




## Article

# Which Institutional Conditions Lead to a Successful Local Energy Transition? Applying Fuzzy-Set Qualitative Comparative Analysis to Solar PV Cases in South Korea

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**Abstract:** To explore the most desirable pathway for a successful local energy transition, a fuzzy-set qualitative comparative analysis was conducted on 16 regional cases in South Korea. We developed four propositions based on previous studies and theories as a causal set. Based on the South Korean context, we selected the solar photovoltaic (PV) generation and solar PV expansion rate as barometers for measuring the success of a local energy transition. Our analysis highlights the importance of the International Council for Local Environmental Initiatives (ICLEI) membership (network), local legislation, and the environmental surveillance of locally-based non-governmental organizations (NGOs). The implications of this study will provide insights for developing or newly industrialized countries where an energy transition is underway.

**Keywords:** local energy transition; fs-QCA; qualitative analysis; South Korean energy policy; solar PV

## 1. Introduction

Can only regions with excellent geographical conditions produce renewable energy? If the answer to this question is “yes,” countries such as South Korea (which has high population density and mountainous topography that occupies 70% of the country) can hardly expect to be capable of utilizing renewable energy. Fortunately, the answer to this question is not always “yes.” Through the creation and implementation of public policies and various institutional arrangements, our society has overcome its underlying limitations. Natural conditions are unalterable, but institutional conditions are flexible and variable depending on human effort and ingenuity. The purpose of conducting this study is to highlight the importance of institutional efforts in developing renewable energy (Hereinafter “RE”) and encouraging an energy transition that can even overcome natural conditions through an analysis of local energy transition efforts in South Korea.

Given the ceaseless increase in energy consumption and the growing concern about climate change, the most likely means of successfully reducing Greenhouse gas (Hereinafter “GHG”) emissions is to achieve an energy transition, or a rapid change from traditional to renewable energy sources [1,2]. Germany pioneered the concept of energy transition, “Energiewende” [3], but energy transition has recently become the prevailing paradigm, especially at the local level [4]. With the emergence of energy transition phenomena, local actors have become newly powerful entities capable of leading local energy transitions [5,6]. Communities have become influential local authorities [7,8] aligned

with grassroots approaches, and local governments have also been driving institutional initiatives for localized energy agendas [9]. Local agencies are also participating in local energy transition efforts [10]. In the case of Japan, citizens have played a crucial role by sharing their views during local policy deliberations [11,12].

Many attempts to achieve more-sustainable development and energy transitions can be found at the local level [6]. Inspired by “*Energiewende*” in Germany, local governments throughout the world, such as those of Barcelona, London, and Paris, are seeking to promote energy transitions in the regions where they are located. An energy transition is not only a transition in an energy system but also an effort to meet a societal challenge that includes institutional changes in a region. Borrowing from several scholars’ definitions, a sustainable local energy transition can be defined as a process of transformation that leads to low-carbon patterns of energy production and consumption [13] and includes changes in behavior and cultural discourse [14,15].

Energy transition has now emerged in the South Korean policy context. The current Moon Jae-In administration declared energy transition the basic national energy policy goal. The 3020 energy roadmap promotes increasing the proportion of renewable energy to 20% by 2030. This aim is an ambitious policy goal based on current energy production and consumption trends in South Korea. The goal is to decrease the proportions of coal and nuclear energy to 22 and 21.6 percent, respectively, by 2030 [16]. The South Korean government has several reasons for promoting this ambitious energy transition policy.

The first reason is the need to participate in the fight against climate change. High dependence on the manufacturing industry makes it difficult for South Korea to reduce GHG emissions. Furthermore, achieving the goal of the NDC (Nationally Determined Contributions) has become a major challenge in energy and environmental policy for the South Korean government. The second reason is to improve sustainability and increase energy security. The last reason is the need to improve safety. Since South Korea has a dense population and mountains constitute 70 percent of its territory, the NIMBY (not in my backyard) regarding energy facilities has increased.

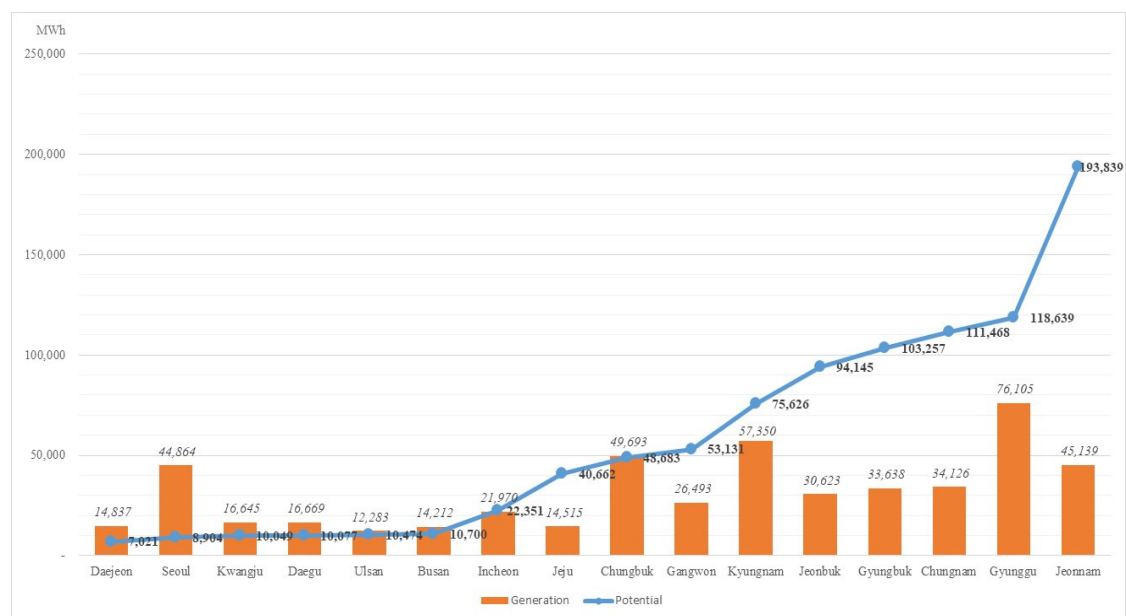
Over the past few years, South Korea has experienced a new phase in national energy policy. First, the policy instrument for boosting renewable energy has changed. South Korea switched from the “Feed in Tariff” system to the “Renewable Portfolio Standard (Hereinafter “RPS”)” in 2012. This choice has apparently led to a visible increase in domestic renewable energy production [17]. Second, the renewable electricity target was set at 20% in 2030 [18]. In reality, this goal is a highly ambitious target for South Korea regarding the industrial structure and energy mix. Third, the decision-making process of the government regarding energy policy was shifted [19]. The central government-oriented policy-making system is not sustainable for achieving an ultimate energy transition. Throughout history, high dependence on nuclear and fossil fuels has hindered various actors from participating in the establishment of a basic energy plan [4,20].

In addition to waste-based and large-scale hydro energy, solar energy is the dominant renewable resource in South Korea [21]. Indeed, the adoption of the RPS led to an increase in the total amount (or proportion) of renewable energy production for industrial use [22]. As a holistic approach, the RPS system was an effective policy instrument in South Korea [23,24]. However, a problem remains at the local scale. RPS did not affect small-scale renewable energy facilities that service houses [25]. The growing demands of households are a critical issue affecting the energy situation in the region [26]. Households need energy for heating, lighting, and cooking daily. RE for household use usually depends on small-scale solar PV in South Korea. Small-scale solar PV facilities have numerous advantages; they do not occupy large spaces, nor do they aggressively harm the environment [27].

To gauge the progress of local energy transitions, we focus on solar PV facilities that are representative of the actual RE facilities governed by local authorities. As explained above, the South Korean RE support system is designed around quotas for select major electric power producers through the RPS [28]. This system affects overall RE generation and the domestic energy transition for mainly non-household, industrial uses. However, the number of small-scale RE facilities and their potential

output (maximum ability to produce electricity in the region) have also been growing, regardless of the system. Among small-scale RE facilities, solar PV is dominant [29].

In general, the development of renewable energy is highly correlated with the geographic potential of renewable resources. However, from Figure 1 below, it can be seen that this assumption does not match the South Korean context exactly. This mismatch implies that there are attractive factors present in addition to the region's environmental and geographical resources. Before we present our research question, two assumptions must be articulated. First, RE production for industrial use is beyond our research scope. Second, the non-institutional factors that might influence an energy transition, such as population density, infrastructure (grid), and energy resource potential, are not our concerns. To concentrate on institutional conditions, we derived several propositions from previous studies. Then, we inquired about the other conditions that can increase local renewable energy generation. Our research question can be formulated as follows.



**Figure 1.** Solar resource potential compared to solar power generation in 16 regions.

**Q.** What is the most desirable pathway to accomplish a successful local energy transition?

Our study's objective is to provide an explanation of the pathways that lead to successful (meeting the necessary or sufficient conditions) local energy development by analyzing 16 regional cases in South Korea. In our study, a successful energy transition indicates a "comparatively successful" outcome. Considering its methodological limitations, our study cannot provide an imperative numerical outcome. However, it is possible to compare 16 regions' accomplishments in encouraging solar PV generation. Some regions demonstrate lower performance than average, while others demonstrate higher performance. In our study, we focus on solar PV generation when measuring the progress of a local energy transition.

A case-oriented study seeks to utilize the in-depth findings that best fit the specific socio-environmental culture. To explore the possible pathways, we use fuzzy-set Qualitative Comparative Analysis (Hereinafter "fs-QCA") [30]. The remainder of our study is presented as follows. Sections 2 and 3 consists of a literature review, which includes causal conditions and outcomes. Sections 4 and 5 highlights the research design, including the case selection and methodology. Section 6 consists of an analysis of the conditions of successful pathways applying fs-QCA. A summary, and the study's limitations are discussed in Section 7.

## 2. Local Energy Transition: Solar PV as a Key Measure in the South Korean Context

Local energy transitions cannot be separated from the national one. However, as in most other contexts, unique factors can be found in successful local energy transitions, which are differentiated from the national-scale energy transition. For example, local commitments to ensuring climate protection can provide a good illustration of this phenomenon.

In South Korea, a local energy transition can be a critical factor in achieving national targets, especially at small-scale renewable energy facilities. In the context of industrial use, RPS systems impose generation quotas on selected electricity companies. Accordingly, these electricity companies prefer to establish large-scale RE facilities instead of scattered, small-scale ones that are appropriate for supplying power to households.

Solar PV energy is the most cost-effective renewable energy source for most developed countries. As a result, previous studies have focused on solar PV generation for household use when measuring the expansion of RE [31–34]. The level of technology has already reached the break-even point in the market. In the South Korean energy-generation context, solar PV accounted for 7% of the total RE generation as of 2016 [35].

Moreover, solar PV is a core component of the energy transition in the South Korea [36]. The outcomes of small-scale solar PV implementation for household use can be considered a suitable barometer of the progress of an energy transition for two reasons. First, solar PV is the most feasible source of renewable energy given the population density and geographical features of the nation. South Korea's population grew to 50 million as of 2015, and more than 80% of its population lives in urban areas and cities. The geographical area of South Korea comprises 38,691 square miles, which is equivalent to 1/3 the size of Germany or 1/4 the size of Japan. Thus, it is evident that South Korea does not have appropriate natural terrain for implementing some renewable energy generation methods [37]. A small-scale solar PV facility can be a useful option and can be installed regardless of space constraints (panels can be installed on a rooftop or hung on a balcony in an apartment or multiplex).

Second, only solar PV energy is systematically affordable in the social economy in South Korea. Although the wind power generation accounts for a high proportion of renewable energy globally, in Asia, apart from China, wind power supply is progressing slowly [38]. Since the enactment of the framework act on cooperatives in 2012, the social economy of energy has experienced rapid growth in Korean society. Over 60% of South Korea's energy cooperatives are related to solar PV [39]. Thus, solar PV may be the only renewable resource that can facilitate the energy prosumer trend in renewable resources.

Based on these rationales, we used the amount of regional solar PV energy generation and the regional solar PV expansion rate per year to measure the level of local energy transition that had been achieved. The amount of solar PV generation suggests the mechanism for the current outcome, while the solar PV expansion rate overlooks the mechanism for the acceleration of the energy transition and path.

## 3. Drivers of Local Energy Transition and Operative Propositions

Numerous studies have illuminated the correlation between local energy transitions and the expansion of RE generation. Zahran et al. [31] focused on using environmental, economic, and socio-political factors to explain the expansion of solar PV for household use. In their study, a political preference for the democratic party and ICLEI membership turned out to be significant factors in the expansion of solar PV in the US. In Kwan [32] and Crago and Chernyakhovskiy [33] studies, incentive programs supported by local financing were found to be one of the most critical factors influencing the prevalence of solar PV facilities.

Recent studies have highlighted the important role of ICLEI membership in the local commitment to sustainable development and awareness of climate change issues [40]. The International Council for Local Environmental Initiatives (ICLEI)-Local Governments for Sustainability was founded in 1990 as a global network of cities and regions dedicated to creating a sustainable future. To date, the ICLEI

network includes more than 1700 local governments in more than 100 countries. The critical tasks of the ICLEI consist of 5 pathways: low emission development, nature-based development, circular development, resilient development, and equitable people-centered development.

Although a local energy transition can be achieved without membership in the ICLEI, previous studies have found that membership in the organization is a significant factor in local climate change action [31,41,42]. Moreover, ICLEI membership shows the willingness of local governments to tackle climate change and energy transition in a cleaner and more ecologically friendly way [43]. Seoul city, for example, pioneered the solar city project in accordance with the ICLEI's policy and invested in and implemented solar PV methods to comply with a 100% RE initiative and achieve its zero-carbon goal [44].

The amount of attention paid to local-level legislation has accelerated in recent years [45]. Local ordinances and regulations provide the institutional foundations for local governments to implement their actual climate change actions in a region. Establishing an energy ordinance is not mandatory for every local government in South Korea [19]. In South Korea, a local government has the power to enact local ordinances and regulations regarding energy issues. Accordingly, the level of legislation in this area differs among local governments. However, in areas with local governments that have enacted the energy ordinance, local renewable energy projects are being established based on such ordinances. Blanchet [46] analyzed the two local energy initiatives that were implemented in Berlin city. Although the details varied, the regulations, especially local-scale citizen-led laws, were considered important components of the initiatives.

Financial capacity was considered an influential factor in previous studies [32,33,47]. Unsurprisingly, the most active countries in terms of climate change actions and energy transitions are primarily those in the North. Indeed, "Green (cleaner production) needs green (money)." South Korea has experienced rapid economic growth during the past decade [48]. However, financial strategies for coping with rapid growth can lead to the presence of relatively underdeveloped regions. This regional discrimination has led to differences in the level of financial abundance between regions in South Korea.

Many of the previous studies highlighted the importance of green parties, especially in EU member countries [47,49]. In South Korea, local-scale environmental actions were largely influenced and initiated by grassroots NGOs on behalf of political parties. In South Korea, environmental activism was suppressed by authoritarian regimes in the mid-1980s [50]. Despite the country's late start, NGOs in South Korea have become increasingly active in issues related to the promotion of the public welfare, such as the environment and other social issues [51]. As NGOs in South Korea have become more institutionalized and issue-specific, their social roles have extended their policy influence, making their role equivalent to that of green parties [52].

Environmental NGOs in South Korea grew up in a context of ecologically destructive regional development [19]. As industrialization accelerated, pollution worsened and more frequent local protests by environmental NGOs became prevalent [53]. The role of NGOs in environmental policy is currently apparent at several levels [54,55]. As Korean society does not have empowered political parties focusing on environmental issues, environmental NGOs are assuming the role of green parties. Thus, in our study, environmental NGOs possess the capacity for environmental surveillance and expertise instead of the green parties that were discussed in previous studies. As our study relies on qualitative methodology, we cannot empirically verify its hypotheses. However, it is possible to explore the best combination of several conditions in a qualitative way. Based on our literature review and the logic of qualitative comparative analysis, we formulated four propositions, as shown below.

**Proposition 1.** *Local Commitment is a necessary or/and sufficient condition for the success of a local energy transition.*

Here, local commitment can be measured by the level of ICLEI membership. Previous studies have highlighted ICLEI membership as a critical factor in the expansion of RE generation [31,40–42]. As ICLEI



membership represents the willingness of local governments to promote energy transitions [43], it best indicates the level of local commitment to ensuring the success of an energy transition.

**Proposition 2.** *Local legislation is a necessary or/and sufficient condition for the success of a local energy transition.*

The importance of local legislation is growing along with the increase in climate change action. Energy-related law is the basis of local energy policies. As mentioned in previous studies, growing numbers of newly enacted energy-related decrees have contributed to the success of local energy transitions [45,46,56]. Therefore, the indispensability of local legislation concretized by the enactment of energy decrees by regional governments should be considered our second proposition.

**Proposition 3.** *Local financing is a necessary or/and sufficient condition for the success of a local energy transition.* In the past, regional infrastructure development in South Korea has been aligned with the financial

capacity of regions. As in other previous studies [32,33,47], in this study, local financing is considered an important factor in local energy transitions. Local financing can be measured as the GRDP (gross regional domestic product) of 16 regions in South Korea.

**Proposition 4.** *Environmental surveillance/expertise is a necessary or/and sufficient condition for the success of a local energy transition.*

In Korean elections, green parties are not influential in decision-making even at the national level. On behalf of the green party, environmental NGOs have showed strong leadership in local environmental policy since the 1990s. Environmental NGOs in South Korea have replaced the green parties of Europe, and they are considered “political” actors in the Korean energy policy-making system in reality [56]. Thus, in our study, our last proposition is related to environmental NGOs; Korean environmental NGOs are participating in making and implementing local energy policies with their surveillance capacity and expertise in environmental issues. As a result, environmental surveillance and expertise at the local scale can be measured by the number of environmental NGOs in a region.

#### 4. Methodology: Fuzzy-Set QCA for Intermediate Number Cases

Fuzzy-set qualitative comparative analysis strives to explain complex issues in the social science fields. Developed by Ragin [30], this case-oriented methodology focuses on a combination of specific conditions. A conventional crisp-set is comparable to binary variables of 1 and 0. Thus, a crisp-set is either inside or outside of a set that is dichotomous [57]. For example, the object can be a Protestant (membership = 1) or non-Protestant (membership = 0) in a survey [57]. By contrast, a fuzzy set provides a level of membership between 0 and 1, which can eventually imply the existence of more qualitative information in transforming each variable. For example, the fuzzy set of “Protestant” includes objects who are fully inside the set (membership = 1); those who are almost fully inside it (membership = 0.90); those who are at the cross-over point in it (membership = 0.50); those who are slightly more outside than inside it (membership = 0.45); and even those who are fully outside of the set (membership = 0), or “non-Protestant” [57]. Thus, a fuzzy set is more empirically grounded and more powerful as a means of explanation than a conventional crisp-set [57]. Fs-QCA methodology has been applied in various fields, including energy policy [47]. Fs-QCA has some powerful advantages in research; first, it is an appropriate tool for explaining causal conditions for particular pathways. Specifically, fs-QCA can demonstrate joint causal relations by considering interactive effects between variables (which regression models cannot do because of multi-collinearity).

Second, fs-QCA provides a comprehensive understanding of middle-number cases (15 to 30 examples). Research in social science has mainly been focused on small-N studies and large-N studies. For small-N studies, we use traditional qualitative methodologies, such as in-depth interviews.

For large-N studies, we mostly use empirical methodologies based on statistical models. However, no clear solutions have been suggested for conducting intermediate-sized-N studies, such as, for example, those including 15 to 30 examples [57]. Fs-QCA provides an apt solution to social scientists who have suffered from a “limited repertoire of methods” for studies of intermediate size [57]. In our study, the number of cases is 16, thus fs-QCA is an appropriate methodology.

Third, the causal complexity considered by fs-QCA provides a realistic description of social phenomena [30,58]. When using variable-oriented methods, it is possible to identify broad and theory-related patterns, but case-oriented methods can provide a realistic picture of the specific social phenomena [57] that are actually affecting our society.

Analyzing necessary or sufficient conditions is the key task when implementing fs-QCA methodology. Necessary conditions are usually simple and singular conditions with a high level of consistency. When using an fs-QCA program, we can analyze the necessary conditions before identifying sufficient conditions [59]. The biggest difference between the two types of conditions is the level of consistency. The level of consistency indicates how strongly a condition relates to the results of the analysis [60]. In general, a cut-off point of 0.90 is suggested as the minimum acceptable level of consistency [59]. In the next step, it is possible to analyze the sufficient conditions for a successful energy transition. In general, the threshold for consistency is set at 0.80 for raw consistency [61]. Thus, when analyzing sufficient conditions, we can suggest more complicated combinations of conditions.

The goal of social scientists when using fs-QCA is to find specific patterns [30,62] of solutions that are not unique or universal. Thus, the results of fs-QCA cannot be considered a panacea for every context. However, the results can suggest a plausible solution regardless of the unique context of each region and country.

## 5. Research Design: Fuzzy-Set QCA Model for Energy Transition Study

Fs-QCA provides a better understanding of middle-number cases, such as those with 15–30 examples according to Ragin, and it also has a powerful explanatory power for “joint causal relations” that regression models do not support because of multicollinearity. First, 16 upper-level local government cases in South Korea were selected for this study which perfectly fits for conducting fuzzy set QCA. Among 16 regions, Sejong was not included because of its short history (Sejong city was created in 2012 to establish a new administrative capital in South Korea). The 16 regional cases selected for this study were Seoul, Busan, Daegu, Incheon, Gwangju, Daejeon, Ulsan, Gyunggi, Gangwon, Chungbuk, Chungnam, Jeonbuk, Jeonnam, Gyungbuk, Gyungnam, and Jeju.

First, solar PV generation and the solar PV expansion rate per year for residential use in 16 regions were selected as dependent variables. The data were collected through Korea Energy Statistical Information System (Hereinafter “KESIS”, URL: <http://www.kesis.net/main/mainEng.jsp>) With the goal of using the most recent data available, we used data from 2015, which is the most recent year for which there is a dataset in KESIS. To measure the solar PV expansion rate, we used the compound annual growth rate of solar PV for each region. The formula was constructed as below.

$$\text{CAGR}(t_0, t_n) = \left[ \frac{V(t_n)}{V(t_0)} \right]^{\frac{1}{t_n - t_0}} - 1$$

where  $V(t_0)$ : start value,  $V(t_n)$ : finish value, and  $t_n - t_0$ : number of years.

Second, four causal variables were selected: network, local legislation, financial abundance, and environmental surveillance. A region’s level of ICLEI membership was used to determine the local commitment to climate change actions. The data were collected from the ICLEI South Korea Homepage. We calculated the engagement rate of the sub-regions of 16 upper-level local governments from 2015. To measure local legislation power, the number of energy ordinances in each region was compiled from 16 local energy plans. We divided the aggregated numbers of ordinances by the total number of local governments.

To determine a region's financial capacity, we employed the GRDP (gross regional domestic product) of the 16 regions. GRDP can be used to measure the size of a region's economy. GRDP includes the agriculture, fishery, forestry, industry, and service sectors.

Lastly, environmental surveillance was calculated according to the number of environmental NGOs in a region. We compiled data from the list of NGOs registered with the Ministry of Environment (see Appendix A).

Before the calibrations were conducted, descriptive statistics were selected to identify the minimum, the maximum, the mean, and the median. To calibrate the raw data, we used the median to avoid overestimating the dispersion. MS Excel ver.2016 was used to obtain the descriptive statistics from the raw data (see Appendix B for summary of descriptive statistics).

The compiled data from 16 regions were converted to fuzzy-set scores for each case according to the various levels of fuzzy membership. To determine the fuzzy membership classification for each case, we used the maximum, median, and minimum to convert the raw data into fuzzy scores that varied from 0 to 1. For example, regarding local commitment, the minimum raw data score was 1 percent, and the maximum was 13 percent. We used the median of 2 percent as the cross-over point and set 0.95 as the maximum and 0.05 as the minimum for the raw data. The other digits were calculated accordingly, considering the ratio mentioned above. For calibration, we used Microsoft Excel software and fs-QCA 3.0 software by Ragin. The converted fuzzy scores are shown in Table 1 below.

**Table 1.** Fuzzy scores (calibrated variables).

City (N)	Outcome			Causal Conditions		
	Solar_g	Solar_Exp	ICLEI	Decree	Financing	NGO
Seoul	0.74	0.84	0.87	0.72	0.95	0.95
Busan	0.07	0.95	0.05	0.58	0.7	0.51
Daegu	0.1	0.52	0.05	0.05	0.63	0.5
Incheon	0.23	0.60	0.5	0.75	0.81	0.5
Gwangju	0.1	0.05	0.05	0.05	0.56	0.5
Daejeon	0.07	0.38	0.05	0.05	0.66	0.53
Ulsan	0.05	0.35	0.05	0.85	0.88	0.05
Gyeonggi	0.95	0.80	0.95	0.95	0.83	0.71
Gangwon	0.41	0.77	0.8	0.51	0.07	0.53
Chungbuk	0.79	0.62	0.5	0.8	0.19	0.05
Chungnam	0.61	0.45	0.84	0.75	0.2	0.5
Jeonbuk	0.53	0.35	0.05	0.41	0.08	0.12
Jeonnam	0.74	0.20	0.63	0.48	0.05	0.05
Gyeongbuk	0.58	0.71	0.5	0.2	0.11	0.51
Gyeongnam	0.86	0.23	0.57	0.28	0.41	0.05
Jeju	0.07	0.48	0.5	0.05	0.22	0.05

## 6. Analysis and Results

Analyses of the necessary and sufficient conditions for a successful local energy transition were performed using fs-QCA software version 3.0. The necessary conditions are those that are directly theoretically relevant to the outcomes and are present all the time. The main reason for studying the necessary conditions is that they have powerful policy implications [57]. How to identify necessary conditions depends on consistency and coverage. Consistency indicates the level of sharing conditions for each case, and it helps the researcher to determine “how well a finding reflects the empirical



data” [60]. Coverage is the level of the explanatory capacity covered by the cases. The consistency and coverage scores for the necessary conditions are 0.9 and 0.3, respectively. The objective of investigating the sufficient conditions is to support diversity-oriented research [57]. The sufficient conditions are meaningful when causes are combined. In accordance with Ragin [57], the sufficiency consistency threshold was set at 0.80.

### 6.1. Necessary and Singular Conditions for a Successful Local Energy Transition

The converted calibrated data were first analyzed to determine the necessary conditions for a successful local energy transition, as shown in Table 2 below. The analysis of necessary conditions was conducted with a two-outcome set: solar PV generation and the solar PV expansion rate. The 0.9-point consistency score is the recommended threshold for determining necessary conditions. As can be explored from Table 2, the environmental surveillance (0.88) for the solar PV expansion rate nearly meets the required consistency score of 0.9. If we adopt a strict interpretation of the textbook definition of fs-QCA, a score of 0.88 cannot indicate a necessary condition because it does not exceed 0.9. However, if we employ the more flexible interpretation of Ragin [57], 0.88 can be considered a quasi-necessary condition for the outcome set. Given the restricted number of cases, this finding indicates that the role of environmental NGOs in a region can be assumed to be a necessary condition for a successful local energy transition.

**Table 2.** Analysis of necessary conditions.

Conditions	Solar PV Generation		Solar PV Expansion Rate	
	Consistency	Coverage	Consistency	Coverage
Local Commitment (ICLEI)	0.79	0.80	0.80	0.67
Local Legislation Power (DECREE)	0.72	0.78	0.78	0.7
Local Financing (GRDP)	0.76	0.76	0.82	0.68
Environmental Surveillance & Expertise (NGO)	0.62	0.55	<b>0.88</b>	<b>0.64</b>

### 6.2. Sufficient Conditions for a Successful Local Energy Transition

Table 3 presents the possible combinations of sufficient conditions for solar PV generation and the solar PV expansion rate. The number of logically possible combinations is  $16(2^4) + 16(2^4)$ . Analysis of the sufficient conditions includes three steps: constructing the model, editing the rows, and setting the truth table. Truth table analysis is conducted to examine the logical combinations of all possible causes and conditions to explain the resulting conditions. The construction of a truth table begins with an algorithm, which is first inputted into qualitative comparative analysis software [63]; the current version of fs-QCA software also offers a truth table, which is essentially the result of conducting fs-QCA. A truth table shows the possible combinations of conditions and their consistency. In general, a consistency score of 0.8 is the cross-over point.

In this process, setting a truth table is the key procedure for verifying causal conditions [64]. The fs-QCA software shows intermediate, parsimonious, and complex solutions. These three types of solutions provide the combinations of causal conditions. In parsimonious solutions, the model introduces the elimination of existing or absent causes and minimizes additional causes except those of core origin. On the other hand, complex solutions show the maximum amount of combinations of causal conditions. Intermediate solutions are suggested automatically through the process of deriving the most complex result and inversely analyzing the causal conditions. In this study, we will suggest both parsimonious and intermediate solutions and their pathways.

As shown in Table 3, of 16 possible configurations, 8 were empirically observed. A score of “1” implies the partial or full presence of a condition or outcome. Conversely, a score of “0” represents the partial or full absence of a condition or outcome [60].

If we closely examine Table 3, an overall policy evaluation can be conducted according to the truth table. An outcome score of “1” indicates the success of solar PV generation and expansion. Regions such as Jeonbuk had a score of “0” for both of their outcomes in solar PV generation and expansion, signifying the failure of their local energy transitions. However, regions such as Gangwon, Seoul, Gyunggi, and Jeonnam obtained a score of “1” for their outcomes in both solar PV generation and expansion, indicating the success of their local energy transitions.

Regions such as Busan, Ulsan, and Daejeon obtained a score of “0” for their outcomes in solar PV generation; however, they obtained a score of “1” for their outcomes in solar PV expansion. This study indicates that these three regions continue to lack the required absolute production output in solar PV; however, they are constantly endeavoring to promote solar PV generation and to achieve an energy transition. By contrast, regions such as Gyungnam obtained a score of “1” for the outcome of solar PV generation but obtained a score of “0” for the expansion outcome, indicating the opposite result of the above-mentioned cases.

**Table 3.** Truth table of sufficient conditions for the outcome of solar PV generation.

Conditions	Row	ICLEI	DECREE	GRDP	NGO	Outcome	Consistency	Cases
Solar PV Generation	1	1	0	1	0	1	0.99	Gyungnam
	2	1	1	1	1	1	0.92	Seoul Gyunggi
	3	1	0	0	0	1	0.85	Jeonnam
	4	1	1	0	1	1	0.84	Gangwon
	5	0	1	1	1	0	0.68	Busan
	6	0	1	1	0	0	0.67	Ulsan
	7	0	0	0	0	0	0.58	Jeonbuk
	8	0	0	0	1	0	0.53	Daejeon
	9~16	Logical Remainders						
Solar PV Expansion	1	1	0	0	1	1	1	Gangwon
	2	1	1	1	1	1	1	Busan
	3	1	1	1	1	1	0.98	Seoul Gyunggi
	4	1	1	1	0	1	0.89	Ulsan
	5	0	0	0	0	1	0.84	Jeonnam
	6	0	0	0	1	1	0.82	Daejeon
	7	0	1	1	0	0	0.78	Gyungnam
	8	0	0	0	0	0	0.78	Jeonbuk
	9~16	Logical Remainders						

The overall cut-off for sufficient conditions was constructed using two criteria: a consistency score of 0.8 and a minimum of two cases. Accordingly, the models that could not achieve a consistency score of 0.8 were excluded in the first step. In the second step, the models with a single case were excluded from the final analysis.

An analysis of the combinations of conditions that were sufficient for Solar PV generation was conducted based on three kinds of models as shown in Table 4. The first model, which is a parsimonious solution, includes a single “iclei” condition with a coverage score of 0.80 and a consistency score of 0.79. The Gyunggi (0.95, 0.95), Seoul (0.87, 0.74), Chungnam (0.84, 0.61), Gangwon (0.8, 0.41), Jeonnam (0.63, 0.74), and Gyungnam (0.57, 0.86) cases fit Model I.

The second model is an intermediate solution that includes “iclei\*~decree\*~ngo.” The Gyungnam (0.57, 0.86) and Jeonnam (0.52, 0.74) cases fit Model II. The third model, which is also an intermediate solution, includes “iclei\*decree\*ngo.” Model III includes Seoul (0.72, 0.74), Gyunggi (0.71, 0.95), and Gangwon (0.51, 0.41).

**Table 4.** Pathways for solar PV generation.

Solution	Model	Pathway	Coverage	Consistency	Number of Cases
Parsimonious	I	iclei	0.80	0.79	6
Intermediate	II	iclei*~decree*~ngo	0.46	0.86	2
	III	iclei*decree*ngo	0.47	0.89	3

An analysis of the combinations of conditions that were sufficient for solar PV expansion was conducted based on six kinds of models as shown in Table 5. Two of the models are based on parsimonious solutions, and the other four models are based on intermediate ones.

The first model, which is a parsimonious solution, includes a single “ngo” condition with a coverage score of 0.64 and consistency score of 0.88. Cases such as Seoul (0.95, 0.84), Gyunggi (0.71, 0.8), Daejeon (0.53, 0.38), Gangwon (0.53, 0.77), Busan (0.51, 0.95), and Gyungbuk (0.51, 0.71) fit Model I.

The second model, which is also a parsimonious solution, includes “iclei\*~grdp,” a with coverage score of 0.46 and a consistency score of 0.87. Two cases, Gangwon (0.8, 0.77) and Jeonnam (0.53, 0.2), fit Model II.

The third model, which is also a parsimonious solution, includes a “decree” with a coverage score of 0.70 and a consistency score of 0.78. Model III has the most powerful explanatory pathway among the parsimonious solutions for solar PV expansion. Half of the cases fit model III: Gyunggi (0.95, 0.8), Ulsan (0.85, 0.35), Chungbuk (0.8, 0.62), Incheon (0.75, 0.6), Chungnam (0.75, 0.45), Seoul (0.72, 0.84), Busan (0.58, 0.95), and Gangwon (0.51, 0.77). The fourth model, which is also a parsimonious solution, includes “~iclei\*grdp” combinations. The Busan (0.53, 0.95) and Ulsan (0.51, 0.35) cases fit Model IV.

**Table 5.** Pathways for solar PV expansion.

Solution	Model	Pathway	Coverage	Consistency	Number of Cases
Parsimonious	I	ngo	0.64	0.88	6
	II	iclei*~grdp	0.46	0.87	2
	III	decree	0.70	0.78	8
	IV	~iclei*grdp	0.46	0.86	2
Intermediate	V	~iclei*decree*grdp	0.39	0.89	2
	VI	iclei*decree*ngo	0.43	0.98	3

Note: “iclei\*~decree\*~grdp\*~ngo” (0.35, 0.84) and “~iclei\*~decree\*~grdp\*ngo” (0.34, 0.82) were excluded because only a single case of each exists.

The fifth and sixth models were constructed through intermediate solutions. The fifth model includes “~iclei\*decree\*grdp” combinations with a coverage score of 0.39 and consistency score of 0.89. The Busan (0.53, 0.95) and Ulsan (0.51, 0.35) cases fit Model V. The sixth model consists of “iclei\*decree\*ngo,” with a coverage score of 0.43 and consistency score of 0.98. A score of 0.98 is exceptionally high and indicates how strongly the combinations of “iclei,” “decree,” and “ngo” relate to solar PV expansion. The Seoul (0.72, 0.84), Gyunggi (0.71, 0.8), and Gangwon (0.51, 0.77) cases fit the powerful Model VI. Based on the results presented above, an optimal pathway for achieving a local energy transition can be suggested by the simple formula below.

Solar PV generation = iclei

+iclei\*~decree\*~ngo

+iclei\*decree\*ngo(redundancy)

Solar PV expansion = ngo

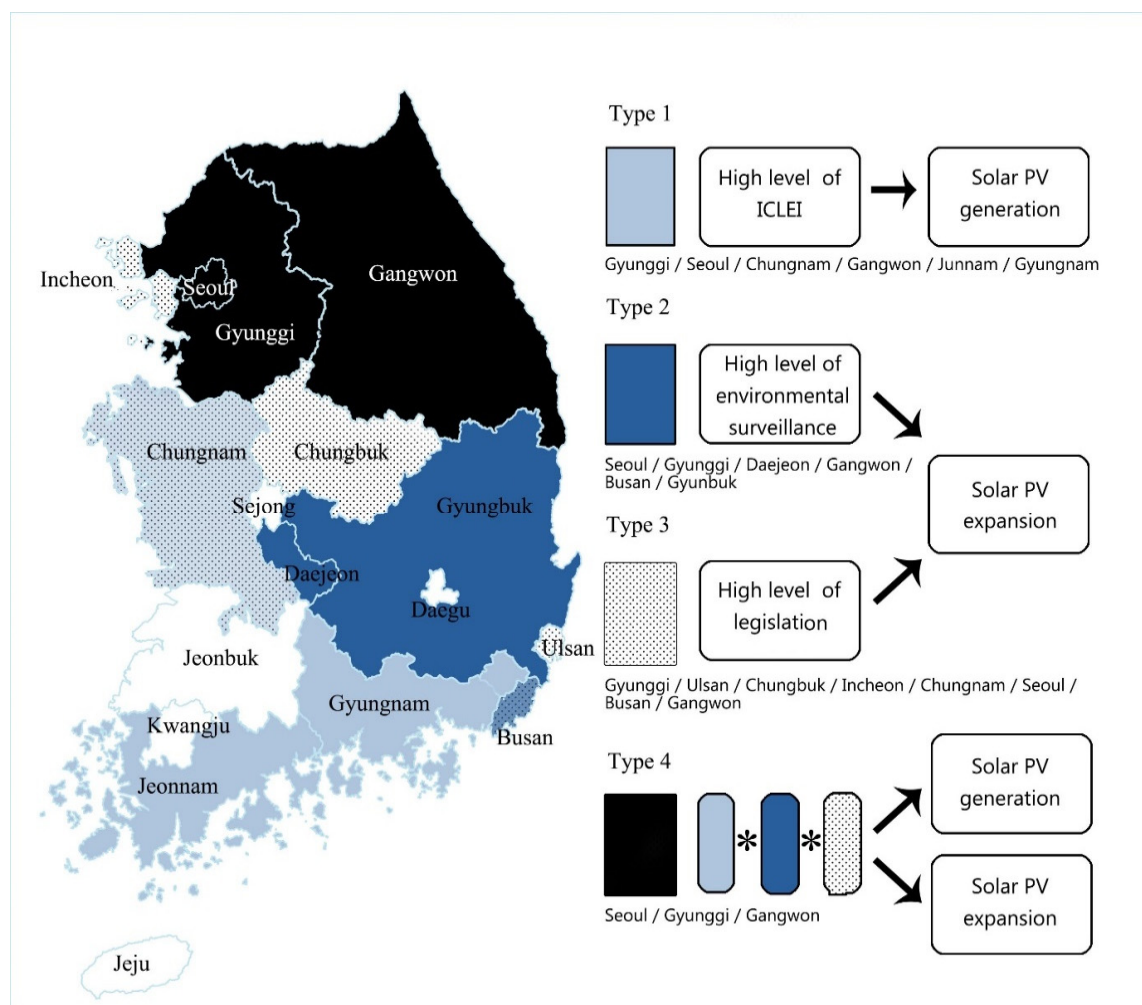
+iclei\*~grdp

+decree

$$\begin{aligned}
 &+ \sim \text{iclei} * \text{grdp} \\
 &+ \sim \text{iclei} * \text{decree} * \text{grdp} \\
 &+ \text{iclei} * \text{decree} * \text{ngo}(\text{redundancy})
 \end{aligned}$$

$$\text{Local energy transition} = \text{solar PV generation} + \text{solar PV expansion}$$

From the results presented above, the ideal types for a local energy transition can be simplified and summarized as follows (see Figure 2). To suggest a persuasive solution for a local energy transition, we sorted the models that exhibited more than two cases (see the blocks in Tables 4 and 5). In this study, we applied the outcome set through two means: solar PV generation and the solar PV expansion rate. Solar PV generation shows which factors actually facilitated the energy transitions. Below, Type 1 can be used to predict important factors and pathways for other countries.



**Figure 2.** Pathways to a successful local energy transition.

**Type 1: High level of ICLEI membership:** A high level of ICLEI membership affected the growth of solar PV generation. ICLEI membership singularly proved to be an important condition for the success of a local energy transition. (6 cases observed)

While solar PV generation verified what was important in the future, the solar PV expansion rate showed what will likely be important moving forward. In other words, Types 2 and 3 indicate which factors will promote and accelerate the energy transition henceforth.

Type 2: High level of environmental surveillance: A high level of environmental surveillance obtained from environmental NGOs in a region can be an important factor in expanding and accelerating a local energy transition. (6 cases observed)

Type 3: High level of local legislation: A high level of local legislation power related to the energy decrees in a region can be an important factor in expanding and accelerating a local energy transition. (8 cases observed)

Lastly, Type 4 meets both positive outcomes for solar PV generation and expansion. Type 4 can be summarized as an ideal type of pathway that includes the crucial conditions for accomplishing a local energy transition.

Type 4: A combination of a high level of ICLEI membership, local legislation, and environmental surveillance: The combination of high levels of ICLEI membership, local legislation power, and environmental surveillance can be a successful pathway for promoting a local energy transition. (3 cases observed for each outcome set).

This study presents several meaningful findings as follows. First, ICLEI membership can be a crucial condition for local energy transitions [40,42]. ICLEI membership represents two conditions: a support network and the willingness to achieve sustainability. A previous study highlighted the importance of ICLEI membership. Our findings additionally support those of previous studies and affirm that ICLEI membership can have positive implications for countries such as South Korea, which has unfavorable geographical conditions for renewable energy generation.

Second, environmental surveillance at the local scale has positive effects on local energy transitions. From a global perspective, locally based NGOs are not always pro-renewables [65] since renewable energy facilities contribute to environmental degradation [66]. This situation generally occurs in developed countries where the use of renewable energy is already established. However, countries such as South Korea continue to rely heavily on conventional resources (nuclear and fossil fuel). Accordingly, the positive effect of local NGO involvement in local energy transitions will possibly provide more insight into the situation in developing and newly ascendant countries.

Third, local legislation can positively affect the acceleration of a local energy transition. Since the enactment of an energy ordinance is not mandatory for local governments, the level of legislation also illustrates the amount of effort directed towards a local energy transition. In addition, codified legislation creates an institutional foundation for implementing renewable energy projects in a region. However, the energy ordinance enactment rate remained 39% among lower-level local governments as of 2015 [67].

Lastly, a combination of factors that yields a desirable pathway for a local energy transition can be suggested as follows: a high level of ICLEI membership, a high level of local legislation power, and a high level of environmental surveillance. According to our results, this combination has a positive outcome for both solar PV generation and solar PV expansion. Regarding the strong explanatory power of fs-QCA on social problems, this combination of causal conditions allows us to identify a possible desirable pathway to achieve a successful local energy transition.

In our research, local financing was not a necessary or sufficient condition for a successful local energy transition. This result implies the institutional alignment of a region and the efforts of its local government are more crucial conditions than financial capacity. Another noteworthy finding is that institutional efforts, such as legislation enacted at the local level, the presence of a solid network (e.g., the ICLEI) [68], and the actions of local NGOs, can overcome limitations related to renewable resource potential and geography. This finding provides a rationale for cities or urban areas to organize and promote institutional involvement regardless of the regional environment.

Among the 16 regions that were analyzed, three outstanding ones, Seoul, Gyunggi, and Gangwon, demonstrated the ideal pathway to a successful local energy transition. Especially in the cases of Seoul and Gyunggi, our results support those of previous qualitative studies concerning local energy transitions. Seoul has pioneered an innovative energy strategy involving “One Less Nuclear Power Plant” initiatives, which are focused on achieving energy autonomy and which also highlight the



strong leadership of the Seoul city government [4,37]. Mayor Park of Seoul city, who was elected as a chairman of the ICLEI in 2015, announced the “Seoul Declaration, “which clearly indicates the justification for a sustainable energy transition led by a local government.

Gyeonggi is also known for its ambitious implementation of solar energy policies, and it claimed a 70% increase in energy independence within the region, promoting a goal of increasing its proportion of renewable energy to 20% in the “Gyeonggi Energy Vision 2030” [69]. To accomplish this target, the Gyeonggi local government supports a community energy project [70] and established a local energy center, which is the first energy-related public agency in the local level [71]. In the case of Gangwon, no significant in-depth case studies have been conducted qualitatively. The Gangwon region is known for its abundant wind-generation potential in mountainous areas [35], but less is known in terms of its capacity for solar energy generation. However, our analysis implies the rationale for commencing an in-depth case study of the Gangwon region as our next step.

## 7. Limitation and Conclusions

The main research objective of this study was to explore which combinations of institutional conditions are necessary and/or sufficient for successful local energy transitions and which might be the most desirable pathway to accomplish a local energy transition. To address these issues, 16 regional cases in South Korea were selected for analysis. We examined which conditions affected local energy transitions and which combination of conditions eventually led to successful local energy transitions. To measure the success of local energy transitions, we used solar PV generation for residential use and the solar PV expansion rate for residential use in each region.

In our research, a successful pathway to local energy transition (for both solar PV generation and solar PV expansion) is composed of a high level of ICLEI membership, a high level of local legislation, and a high level of environmental surveillance. This result is quite a convincing result, which can align with the German case. In Wuster and Hagemann’s study [48], they found two ways of being successful: green party involvement in governance and high potential, or high potential and a low share of industry in the region. However, the rich federal state (local financing) was not a crucial factor for successful local energy transition. Unlike Germany, the Green party does not play an important role in politics in South Korea. Instead, the South Korean NGOs are much more empowered in local governance systems. Also, their study supports our result that local financing does not affect the success of local energy transition compared to other institutional conditions.

Despite the implications and findings discussed above in Section 6, our study has some limitations. Our study is qualitative in nature. As with other qualitative studies, our study lacks the consideration of control variables for a successful local energy transition. In addition to our four propositions, there might be another, stronger institutional or non-institutional factor that affects local energy transitions. Since the purpose of our study is to explore combination of successful pathway, we failed to consider all factors which might have an effect on local energy transition. Although we did not verify each factor’s separate effect, we succeeded to find synergies by combining four institutional conditions derived from previous studies. If we neglect the order of incident of four conditions, we can possibly approach this theme with the regression model using interaction term. And also, it can be a meaningful study to compare four condition’s priorities by the utilizing hierarchical regression model if we can update more observations in the future. Nevertheless, the data for solar PV electricity generation for housing first separately collected from 2015. Therefore, the data we used in our study are the best, and it is the most up-to date data collection that we can do. In this regard, the fuzzy set QCA fits perfect for this intermediate sized N.

Additionally, the pathways to a local energy transition may differ according to a country’s environment and economic conditions. Our results can provide more useful takeaways for countries where the energy transition process has not yet reached the average level of RE production. Indeed, in terms of energy transition, South Korea remains among the latecomers. In subsequent research,

we will expand on the most desirable pathway to a successful local energy transition by examining the cases of other countries, and subsequent research will also provide feedback regarding our results.

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## Appendix A

**Table A1.** Description of the outcome and causal set.

Set	Conditions	Raw Data	Unit	Measurement	Year	Reference
Outcome Set	Solar PV generation	Solar PV electricity generation (for housing)	MWh	-	2015	KESIS (Korea Energy Statistical Information System)
	Solar PV expansion rate	Solar PV expansion rate per year	percentage	-	2015–2017	KESIS (Korea Energy Statistical Information System)
Causal Set	Local commitment	Level of ICLEI membership	percentage	Number of ICLEI members/total number of local governments	2015	ICLEI South Korea
	Local legislation	Enactment of energy decree	percentage	Number of energy decrees in a region/total number of local governments	2015	Local Energy Plan
	Local financing	GRDP	Won	-	2015	Local Finance 365
	Environmental surveillance	Environmental NGO	number	Number of NGOs in a region	2016	Ministry of Environment

## Appendix B

**Table A2.** Descriptive statistics of cases.

Set	Conditions	Unit	Number of N	Minimum	Maximum	Mean	Median
Outcome Set	Solar PV generation	MWh	16	12,273	76,105	28,558	31,919.06
	Solar PV expansion rate	percentage	16	15.3	32.5	24.7	24.7
Causal Set	Local commitment	percentage	16	1	13	3.625	2
	Local legislation	percentage	16	0	80.6	32.11875	32.55
	Local financing	Won	16	15,366	352,857	97,828	67,564
	Environmental surveillance	number	16	0	109	11.1875	3

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