins, 2015). This inter-class conflict is pervasive in rural-urban divide in South Korea as well. During 1960s and 1970s when South Korea started to recover from post-war deterioration and achieve rapid economic growth, the government heavily relied on labor-intensive manufacture industry which was predicated upon the "squeezing" of the agricultural sector (Moore, 1984-1985). The South Korean government in these periods strove to depreciate domestic grain prices through massive imports of American grain, most of which was provided on concessionary terms. This enabled the government to lower the reproduction costs and therefore wage levels, and continue a supply of new urban laborers from rural areas who had suffered poorer material conditions of farming due to lower grain prices (Moore, 1984-1985). Although president Park Jung-hee, a military junta leader, sought to reduce the rural-urban gap through his aggressive policy called "Saemaul Movement," the gap became further widened when the government embraced neo-liberal economic policies. Shin (2014) explains that the opening of international agricultural markets in the 2000s has negatively impacted the South Korean farmers with less international comparative advantage due to their small-scale farmlands.

Second, experiencing a rapid economic growth in 1980s and 1990s, rural communities observed a large population of their young generation to migrate to urban areas for better education and employment opportunities. Demographic observations clearly show this trend.[2] In 2019, the share of total population over the age of 65 in the Seoul Metropolitan area[3] was 13.03%, while that in the rural area[4] was 18.51%. In the same year, there was a net influx of 94,190 in their 10-30s from rural to urban areas, in contrast to a net influx of 12,287 in their 40-70s from urban to rural areas. This inter-generational divide has contributed to widening the gap in information and digital literacy between rural and urban areas in South Korea (Moon et al., 2012; In et al., 2016).

[2]KOSTAT, http://kostat.go.kr/portal/eng/index.action (Last access on March 17th, 2021)

[3]Includes two cities (Seoul and Incheon) and one province (Gyeonggi) which make up the Seoul Metropolitan Area

[4]Includes 7 provinces (Gangwon, Chungbuk, Chungnam, Jeonbuk, Jeonnam, Gyungbuk, Gyungnam)

3.2 South Korean renewable energy policy and its entrenchment effect

The Action Plan which was announced in December 2017 clearly addresses that RPS will be actively used as its main tool to expand renewable energy production. RPS or renewable energy standard (RES) is a policy instrument that requires electricity suppliers to produce a certain share of their electricity from renewable energy sources. Since its first introduction in 2012, there are 22 electricity suppliers in South Korea which are regulated by RPS as of 2020, the sum of which should be produced from renewable energy sources amounts to 31.402 TWh, about 6.03% of the total electricity consumption in 2019 (520.5TWh).[5] The Action Plan plans to increase the required share of electricity production from renewable energy sources to meet its target of producing 20% of the total energy production from renewable energy sources by 2030.

RPS is often supplemented by market-based policy instruments such as renewable energy certificates (RECs). RECs are issued to renewable energy companies based on the amount of electricity they produced from renewable energy sources, and "weights" added to that amount. These weights vary depending on the type of facilities and sources of renewable energy the government aims to further incentivize. Renewable energy companies can first sell their electricity production at a system marginal price (SMP) and further benefit by selling these RECs to RPS[6].

RPS supplemented with REC is one of the widely used policy instruments that rely on the market mechanism through price signals (Polzin et al., 2019). Under this policy scheme, market actors producing and sell electricity from renewable energy sources are considered as a main driver of national renewable energy development. This policy scheme, however, risks creating various energy injustice issues, particularly perpetuating the process of entrench-

[5] The 9th Basic Plan of Long-Term Electricity Supply and Demand in South Korea (2020-2034), announced in December 2020.

[6] Therefore, the total profit that renewable energy companies can earn by selling RECs to RPS producers is calculated by (SMP + REC $\times$ Weight), multiplied by the amount of renewable electricity produced.

ment for the following reasons.

First, market-based renewable energy policies use economic incentives to encourage private institutions to produce renewable energy, whose primary concern is to maximize their profits. For this aim, private actors strive to lower their costs for renewable energy production which compels them to seek out large available areas with cheaper rents to site their facilities. Therefore, these policies accelerate penetration of private actors largely based in urban areas to rural areas of which lands are abundant and cheaper than those in urban areas. This implies that market-based policies can reinforce the process of *enclosure* of rural population by urban-based private institutions, and causing entrenchment by perpetuating this process.

Second, as their primary motivation is to seek profits from renewable energy, private institutions often face difficulty in interacting with rural residents and local communities who often possess different value systems. Being outsiders at large, private renewable energy companies lack knowledge of the history, culture, and values cherished by local communities (Park and Yun, 2018). Since long-term planning process means increasing opportunity costs, private companies view rural residents who oppose renewable energy projects as “obstacles” or “barriers,” delaying the payback of their investment in projects. The lack of consideration on the needs and values of local communities in the siting locations, therefore, can prevent their full engagement and representation throughout the participation, consultation, or deliberation in the planning process of renewable energy projects, all of which lead to the process of *exclusion*.

4 Discussion on preliminary findings and future research

While not discussed here in depth for the scope of this paper, my preliminary finding supports the argument that the process of entrenchment caused by the primacy on market-based policy instruments in the Action Plan 3020 has fueled local oppositions in various rural areas of South Korea, which contributed to the diffusion of local siting regulations against solar energy projects. Cases of entrenchment are evident in various incidents of local opposition, for instance, where agricultural peasants had to leave their farmlands lent by the government when it decided to site solar panel facilities on those lands (e.g., Hyul-do landfill area in Haenam-gun, Jeonnam province).[7] Local governments faced administrative burdens and the lack of institutional mechanisms to resolve these local conflicts, a majority of which chose to significantly reduce the available areas for solar panels to be sited in their jurisdiction through implementing distance-based local regulations. Stratified Cox proportional hazard model with data of 206 local governments from 2005 to 2019 also supports the spillover effect by showing that a local government was more likely to adopt the local regulation when neighboring governments had adopted it last year. I present the results in detail in Appendix A of this paper.

The diffusion of local siting regulations provides various implications for future policy and studies of energy injustice renewable energy development. First, if market-based policy instruments are not supplemented by institutional mechanisms that identify and resolve their possible entrenchment effect, they are at risk of spreading nation-wide local opposition to renewable energy development. Not only would it undermine the social "acceptability" of RETs but also create unintended consequences such as local legislation against renewable energy projects themselves, which prevents the central government from promoting national climate change mitigation. This means ambitious net-zero emission targets spreading over the world may become more onerous to be achieved. Rather than regarding local opposition as "policy barrier," policymakers and private actors should form a deeper understanding of its origins, implications of energy injustice in climate change mitigation, and prioritize deliberative processes with rural residents and local communities when planning renewable energy projects.

[7] http://www.ikpnews.net/news/articleView.html?idxno=41155 (in Korean, Last access on March 17th, 2021

Second, a similar unintended consequence can occur or might have already taken place in countries where the government intensively relies on market-based policy instruments to promote national renewable energy development and at the same time rural-urban divide is severe. As shown in the case of South Korea, the scope and the extent of rural-urban divide reflects a country-specific context which entails various inequalities pre-existing in the society. Future studies can benefit by looking at how different rural-urban divides are exploited by market-based policy instruments, particularly in the Global South or non-Western countries.

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A Cox proportional hazard analysis

This appendix briefly explains data, methods and results of the Cox proportional hazard model used to explain what factors influenced the likelihood of adopting a local siting regulation against solar panels by local governments in South Korea.

A.1 Research hypotheses

I argue that more solar energy projects in a local jurisdiction increase local resistance against solar panels, which increases the likelihood of implementation of a local siting regulation. However, their effect on the likelihood may vary depending on their size. Solar energy projects with larger power capacity in rural areas are more likely to be initiated by private businesses in urban areas as they require more technical expertise and capital investments. This implies that larger projects can cause more enclosure and exclusion. Also, larger projects are more visible than smaller projects as they require larger areas and solar panels to be sited, which makes encroachment more likely. Therefore, the number of larger projects in a local jurisdiction will more likely increase the likelihood of implementing a local siting regulation by the local government than the number of smaller projects. In this paper, I classify projects with power capacity less than 100kw as smaller projects, and those with power capacity of 100kw and over as larger projects.[8] I derive two hypotheses from this conjecture:

1. *Local governments where more larger projects are approved will more likely implement a local siting regulation against solar energy panels than those with larger projects less*

[8] One can offer a different typology of solar projects based on their size referring to the threshold under which projects should be approved by either lower-level government or upper-level government. For instance, while Chungbuk and Gangwon province requires projects to be approved by upper-level (provincial) government that are over 100kw, other provinces have set different thresholds, such as Gyeongbuk which has set 1,000kw as its threshold. Given that each province, however, has set different thresholds at different periods, for the benefit of quantitative analysis I maintain the threshold of 100kw to differentiate between small and large projects. This typology does not undermine, however, the internal validity of my argument, as patterns identified in two reasons that I discussed above generally follow the 100kw threshold. I do not examine the impact of projects over 3,000kw on the likelihood of adopting local restrictions due to the lack of availability for data.

approved.

2. *The number of smaller projects approved in a local jurisdiction will have no significant effect on the likelihood.*

I offer an additional argument for the likelihood of implementing a local regulation which is a spillover effect. A brief case study of Mu'an, one of the local governments in South Korea, demonstrates this effect (Lim and Yun, 2019). Before implementing the local siting regulation, the local government of Mu'an had a non-binding guideline for distance-based siting regulation of solar panels. When it abolished the guideline in August 2017, however, it faced with over 1,000 new proposals for solar projects only in three months, intensifying local conflicts surrounding solar panels. Mu'an local government responded to these crowding projects by introducing a legally-binding local siting regulation in 2018. This shows that solar companies can strategically find locations where restrictions do not exist. When local governments are rushing toward placing new restrictions, those without restriction are at higher risk of more approval requests of solar projects, which will impose additional burdens on them for managing new projects as well as mediating local conflicts. Therefore, I further hypothesize that:

3. *The likelihood of implementing a local regulation by a local government increases when more of its neighboring local governments have implemented it in the last year.*

A.2 Data and methods

To test these three hypotheses, I use a novel time-series cross-sectional data of all approved solar panel projects in 205 lower-level (local) governments from 2005 to 2019.[9] Although the

[9] To give a better understanding of the local governance system, South Korean government has 15 upper-level governments that are either Metropolitan Cities or Provinces, e.g. Seoul Metropolitan City or Gangwon Province, and 226 lower-level governments that are affiliated with each of the upper-level governments. Sejong City and Jeju Province are treated as special autonomous governments whose local governments within their jurisdiction do not have the same authority as 226 lower-level governments. For instance, there are no elected officials for lower-level governments in Jeju Province after 2006. In the following, I will interchangeably use "local" and "lower-level."

total number of lower-level governments in South Korea is 226, there are missing observations for solar panel projects in 21 lower-level governments. The outcome variable is a binary variable which indicates whether a lower-level government in each year has a local regulation with distance-based restrictions for siting solar energy projects passed by its local legislative body. I model the probability of adopting this local regulation using a Cox proportional hazard model (Cox, 1972; Box-Steffensmeier and Jones, 2004) with various specifications I discuss below.

I use four explanatory variables related to the number of solar energy projects. The first set of two variables is about small-sized solar projects. I measure the number of small-sized projects newly approved by lower-level governments in each year as well as the number of total projects approved up to each year. The second set is about large-sized solar projects which also uses the same measurements for two other variables. These sets of variables capture how many solar projects were approved newly in each year and have been approved by each year for each government, by their capacity. There is an interesting variation to look at between the number of projects approved and projects initiated (Stokes, 2016). However, most of the observations for the initiated projects are either missing or not up-to-date, which makes this study focus on the approved projects first. I add one more explanatory variable which is the number of local laws adopted by neighboring lower-level governments affiliated to the same upper-level government of a given government each year. This is to examine whether the spillover effect was at play in explaining the diffusion of local restrictions.

The first component of the data considered for the model specification is the variation in socioeconomic and institutional characteristics among lower-level governments based on their affiliation to Metropolitan City (in this case, lower-level governments are called as "Gu", which means district) and to the Province (in this case, lower-level governments are called as "Si" or "Gun," which mean city or county) such as population, median age, the level of urbanization, etc. Also, as I discussed earlier, many solar companies prefer rural to urban areas to site their projects due to lower rents, if not all. Therefore, lower-level governments under the Provinces which are mainly rural areas have been exposed to solar energy projects for a longer period of time than those under the Metropolitan cities which are mainly urban areas. This can lead to the different baseline hazard function to explain the likelihood of implementing local restrictions on solar projects. Therefore, **Model 1** estimates a Cox proportional hazard model stratified by a binary variable which indicates whether a lower-level government is affiliated to the Provincial upper-level government.

However, there is a strong possibility that this binary variable used for stratification interacts with the number of projects approved, as lower rents would attract more solar companies to request approval for the projects. The data also reveals that all lower-level governments under the Metropolitan City have not implemented local restrictions, although they do have small and large solar projects approved in their jurisdiction comparable to those under the Provinces. To account for this possibility and the characteristic of the data, **Model 2** estimates a Cox proportional model without stratification but instead only with lower-level governments under the Provincial upper-level government. **Model 1** and **Model 2** have standard errors clustered by each lower-level government to allow for the dependence across observations within each government.

Lastly, the assumption that lower-level governments under the same upper-level governments are homogeneous can be violated when there is a stronger unobserved heterogeneity among lower-level governments regardless of their affiliation. Even though a unique political history of South Korea with regional favoritism by incumbent parties has contributed to the regionalization of party identities across upper-level governments (Lee and Brunn, 1996; Park, 2003), there is a greater variation in political ideology across lower-level governments as shown in election outcomes. While this can be accounted for by introducing a fixed effect term in the model, however, it is well known that unit dummy variables create incidental parameters bias when N is large (Allison, 2002; Greene, 2004). To account for this possibility, I use frailty Cox proportional models (Balan and Putter, 2020) to include unit random effects in **Model 3** and **Model 4**. A frailty is an unobserved random proportionality factor, first introduced in the mortality rate studies to account for individuals' inherent health condition, that adjusts the hazard function of each observed unit (Vaupel, Manton and Stallard, 1979, Clayton, 1978). It is often considered an equivalent of time-invariant unit-specific random effects in the context of time-series and cross-sectional analysis for survival data (Wienke, 2003). Specifically, **Model 3** is a frailty Cox proportional model with all data included, while **Model** 4 is the same model only with lower-level governments under the Provinces.

A.3 Results

Table 1 summarizes results from all four models. Spillover effect is the most significant explanatory variable in all four models, yet the total number of large-sized solar projects approved has significant effects on the probability of adopting a local law only in **Model 1** and **Model 2**. This indicates that the total number of large-sized projects, rather than newly approved projects by each year, had more significant impact on the probability. I suggest this implies that the administrative burden for lower-level governments was cumulative as new projects have been more approved, placing additional costs such as from monitoring projects once they were approved. Small-sized projects did not have a significant impact on the probability, which supports the hypotheses 1 and 2.

The fact that lower-level governments under the Metropolitan City had no local laws implemented from 2005 to 2019 (i.e., no events for those observations) explains the same results between **Model 1** and **Model 2**. Interestingly, this fact, however, does not make the results of **Model 3** and **Model 4** identical, which implies that unit effects have a meaningful impact on the variation in the probability of adopting local laws depending on what units were included in the model.

[Table 1 to be inserted here]

Based on the results from **Model 4**, when one more government under the same upper-level government of a given lower-level government has adopted the local law, it led to 1.067 times higher the risk of the government adopting the same on average. This lends support to the second hypothesis for the spillover effect. Even when controlling for the number of solar project with different sizes approved, lower-level governments were highly aware of whether their neighbors have adopted the local law when deciding to do the same. Lim and Yun (2019) have also found that a majority of local authorities have responded that they referred to the first distance-based restriction adopted by the Youngwang-gun lower-level government when creating their own counterparts. I suggest that the reason that hazard ratio of the total number of large-sized solar projects approved has lost significance **Model 3** and **Model 4** is because its effect is captured by unit effects as well. This means more solar projects did not mean the same not only among all lower-level governments, but also among those under the Provinces which have relatively cheaper rents than those under the Metropolitan Cities. I plan to further investigate what unit-level factors can explain through interview and field studies.

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Table 1. Cox proportional hazard model results with various specifications (Hazard ratio, 95% CI in brackets)

	Model 1	**Model 2**	**Model 3**	**Model 4**
Small-sized solar projects, newly approved	1.001 [.999, 1.002]	1.001 [.999, 1.002]	1.001 [.998, 1.003]	1.001 [.998, 1.003]
Small-sized solar projects, cumulative	1.000 [.999, 1.001]	1.000 [.999, 1.001]	1.000 [.999, 1.001]	1.000 [.999, 1.001]
Large-sized solar projects, newly approved	1.000 [.998, 1.002]	1.000 [.998, 1.002]	1.001 [.999, 1.002]	1.000 [.997, 1.003]
Large-sized solar projects, cumulative	**1.001 [1.000, 1.001]**	**1.001 [1.000, 1.001]**	1.001 [.999, 1.002]	1.001 [.999, 1.002]
Spillover effect	**1.067 [1.043, 1.091]**	**1.067 [1.043, 1.091]**	**1.117 [1.094, 1.140]**	**1.067 [1.041, 1.093]**
Stratified by the upper-level government affiliation?	**Yes**	**No**	**No**	**No**
Standard errors clustered by unit?	**Yes**	**Yes**	**No**	**No**
Unit random effects included?	**No**	**No**	**Yes**	**Yes**
Total local governments at risk	205	132	205	135
Total local government-years at risk	3075	1980	3075	1980
Total events	202			
Robust score test	50.23	50.23		
Variance of random effects			.212	.137
Concordance index (standard error)	.832 (.029)	.832 (.029)	.971 (.006)	0.941 (.012)