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The Factors of Local Energy Transition in the Seoul Metropolitan Government: The Case of Mini-PV Plants

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Abstract: As a way of enhancing urban sustainability, Seoul Special City, the capital of South Korea, has shown strong enthusiasm for urban energy transition by tackling climate change and expanding renewable energy. The Seoul Metropolitan Government (SMG) has adopted the "One Less Nuclear Power Plant (OLNPP)" strategy since April 2012 and specific policy measures, including a mini-photovoltaic (PV) plant program, were introduced to facilitate the energy transition. However, varying degrees of success were achieved by 25 district-level local governments (Gu) with mini-PV plant programs. This study explored the reason why those local governments showed different levels of performance despite the strong will of municipal government (SMG) to implement urban energy transitions through the mini-PV plant program. The tested hypotheses were based on capacity, political context, public awareness and geographical diffusion. The findings indicated that institutional capacity, financial dependence, political orientation and public perception had positively affected the performance of mini-PV plant installation at each district level. Especially, the political will of each district mayor played an important role in the implementation of the policy.

Keywords: One Less Nuclear Power Plant; mini-PV plant; sustainable city; energy transition; Seoul Metropolitan Government (SMG)

1. Introduction

Recent consensus on the need to tackle climate change through greenhouse gas (GHG) mitigation and the Fukushima Daiichi nuclear accident have justified the call for a faster transition from fossil fuels and nuclear power to renewable energies [1–6]. Most countries have devised and implemented national energy plans to accelerate the mitigation of carbon emission and the introduction of renewable energies [7]. The attempts for a more sustainable development and energy transition were also found at the city level [8,9]. Cities have the potential to play an important role in realizing a low-carbon economy as they are large energy consumers and GHG emitters, as well as direct regulators of energy production and distribution [10–16]. Therefore, cities can be forerunners in energy transition by installing renewable energy equipment, enforcing requirements for energy-efficient buildings, improving public transportation infrastructure and encouraging carpooling and biking [17]. Indeed, a number of municipalities, including Barcelona, London, New York City and Tokyo, have put initiatives into place to contribute to the mitigation of GHGs and to transition urban areas to green energy [13,18].

South Korea has established various policies on GHG reduction and urban energy transition both at the national and local level [19]. As the eighth largest energy consumer with a high dependence on imported fossil fuels (in 2014, the share of fossil fuels in South Korea's primary energy supply and electricity generation reached 83.2% and 65.8%, respectively, and dependence on primary energy sources from overseas was 95.2% [20]) and the seventh biggest CO_2 emitter in the world as of 2014 [20,21], South Korea has faced dual challenges of increasing energy self-sufficiency and decreasing carbon emissions. Growing concern about climate change and the rise in oil prices during the mid-2000s led South Korean governments to the realization that a new paradigm was necessary to replace the existing model of unsustainable rapid industrial growth. The "Green Growth Strategy" was announced in 2008 as a new national vision comprised of the following benchmarks: adopting policies reflecting an adaptation to climate change, the achievement of energy independence, the creation of new engines for economic growth and enhancement of South Korea's international status [22]. Under the strong political momentum of green growth, South Korean governments accelerated the measures for sustainable development and introduced key projects including a national GHG inventory system, energy efficiency of lighting equipment, greening of buildings, renewable portfolio standards (RPS) and an emission trading scheme [22].

The vision of green growth was designed mainly by the central government in a top-down manner, but it also encouraged the local governments to develop their own energy and climate policies. Seoul Special City, the capital city of South Korea, was the first municipal government to present a city-level vision of the low-carbon economy. Seoul Metropolitan Government (SMG) established a municipal climate fund in 2007 for the first time in South Korea and established the "2030 Seoul Low-carbon Green Growth Master Plan" in 2009, which targeted at the reduction of 2030 GHG levels by 40% compared with 1990 levels of these gases. [23] (pp. 62–63). A representative case is the "One Less Nuclear Power Plant (OLNPP)" project, which SMG launched in April 2012. Influenced by the Fukushima nuclear disaster and growing concern about climate change, SMG set a goal to increase the city's self-reliance on electricity and declared a pledge to pursue energy transition under a new slogan of OLNPP [24]. OLNPP is a municipal energy strategy to cope with climate change, environmental disasters and the energy crisis, either by reducing or by producing the equivalent amount of energy from one nuclear power plant, i.e., two million TOE (tons of oil equivalent). This strategy would be supported by increased energy efficiency, energy savings and renewable energy production [25].

OLNPP is unique and appreciable since it has taken a different stance to the policy framework of national government. The Green Growth Strategy and OLNPP shared the same objective to reduce GHGs in the energy sector, but they focused on different means to achieve this goal. Lee Myung-bak, former South Korean president (2008–2012) and an ardent proponent/supporter of green growth, has regarded nuclear power generation as a new major industry and as an effective way to achieve affordable low-carbon generation of electricity [22]. On the other hand, the goal of OLNPP has been to reduce reliance on fossil fuels and nuclear energy while emphasizing the importance of renewable energy and energy savings [26,27]. After the political will to achieve green growth weakened under the new Park Geun-hye administration, OLNPP has filled the void by pushing ahead with its plans. The change in the national growth priority from "green growth" to "creative economy" and the fall of oil and gas prices resulted in decreased support of the central government for renewable energy [19] and the reinforcement of a centralized energy system based on fossil fuels and nuclear energy [25]. In contrast, SMG set more ambitious goals when it launched the second phase of its program in August 2014 after exceeding expectations by achieving the goal of the first phase of saving two million TOE by the end of 2014 [26,27]. The OLNPP and other municipal-level strategies for urban energy transition drew attention from the international community, which led to awards, such as the 2013 Climate Action Leadership Award from the World Green Building Council (WGBC), the City Climate Leadership Awards 2014 from the C40 and Siemens and the Global Earth Hour Capital 2015 award from the World Wide Fund for Nature (WWF) and International Council for Local Environment Initiative (ICLEI) [26].

OLNPP instituted various sub-level programs that essentially required public awareness and citizen participation, such as Eco Mileage, which is an incentive scheme for citizens' energy savings, and a mini-PV plant, which supports the installation of small residential-scale photovoltaic (PV) panels. SMG relied on Gu (district) offices for promoting its policies and educating citizens to maximize the effects of green policies. SMG also implemented an incentive program to award the prize to Gu governments showing high performances [28]. While the momentum of energy transition was strong at the SMG level, the performance at the local district (Gu) level showed varying degrees of success. For example, the accumulated number of apartment-type mini-PV installed in each Gu ranged from 47 to 1322, as of June 2016.

Several studies pointed out the importance of voluntary compliance of local governments in climate change policy and the leverage of individual cities to decide their level of support [10,14,17,29]. However, these studies generally focused on programs developed voluntarily by local governments and implemented regardless of the involvements of either the state or national government Furthermore, many studies addressing policy diffusion between the federal government and state governments tended to focus on the mechanism that upper-level governments used to make lower-level governments adopt a certain policy [30–33], but rarely paid attention to how lower-level governments conformed to the federal or state policy. While most of the earlier studies on OLNPP and its sub-programs [23–25,34,35] suggested that capacity and participation of Gu governments should be increased for the success of OLNPP [25], only a few of them paid sufficient attention to these variations among the Gu governments. In this context, this study explores more explicitly the reason why Gu governments showed varying levels of performance in implementing OLNPP and installing the mini-PV plant despite the strong initiative from the municipal government.

Seoul is a megacity with a population of approximately 9.9 million as of 2015 [36], which is equivalent to 19.4% of the entire South Korean population. Its annual budget and collected local tax revenues were 36.3 trillion KRW and 15.4 trillion KRW as of 2014, respectively [37]. Considering that the population and financial size of this single city surpass that of most other major cities and provinces (Table 1), the case of SMG and its district government has relevant implications to the relationship between the city and local neighborhoods, as well as state and municipal governments.

Table 1. Population (2015) and financial indicators (2014) of major cities and provinces in South Korea.

Region		Population (Thousand)	Budget (Billion KRW)	Tax Revenue (Billion KRW)
National		51,069	220,336	-
Cities	Seoul	9904	34,275	15,409
	Busan	3449	12,222	3973
	Daegu	2466	8735	2592
	Incheon	2890	11,351	3219
	Gwangju	1503	5173	1428
	Daejeon	1538	5028	1549
	Ulsan	1167	4237	1611
	Sejong	204	760	387
Provinces	Gyeonggi	12,479	40,296	15,216
	Gangwon	1518	10,804	1474
	Choongbuk	1589	9052	1684
	Choongnam	2108	12,387	2625
	Jeonbuk	1834	12,195	1642
	Jeonnam	1799	14,525	1751
	Gyeongbuk	2680	18,480	2964
	Gyeongnam	3335	17,233	4195
	Jeju	606	3582	909

This paper consists of the following sections: the second section builds a series of hypotheses about the factors inducing local governments to engage in energy transition based on the literature review and theoretical considerations. The third section examines the case of OLNPP and its subprograms, the mini-PV plant program in SMG. The fourth section tests the hypotheses raised in the second section and explains the factors of energy transition in SMG. The conclusion summarizes the key finding of this study and discusses its implications.

2. Theoretical Background and Hypotheses

Policy diffusion studies provide assessments and explain the adoption and rejection of similar policies among different governments and the reason why those governments show a different level of readiness in accepting specific policies. Policy diffusion can be divided into two categories: vertical diffusion (from the state government to local governments, and vice versa) and horizontal diffusion (from a local government to other local governments or a nation to other nations). Whereas a policy can spread horizontally through competition, emulation and learning, a vertical diffusion often occurs through coercion [30–33]. According to the vertical policy diffusion literature, upper-level governments can affect the policy adoption of lower-level governments by "providing resources to help overcome obstacles that prevent innovation" [30] (p. 403) with the form of coercion. Coercion involves various tools, such as official mandates, military conflict, funding and legitimization. The national government often forces states and municipalities to comply with its core policies, gives financial incentives to implement new policy [30,31], legitimizes the new policy and hushes dissenting voices through advocacy campaigns [30]. However, lower-level governments do not always conform to the pressure from the upper-level governments. The theory of vertical policy diffusion does not clearly answer the question about what causes the varying level of conformity of local governments in spite of the coercion of upper-level governments. Therefore, this study tries to explain the response of Gu governments in SMG by using factors stated in the literature about horizontal diffusion and local climate change policy. Local contexts and characteristics wield strong influence over climate change policy adoption and diffusion in their cities [10,14,38]. Several factors contribute to the varying degree of performance of energy transition and climate change policy between the central and local level government.

First of all, capacity is an important factor in determining the level of performance. Administrative and financial capacity have been the traditional determinants of the commitment of local governments to federal policy. For a policy vision to be translated into real action, institutions, human and financial resources should be secured. The size of the organization and budget availability are key resources of governments; local governments with many employees and high financial capacities are more likely to adopt innovative policies, including climate change and low-carbon projects [39,40]. Capacity constraints, including insufficient funding and manpower, inexperienced staff and high staff turnover, are the usual difficulties for the state and local governments in implementing federal environmental programs at the state and local levels [17,41–43]. Since climate policy and the low-carbon policy are relatively new policy areas, local governments often do not have proper organizations and institutions [38] and information on possible opportunities and benefits that they can get from the new projects [44,45]. Furthermore, the insufficient budget of local governments may make officials hesitant about allocating budget to new climate and low-carbon projects [17]. Therefore, local governments need to establish a new institutional framework and create a new team of experts to be responsible for new duties [17,38].

Earlier studies showed that wealthy communities with high household incomes and per capita revenues were more likely to invest and conduct renewable energy programs [10,14,46]. On the other hand, if a policy contained financial aid from the national or state governments, local governments with low financial capacities and low fiscal self-reliance, tended to adopt the policy to get the subsidy and to revive the local economy [19,40]. Based on this literature, the following three hypotheses were tested in this study:

Hypothese 1 (H1). *Gu governments having high administrative capacities will show higher performance (Performance includes both aspects of effectiveness and efficiency, since it is evaluated not only by achievement level, but also by cost and speed. This paper, however, focuses on the effectiveness aspect of performance:*

performance basically refers to how well the Gu government conforms to the plan of SMG, and it is measured by the number of installed mini-PV plants).

Hypothese 2 (H2). *Gu governments having high financial capacities will show higher performance.*

Hypothese 3 (H3). *Gu governments having low financial capacities will implement a policy relying on a subsidy from SMG.*

Burch [38], however, noted that factors other than capacity also existed by explaining Canadian cities, which showed varying levels of performance in spite of sufficient financial, human and technical resources. Recent studies focused on political, cultural and economic contexts as major factors of diverging performance in environmental and energy policies.

Political context includes leadership and partisanship of the municipal and local electorate. Effective political leadership and policy entrepreneurs are requisites for successful diffusion and adoption of any new policy [17,38,47,48]. Although leadership and policy entrepreneurs can emerge from multiple levels, the most important driver is the political orientation of top leaders, such as governors and mayors, because they have the strong potential to set visions and agendas for their provinces and cities [34,45,49]. For instance, former Denver mayor, Wellington Webb, a proponent of economic growth coupled with environmentalism, instituted various environmental programs and strong initiatives in order to establish the environmental leadership of the city. Lee et al. [34] attributed the success of OLNPP of SMG as the product of firm actions from the mayor. The effect of partisanship is still debatable in the literature, but it has been argued that liberal states and communities with democratic political orientations tend to welcome government intervention to deal with air pollution [50–52], be more active on local climate action [10,14] and have more households heated with solar energy [46]. For instance, Daley and Garand [42] found an insignificant correlation between determining patterns of state hazardous waste policies and political variables, including party control of state institutions and liberal citizenries. Rather, another partisanship issue, such as whether leaders of upper-level and lower-level governments belong to the same party and whether the top leaders and the legislature share the same partisanship, becomes the more important issue. Inter-party conflicts are commonly found in the Congress [53], and different partisanship may be a factor to refuse the policy of upper-level governments, especially under the divided-government setting [54]. Based on these political contexts, the following hypotheses can be tested in the case of SMG:

Hypothese 4 (H4). *Gu governments with district mayors exhibiting strong political resolve will show higher performance.*

Hypothese 5 (H5). *Gu governments affiliated with a progressive party will show higher performance.*

Hypothese 6 (H6). *Gu governments with mayors from different parties than the SMG mayor will show low performance.*

Public awareness is relevant to psychological factors, such as preference, acceptance and beliefs of organizations and individual citizens [38]. Because a low-carbon economy is built only on the basis of every actor's concerted efforts at multiple levels, citizens' interests and participation are crucial to successful implementation of climate change and low-carbon policies [55]. Recognition of the seriousness of climate change and associated risks may attract citizens' interests and increase willingness to support climate policy [56,57]. Since risk perception can be understood through cultural rationality, which is geared toward personal and familiar experiences [58] (p. 132), demonstrable impacts of climate change and visible danger can trigger relevant policies [38]. Millard-Ball [59] also shows citizen participation in furthering environmental issues enables local governments to adopt climate and low-carbon policies. On the other hand, cultural and psychological factors may function as barriers to hinder the successful implementation of policy. Citizens may be reluctant to commit themselves to those policies because they do not share enthusiasm about renewable energy [44] or think individual action would not have a visible consequence [38]. To evaluate this evidence from the literature, the following hypothesis is tested:

Hypothese 7 (H7). *Gu governments with a high public awareness of climate change and low-carbon policies will show higher performance.*

Finally, a geographical diffusion was found in several policy cases. In the USA, state governments tend to adopt or tighten regulations if adjacent states have imposed stringent regulations [39]. For instance, city mayors whose neighbor cities participated in the U.S. Mayors' Climate Protection Agreement (MCPA) were more likely to join MCPA. This horizontal diffusion may be a result of communication and information sharing that occurs between officials in neighboring cities or of increased public pressure resulting from heightened regional awareness about the initiative [14] (p. 54). On the other hand, Shipan and Volden [32] argue that policy diffusion as geographic clustering may be misleading and outdated. They explain that the phenomenon that geographically-neighboring states adopt the same policy is not because of simple geographic proximity, but because of their political, economic and demographic similarities. Furthermore, the assumption that communication between neighboring local governments or states will be more frequent is outdated due to the development of communication technology and transportation. In this context, it necessitates a look at whether the classic view of geographic diffusion is relevant to Gu governments in Seoul:

Hypothese 8 (H8). *Gu governments with neighbors who show high performance will also show high performance.*

Economic factors are also important. When manufacturing is a major industry that supports the local economy, the government may not be able to push strong policies to mitigate GHGs due to the pressure from the industrial, sector as well as the concern about the effects of such policies on the local economy [14]. Some local governments, however, sometimes decide to invest in climate technology and renewable energy projects to develop the emerging market. They expect those projects will create new businesses and jobs and build their capacity to dominate future markets [12]. In this paper, the economic contexts of hypotheses were not tested, as the case study of the mini-PV plant program mainly focuses on the residential sector and, therefore, may not be relevant to measure the economic preference of commercial and industrial sectors.

3. Case and Data Collection

3.1. Case: One Less Nuclear Power Plant and the Mini-PV Plant Program

Seoul is a typical metropolitan city, which consumes a far greater amount of energy than it produces and emits a substantial amount of GHGs. In 2011, shortly before OLNPP was launched, Seoul consumed 46,903 GWh of electricity, 10.3% of the national electricity consumption, while generating only 1384 GWh, and emitted 90.9% of total annual GHG emissions (49 million tCO_2) in the energy sector (Figure 1) [27]. Under these conditions, a series of events occurred in the early 2010s that propelled SMG to recognize problems such as low energy self-sufficiency and to devise a policy to change this situation by using more sustainable energy. The direct trigger was power outages on 15 September 2011, which rang an alarm bell by causing supply and demand side shortages that precipitated a potential energy crisis. The major blackout was a warning signal that the level of energy self-sufficiency should be increased to ensure the energy security of Seoul [27,34]. Moreover, the conflict between the central government and the residents in Miryang, a rural area in the southern part of South Korea, over the construction of a high-voltage transmission tower made the issue of self-sufficiency of Seoul assume ethical importance [24,34]. Many transmission towers and grid lines were needed for electricity supply to the major cities. Miryang residents, however, resisted the government's decision on the grounds that the electromagnetic waves from high-tension wires and towers would be harmful to them. This event highlighted ethical issues of sacrificing rural residents for the sake of the electricity supply to big cities, such as Seoul [24]. Furthermore, the Fukushima nuclear accident in March 2011 served as a wakeup call case to alert cities to the danger of nuclear energy and to emphasize the need for renewable energy.

At that time, South Korea depended on nuclear energy for 31% (154,723 GWh) of its total national electricity generation [60], and the central government had a plan to expand nuclear power plants to cope with increasing energy demands [61]. The Fukushima Daiichi nuclear disaster and consequent declarations of nuclear power phase-out from a few countries encouraged Seoul to have the vision to increase energy self-sufficiency with more sustainable energy [34]. In April 2012, SMG finally launched OLNPP, which aims to reduce energy demand and increase renewable energy sources in order to mitigate GHGs and to leave a desirable environment to the next generation [27].

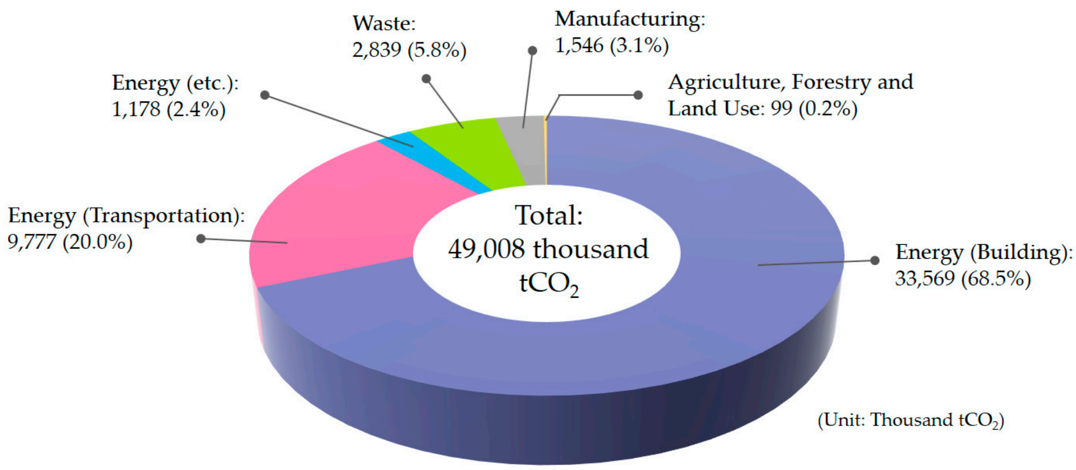


Figure 1. GHGs emissions of Seoul in 2011 [27] (p. 122).

Under the OLNPP Phase 1 (2012–2014), SMG aimed to replace two million TOE (8760 GWh) by 2014, which is equivalent to the amount of generated electricity from one nuclear power plant, into renewable energy production, more efficient energy use and energy savings, thereby reducing dependence on conventional energy sources, including nuclear energy. According to the 'Comprehensive Plan for OLNPP (2012–2014)', which SMG announced in April 2012, OLNPP policy was divided into three areas—renewable energy production, energy efficiency and energy saving—and consisted of six policy categories—expand production of renewable energy in order to build a retrofit program (BRP), establish an environmentally-friendly and high-efficiency transportation system, create jobs in the energy industry, shift to a low-energy and urban spatial structure and create a civic culture promoting energy conservation—as well as 78 sub-programs [27,60]. Key sub-programs in three areas are presented in Table 2.

Table 2. Key sub-programs of "One Less Nuclear Power Plant (OLNPP)" Phase 1.

Area	Key Sub-Programs
Renewable energy production	• Building PV plants and hydrogen fuel cell stations • Utilizing heat from incineration and sewage wastewater treatment • Producing Seoul solar map • Seoul-type feed-in tariff (FIT)
Energy efficiency	• Building retrofit program (BRP) • Replacing indoor light bulbs into highly energy-efficient LEDs
Energy savings	• Eco Mileage • Energy Guardian Angel Corps • Good Shops program • Car sharing

As of June 2014, a total of 1.33 trillion KRW (247.3 billion KRW of municipal funds, 48.7 billion KRW of national funds and 1.04 trillion KRW of private capital) were spent in implementing OLNPP [61]. SMG achieved its two million TOE goal, recording 2.04 million TOE in the first half of 2014 (Table 3). This performance is more remarkable compared to the whole nation and other major cities. Whereas the national electricity consumption rose by approximately 2.4% from 2012 (466,593 GWh) to 2014 (477,592 GWh), Seoul registered an approximately 4.7% decrease from 47,234 GWh–45,019 GWh [62]. Other major cities, except for Busan, also presented increased or unremarkable decreases in electricity consumption (Figure 2).

Table 3. Performance of OLNPP Phase 1 (unit: thousand tons of oil equivalent (TOE)).

Sector	Goal	Performance			
		Total	2012	2013	2014
Energy production	410	260	35	78	147
Energy efficiency	1110	869	145	328	396
Energy savings	480	911	151	515	245
Total	2000	2040	331	921	788

Source: [27] (p. 129).

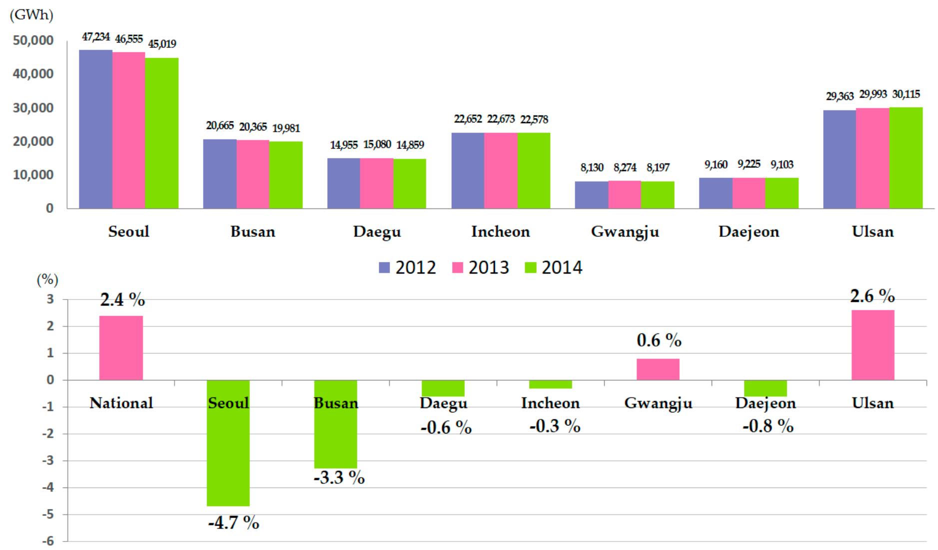


Figure 2. Changes in electricity consumption in South Korean major cities (2012–2014) GHGs [62] (p. 188).

SMG began discussions on OLNPP Phase 2 in January 2014 in anticipation of exceeding expected goals and set the new vision, "Seoul, an Energy Self-Reliant City", and the new goal to achieve 20% of self-sufficiency in electricity by 2020. SMG revealed its ambitions to realize energy self-reliance, energy sharing and energy participation through institutional reform and social structure innovation [63]. In comparison to the Phase 1, OLNPP Phase 2 tended to place more emphasis on citizen participation. For instance, SMG focused on the promotion of large-scale projects for renewable energy production during Phase 1, but it declared a small-scale participatory, decentralized production system in Phase 2 [63]. As of 2014, the proportion of residential electricity consumption used in Seoul was higher than the national level: Seoul recorded 28.64% (12,892 GWh out of 45,019 GWh), but the national level was 13.12% (62,675 GWh out of 477,592 GWh) [62]. Moreover, apartments are the most popular types of residence (44.8%) in Seoul [64]. Considering such housing types and characteristics of electricity consumption in Seoul, demand management of residential buildings, particularly apartments, was of considerable importance [24]. Furthermore, the large-scale renewable energy facilities installed during Phase 1 did not contribute significantly to the improvement of the self-sufficiency of Seoul. For these reasons, SMG proposed the installation of small-scale PV equipment in Phase 2 [63].

SMG has been aggressively implementing the mini-PV plant program for apartments, which can be seen from the fact that SMG designated the program as one of ten core projects of OLNPP Phase 2 [63]. The mini-PV plant program supports part of the installation costs for those who want to install small-scale PV panels in the balconies of apartments. The amount of the subsidy varies depending on the capacity of the module: residents can receive 1500 KRW/W for less than 200-W modules, 1000 KRW/W for 200–500-W modules and 500 KRW/W for 500–1000-W modules. SMG began this program with approximately 2500 households for the pilot in 2014 and had a plan to distribute 10,000 mini-PV plants every year, thereby building 40,000 plants by 2018 [24,63]. The keen interests and participation of district governments and citizens are essential to achieving the goals, but the performance records show that not every Gu government and citizen tapped into the SMG's enthusiasm. This paper explores factors that caused those differences.

3.2. Data Collection

As the mini-PV plant program does not have a long history, it is difficult to construct solid datasets based on observations. Since statistical inferences through regression analysis with insufficient datasets may not have real-world significance, this study tries to explain the gaps in policy implementation among Gu governments without regression. Instead, various descriptive statistics, graphs and close examination of qualitative data, such as transcripts of SMG and Gu councils, administrative documents and newspaper articles, are used to understand and visualize the performance differences. The four factors—capacity, political context, public awareness and geographical diffusion, as stated in hypotheses—are measured with several indicators collected from various sources (Table 4). Performance, the dependent variable, is measured by the number of installed mini-PV plants in each Gu. Capacity is comprised of institutional capacity and financial capacity. The number of relevant government employees and the existence of ordinances on climate change and low-carbon green growth show the institutional capacity, and the amount of collected local tax and tax per household, as well as financial independence indicate the financial capacity of the Gu government. Political context includes political inclination indicated with the party orientation of the district mayor and the district council members, and the political will of the district mayor inferred from council transcripts and ICLEI membership. Public awareness measures citizens' perceptions of climate change and governments and energy-saving lifestyles. Finally, geographical diffusion is presented in the maps. The most recent data were collected: performance, geographical data and ICLEI membership as of June 2016 and the other indicators as of December 2014.

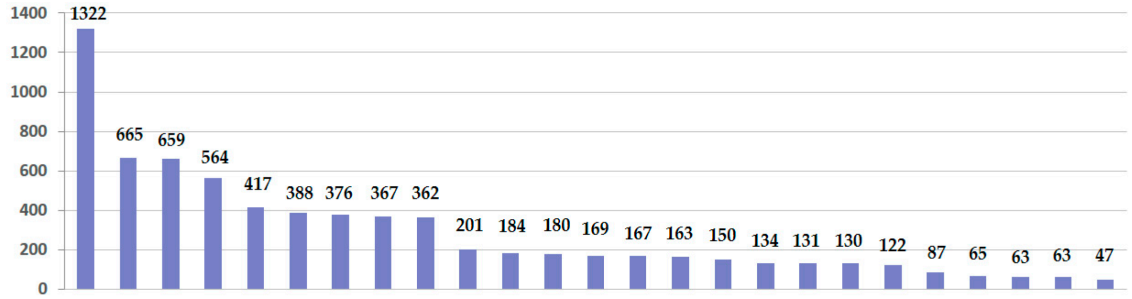
Table 4. Data collection. ICLEI, International Council for Local Environment Initiative.

Category	Indicators (Data)	Source
Performance	• The number of mini-PV plants installed	• SMG
Capacity	• The number of relevant staff • Existence of ordinance on climate change and low-carbon green growth • The amount of collected local tax • The amount of tax per household • Financial independence of Gu	• Web pages of each Gu • Seoul Legal Administrative Services [65] • Seoul Statistical Yearbook 2015 [64] • Seoul Statistical Yearbook 2015 [64] • Seoul Statistical Yearbook 2015 [64]
Political context	• The party of mayor of Gu • The proportion of progressive party council members • Will of mayor of Gu governments • ICLEI membership	• Web pages of each mayor of Gu • Seoul Metropolitan Council [66] • Council transcripts and newspaper articles • ICLEI Korea Office [67]
Public awareness	• Risk perception scores • Trust in governments • Energy saving practice scores	• 2015 Seoul Survey Report [68] • 2015 Seoul Survey Report [68] • 2015 Seoul Survey Report [68]
Geographical diffusion	• Map of Seoul	• Korea National Spatial Data Information Portal [69]

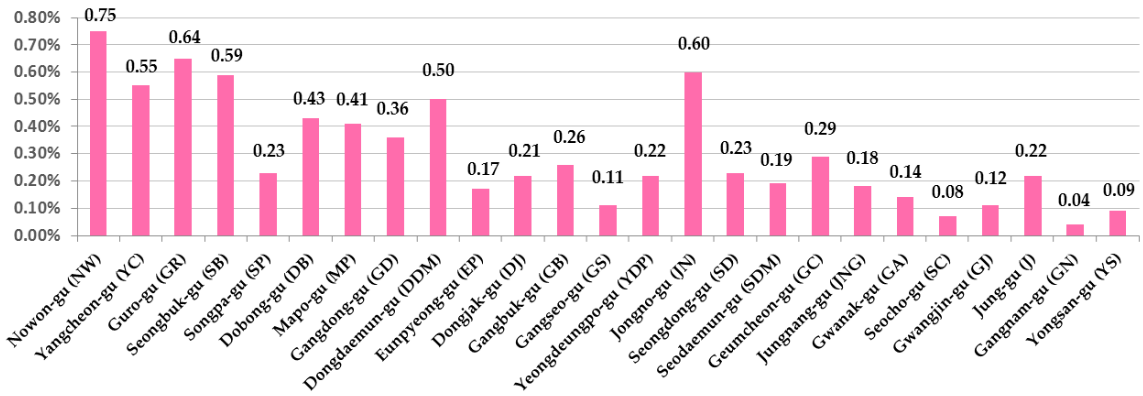
4. Analysis and Discussion

4.1. Performance Gap among Gu Governments

The SMG's ambition of mobilizing active participation from all district-level (Gu) governments on the mini-PV plant program met varied outcomes. As of June 2016, 7176 mini-PV plants for apartments were installed in Seoul. In Yongsan-gu, a mere 47 plants were installed, while 1322 plants were installed in Nowon-gu (Figure 3a). This can draw criticism, as the number of mini-PV plants installed varied from one Gu district to the next district; the absolute number of installed plants might not be appropriate for comparing policy implementation levels, since Gu with more apartments may also have more mini-PV plants. Thus, this study used the proportion of apartment units where mini-PV plants were installed out of all apartment units in each Gu as presented in Figure 3b. The proportion also varies depending on each Gu: Nowon-gu has the highest proportion, 0.75%, and Gangnam-gu has the lowest proportion, 0.04%. As shown by these very low proportions, the mini-PV plant program is a fledgling program with aims to expand absolute quantities in order to achieve the main SMG goal, 40,000 plants, by 2018.



(**a**)



(**b**)

Figure 3. (**a**) The number of installed mini-PV plants by Gu district; (**b**) the proportion of apartment units where mini-PV plants were installed out of all apartment units in the Gu districts.

4.2. Capacity

The number of government employees who work in the climate change or renewable energy teams and the existence of Gu-level ordinances on climate change and low-carbon green growth were used for administrative capacity indicators, and the amount of local tax collected, the tax per household and financial independence of Gu were used to gauge the financial capacity of Gu governments. Table 5 presents correlation coefficients between the performance of mini-PV plant installations and capacity indicators of Gu governments.

Table 5. Correlation coefficients between the performance of mini-PV plant installation and capacity indicators.

Category	Indicators	The Number of Mini-PV Plants Installed	The Proportion of Mini-PV Plants Installed
Administrative	The number of relevant government employees	0.3819 *	0.1503
	Ordinance on climate change	0.5362 ***	0.3228
	Ordinance on low-carbon green growth	−0.1211	−0.0628
Financial	Local tax collected	−0.2735	−0.3623 *
	Tax per household	−0.3378 *	−0.1823
	Financial independence	−0.4246 **	−0.3246

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

A significant correlation exists between the ordinance on climate change and mini-PV plant installation. Figure 4 compares the number of mini-PV plants installed in Gu governments having an ordinance on climate change and those in Gu governments without a climate change ordinance. The average number of mini-PV plants installed in eight Gu governments with a climate change ordinance, 503.4, is much higher than the other 17 Gu governments, i.e., the average number was 185.2 plants. Another ordinance covering the dissemination of renewable energy, i.e., the ordinance on low-carbon green growth, does not show significant correlation with the number of installed mini-PV plants. However, it is noteworthy that, among 17 Gu governments without a climate change ordinance, three Gu governments ranked as the lowest—Jung-gu (J), Gangnam-gu (GN) and Yongsan-gu (YS)—have not even established an ordinance on low-carbon green growth, and some Gu governments showing relatively high performance, such as Seongbuk-gu (SB) and Dongdaemun-gu (DDM), have an ordinance on low-carbon green growth. This phenomenon may infer that the district-level governments possessing relevant institutional and legal frameworks are more likely to successfully implement a particular policy.

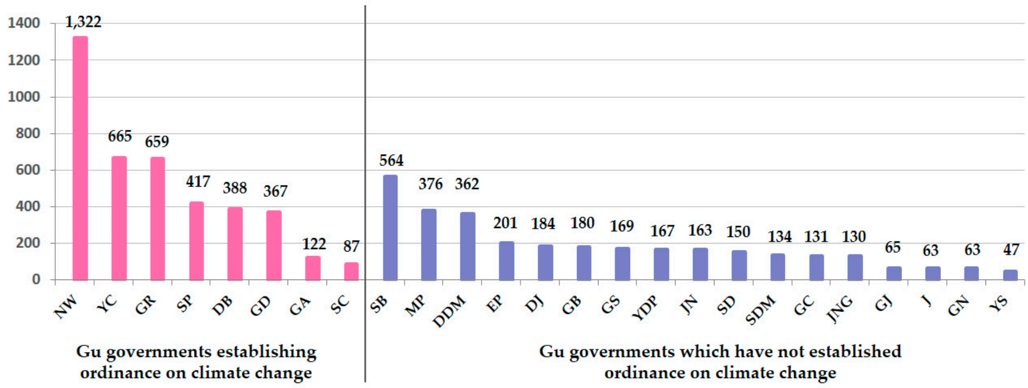
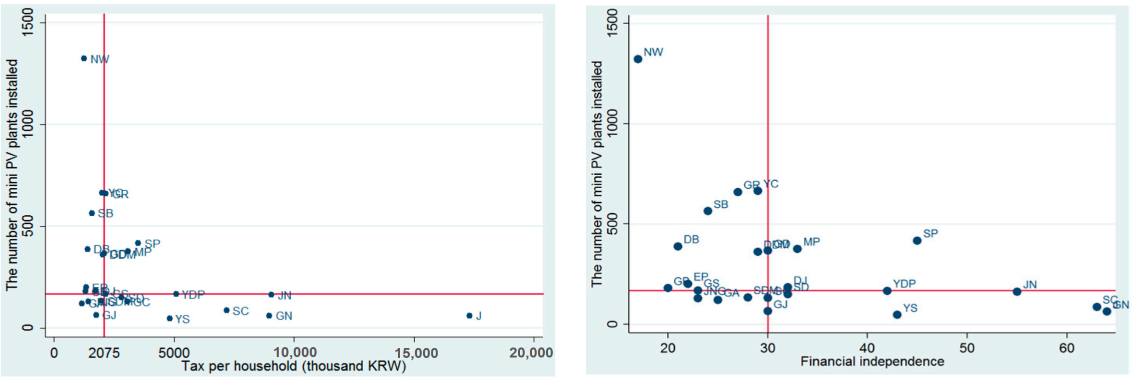


Figure 4. Comparison of the number of mini-PV plants: Gu governments that have established ordinances on climate change versus those who do not have ordinances.

The correlation between human resources measured by assessing the number of employees that form part of the environmental team and the number of mini-PV plants is not clear. Gu governments assigned 4–16 people to the teams dealing with climate change and renewable energy issues. The patterns vary: small staff and high performance (Songpa-gu (SP) and Mapo-gu (MP)), large staff and high performance (Nowon-gu (NW) and Gangdong-gu (GD)), small staff and low performance (Gwangjin-gu (GJ) and Yongsan-gu (YS)) and large staff and low performance (Gangnam-gu (GN) and Seocho-gu (SC)).

Figure 5a presents the relationship between the number of mini-PV plants installed and tax amounts per household, indicating the income level of residents and the wealth of the Gu governments, with red lines referring to the median value of each variable. While the most affluent Gu governments, such as Jung-gu (J), Gangnam-gu (GN), Jongno-gu (JN) and Seocho-gu (SC), show very low performance of mini-PV plant installation, Nowon-gu (NW), Seongbuk-gu (SB) and Dobong-gu (DB), which have tax amounts per household below the median, show very high performance. For financial independence, the correlation coefficient and the scatter show that the Gu governments with low financial independence from SMG tended to install more mini-PV plants. This supports Hypothesis 3: Gu governments with low financial capacities are more likely to implement a policy relying on a subsidy from SMG.



(**a**) (**b**)

Figure 5. Scatter plots of the number of mini-PV plants installed and financial capacity of the Gu governments: (**a**) tax amounts per household; (**b**) financial independence.

4.3. Political Contexts

Table 6 presents correlation coefficients between mini-PV plant installation and political factors. Political factors are divided into two categories: the characteristics of the district mayors of Gu governments and the political composition of the electorate. First, earlier studies in the U.S. pointed out that states and communities showing Democratic political orientations were more active in local climate action and renewable energy programs [10,14,46]. In the mini-PV plant case, Hypothesis 5, Gu governments supporting a progressive party will show higher performance, is partly supported by the data. The political affiliation of the current mayor of Seoul was the Minjoo (Democratic) Party, an opposition party. According to Table 6, the Gu governments having the same political orientation as the mayor showed higher performance with respect to mini-PV plant installation. The political orientation was defined by a major party of the Gu government council. However, Gu governments having a higher proportion of the Minjoo Party council members did not always show higher performances. From this result, it can be argued that the important driver for implementation of the mini-PV Plant program was not the overall political atmosphere of the conservatism or progressivism of the electorates, but the same party affiliation of the district mayor, the Gu government council and the SMG mayor. The correlation of the mini-PV plant installation and the party affiliation of the mayor of Gu governments can be explained in the same vein. Figure 6 presents the performance of five Gu governments whose mayors belong to a different party than the mayor of Seoul. Their average number of mini-PV plants installed is 152, which is lower than the average number for the other 20 governments, i.e., 320.8. This result suggests that the district mayors of Gu from a different party than the mayor may not give full cooperation to the SMG or mayor's policy.

The political orientation of the district mayor, however, does not explain everything, as Songpa-gu (SP) shows relatively high performance, although its mayor belongs to the Saenuri Party. Rather, the willingness of mayors of Gu governments seems to exert more power to implement the policy. Indeed, Songpa-gu has been implementing its own energy sharing plant, investing money in solar plants and using their profits to assist low-income people since 2009. Taken together, these facts demonstrate the strong will of the previous district mayor. One of the indicators that shows the district mayors' awareness of climate change and the political will to handle the issue is membership in ICLEI-Local Governments for Sustainability, the global network of cities committed to becoming a more sustainable and resilient community [67]. Since ICLEI requires the commitment of sustainable development and climate change mitigation and its members should pay annual fees for membership, it is difficult to join ICLEI without the district mayor's decision. In Figure 6, seven Gu governments with ICLEI membership show relatively high performance in terms of mini-PV plant installation. The average number of installed PV plants is 448.4, whereas only 224.2 plants on average were installed by the other 18 governments.

Table 6. Correlation coefficients between the performance of mini-PV plant installation and political indicators.

Category	Indicators	The Number of Mini-PV Plants Installed	The Proportion of Mini-PV Plants Installed
District Mayor	The same party as the mayor of SMG	0.2440	0.3929
	ICLEI membership	0.3636 *	0.4288 **
Electorate	The proportion of progressive party	0.2818	0.3590 *
	The same party as the mayor of SMG	0.4131 **	0.3695 *

** $p < 0.05$, * $p < 0.10$.

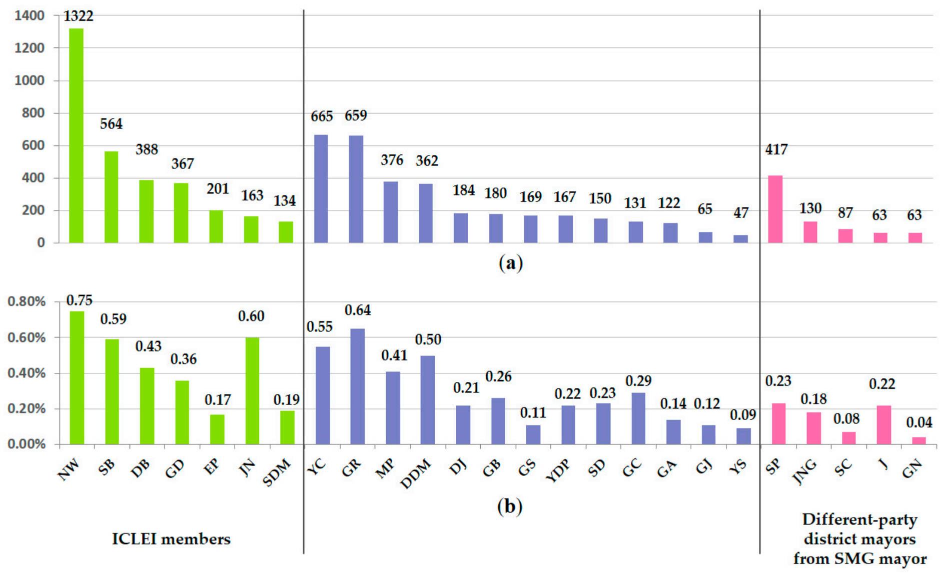


Figure 6. Comparison of the performance of mini-PV plant installation depending different political conditions: (**a**) The number of installed mini-PV plants; (**b**) the proportion of apartment units where mini-PV plants were installed.

4.4. Public Awareness

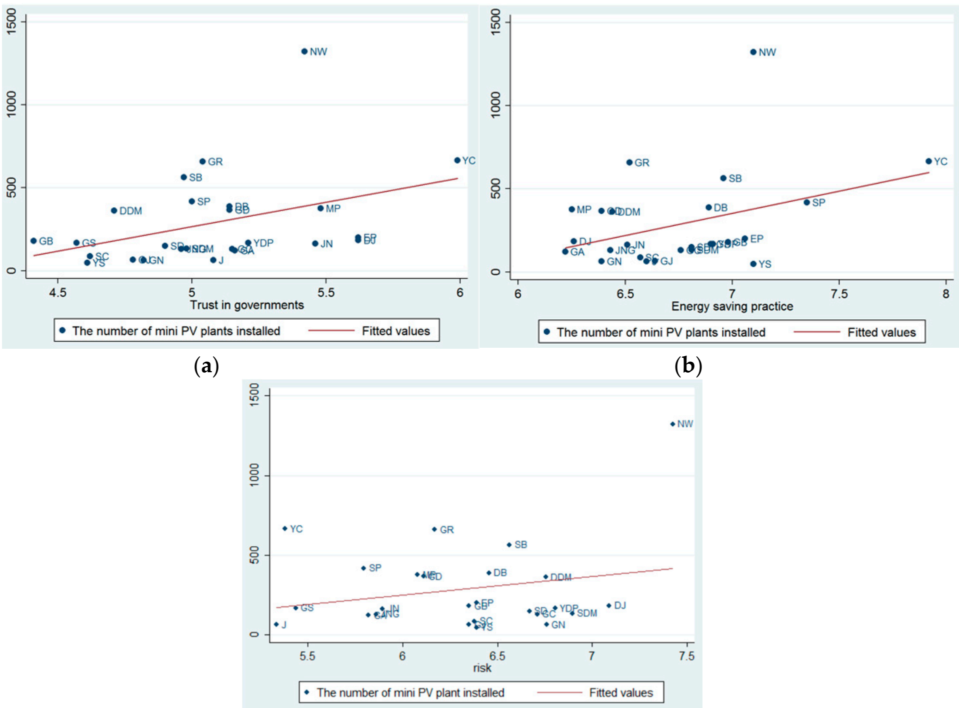
Public awareness includes the perception and practice of each citizen. Even if the SMG and Gu governments hoped to expand mini-PV plants aggressively, it was difficult to achieve the goal without residents' permission because the mini-PV plant is installed in their houses. Based on this perspective, public awareness and perception of climate change and renewable energy, as well as an understanding of the mini-PV plant program are regarded as important factors to determine the success of the program. Table 7 presents the correlation between mini-PV plant installation and cultural factors. Public perception was measured by self-reporting scores based on the perception of natural and nuclear disasters, and trust in governments. Energy saving practices were also measured by self-reporting scores on energy savings, such as electricity and water savings [68].

The indicators showed significant correlations between trust in governments and energy savings. As shown in Figure 7a,b, Gu governments whose residents have more trust in governments and more energy saving practices are more likely to install mini-PV plants. It is not surprising that citizens who trust their governments will have high acceptance rates and compliance with the policies of those governments, and citizens who want to save energy will install renewable energy equipment to save finite resources and electricity bills. Perceptions of natural and nuclear disasters do not show a significant correlation with the number of installed mini-PV plants, except for the interesting case of Nowon-gu (NW). The *X* axis of Figure 7c is the average score for the perceptions of natural and nuclear disasters. Nowon-gu recorded the highest scores in both surveys and on the performance of mini-PV plant installation. In November 2011, a citizen detected, by chance, that the asphalt of Wolgye-dong in Nowon-gu was contaminated with radiation, and Nowon-gu removed and repaved those contaminated asphalts. This accident led the mayor of Nowon-gu to focus on energy transition [24]. This event also may have had an influence on the citizens. Residents in Nowon-gu may have been frightened by the radioactive contamination of their towns after viewing images of the Fukushima Daiichi nuclear disaster and might have become more interested in renewable energy issues.

Table 7. Correlation coefficients between performance of mini-PV plant installation and perceptional indicators.

Category	Indicators	The Number of Mini-PV Plants Installed	The Proportion of Mini-PV Plants Installed
Perception	Perception of natural disaster	0.2213	0.1386
	Perception of nuclear disaster	0.1929	0.0698
	Trust in governments	0.3893 *	0.4319 **
Practice	Energy saving	0.3686 *	0.1910

** $p < 0.05$, * $p < 0.10$.



(**a**) (**b**) (**c**)

Figure 7. Scatter plots of the number of mini-PV plants installed and cultural factors of Gu governments: (**a**) trust in governments; (**b**) energy saving practice; (**c**) risk perception.

The survey conducted by Baek and Yun [24] gives more implications about public awareness. Residents of Nowon-gu installed the mini-PV plants because of subsidies, concerns about climate change and resource depletion, as well as anxiety about nuclear power plants. On the other hand, residents who did not install the mini-PV plants responded that they would not consider installations because of the cost, inappropriate location and bad appearance. Furthermore, a public official of Gangnam-gu stated that the building owners were reluctant to apply to have mini-PV plants installed due to the cost and the appearance of the building [70]. Such survey results reveal that cultural and psychological factors play important roles in executing the strategy to engage citizens to participate in the mini-PV plant program.

4.5. Geographical Diffusion

The distribution of mini-PV plants by Gu is visualized in Figure 8 to determine the presence or absence of geographical policy diffusion. Figure 8a,b shows respectively the equal interval map and natural break map based on the number of mini-PV plants installed in each Gu. As shown in the figures, it seems difficult to assert that Gu governments with neighbors that have a large number of installed mini-PV plants also have many plants. For example, the number of plants installed in Jungnang-gu (JNG) is below the average, although its neighbors, Nowon-gu (NW), Seongbuk-gu (SB) and Dongdaemun-gu (DDM), have relatively high installation levels. Figure 8c,d shows the interval and natural break maps based on the proportion of apartment units with installed mini-PV plants. It is still unclear, however, whether spatial autocorrelation exists even though some clustering patterns are clearer than those in Figure 8a,b. Surrounded by neighbors showing a high proportion, such as Dongdaemun-gu (DDM), Gangdong-gu (GD), Yangcheon-gu (YC) and Mapo-gu (MP), Gwangjin-gu (GJ) and Gangseo-gu (GS) show a low proportion of mini-PV installation.

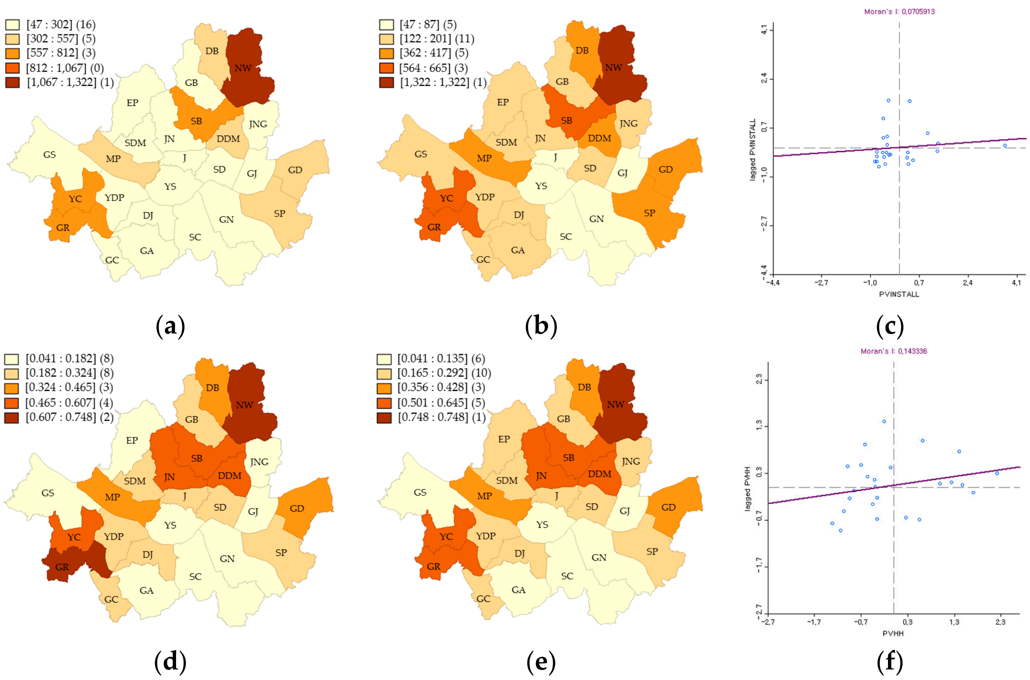


Figure 8. Geographical distribution of mini-PV plant installation: (**a**) equal interval map of the number of mini-PV plants installed; (**b**) natural break map of the number of mini-PV plants installed; (**c**) Moran scatter plot of the number of mini-PV plants installed; (**d**) equal interval map of the proportion of apartment units where mini-PV plants were installed; (**e**) natural break map of the proportion of apartment units where mini-PV plants were installed; (**f**) Moran scatter plot of the proportion of apartment units where mini-PV plants were installed.

Moran's I, the most commonly-used statistical test for spatial autocorrelation in univariate map patterns [71] (p. 187), for both cases is insignificant at the 95% confidence level. Moran's I for the number of mini-PV plants case is 0.071, and the p-value = 0.17 with 999 permutations. Moran's I of the proportion case is 0.143, and the p-value = 0.10 with 999 permutations. No evidence was found to reject the null hypothesis that there is zero spatial autocorrelation. Therefore, the hypothesis of Gu governments having neighbors with high performances leading to similar high performances cannot be supported in the mini-PV plant installation. Moran scatter plots are presented in Figure 8c,f.

4.6. Discussion

The overall result of the hypotheses test is summarized in Table 8. For the capacity factors, organizational capacity measured by human resources did not have a significant correlation with the performance of mini-PV plant installation, whereas institutional capacity and legal framework might have been helpful for successful policy implementation. Gu governments having low financial independence were more likely to implement the mini-PV plant program, which was accompanied by subsidy of SMG, but Gu governments with high financial capacities showed rather lower levels of performance. Political factors were important for successful policy implementation. Gu governments whose district mayor and the majority of the Gu council belonged to the same Minjoo party as the SMG mayor showed relatively higher performances, and the strong political motivations of district mayors' governments were found to be major drivers of mini-PV plant installation. Public awareness, such as risk perception of climate change and nuclear disaster, practice for energy saving and trust in government, was also a necessary condition. Finally, the performance of the mini-PV plant installation did not show spatial autocorrelation in terms of geographical diffusion.

Table 8. Test results for each hypothesis.

Category	Hypothesis	Result
Capacity	1. Gu governments having high administrative capacities will show higher performance.	Partly Supported
	2. Gu governments having high financial capacities will show higher performance.	Not Supported
	3. Gu governments having low financial capacities are more likely to implement a policy relying on subsidy from SMG.	Supported
Political context	4. Gu governments with district mayors exhibiting a strong political resolve show higher performance.	Supported
	5. Gu governments supporting progressive parties will show higher performance.	Partly Supported
	6. Gu governments whose mayor belongs to a different party from the SMG mayor will show low performance.	Supported
Public awareness	7. Gu governments where citizens exhibit a high public awareness of climate change, and low-carbon concept will show higher performance.	Supported
Geographical diffusion	8. Gu governments have neighbors who show high performance will also show high performance.	Not Supported

The crucial factors to implement successful mini-PV installations were administrative capacity, financial capacity and the political will of each district mayor. First, the most obvious correlation was found to be between an ordinance on climate change and mini-PV plant installation. Considering that the provisions of the climate change ordinance typically stated the responsibility of local governments to make efforts for mitigation and adaptation to climate change, officials and council members of Gu governments with a climate change ordinance might have a better understanding of the importance of GHG reduction and renewable energy and regarded the mini-PV plant program as a good opportunity to follow their ordinances.

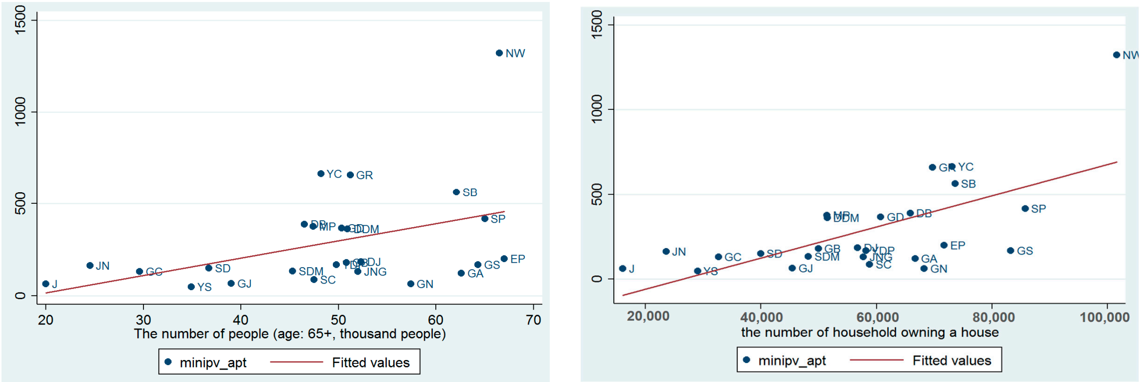
Second, an interesting finding was a correlation between financial capacity and the number of mini-PV plants installed. Many studies have found a positive relationship between community wealth and the adoption of renewable energy programs [10,14,46], but mini-PV plant installation produced a somewhat negative result. The richest Gu governments showed very low performance of mini-PV plant installation, but Gu governments having tax amounts per household below the median showed a relatively high level of installation. This raised doubt that additional factors may impact the adoption and performance of renewable energy programs. One possibility was the financial independence of

Gu governments. The analysis showed that the Gu governments with a low financial independence from SMG tended to install more mini-PV plants. It can be interpreted that financially dependent Gu governments are more likely to comply with SMG's policy. The financial aid from SMG could be a good option to prepare their budget and implement the new programs for Gu governments, which did not have a budget surplus to be allocated to new programs. Even if a Gu government recognized the seriousness of climate change and importance of renewable energy, investing a considerable sum of money in renewable energy programs would face resistance because many other programs the government should pursue, including welfare and education, were also waiting for continuous funding. In this situation, a subsidy from SMG could be a solution to allow the Gu governments to implement renewable energy programs by securing external funding sources. Furthermore, Gu governments would be eager to enhance their performance since Gu governments with high performance and exhausted financial support more easily obtained more subsidies in the following year.

Third, as shown in the case of Songpa-gu briefly introduced in Section 4.3, the will of the district mayor was an important factor to conform to SMG's policy and pursue energy transition in the Gu government. The representative that exemplified a district mayor of a Gu government with the strong will of PV generation was Nowon-gu (NW). The Mayor of Nowon-gu was a fervent supporter of renewable energy, solar energy in particular. For example, he encouraged officials of Gu office to join the "Solar and Wind Generation Cooperative Union" so that about half of the union members could be public officials [35]. Moreover, when this Union planned to build a solar PV plant in the parking lot of the Gu office, he found that a provision of the existing energy ordinance was a barrier for the construction and amended the ordinance to facilitate the construction of the solar PV plant. On the contrary, Gangnam Solar Generation Cooperative Union having the same problem finally gave up the original site since the Gangnam-gu government adhered to the existing energy ordinance [35]. Nowon-gu was the first Gu government that implemented the mini-PV plant program before the SMG's policy. It allocated 120 million KRW to the installation of mini-PV plants for 400 households in 2014 [24]. After the SMG's implementation, Nowon-gu distributed flyers and posters to promote the mini-PV plant program and held information sessions for the residents. Moreover, if more than 10 households apply for the mini-PV plant installation together, the Gu government gave them an additional subsidy of 50 thousand KRW. Emphasizing renewable energy dissemination despite insufficient budget and strong objection of a Gu council member from the different party [72–74] could be interpreted as the realization of the district mayor's motivation. Similarly, Guro-gu (GR) and Yangcheon-gu (YC), which gave additional subsidies in 2015, presented higher performance.

On the other hand, geographical diffusion has not occurred yet. As Shipan and Volden [32] stated, geographical proximity no longer enjoys the advantage of communication and information sharing as much as in the past. Moreover, actual economic or welfare benefits that residents received from the installation of mini-PV plants were not assessed as the mini-PV Plant program has been in the initial stage. This means that the time is not yet ripe for horizontal policy diffusion through competition and learning among Gu governments.

Future research may include demographic and socioeconomic characteristics of residents of each Gu. Figure 9 shows that the mini-PV plant installation and the number of elderly people, and mini-PV plant installation and house ownership have moderately positive relationships. Demographic factors are often considered in research on the public awareness, but are rarely involved in policy diffusion research. Considering the mechanism that demographic characteristics may cause a difference in public awareness and public awareness may affect the adoption of policy, demographic factors may be worthy of attention. Furthermore, the interesting factor is home ownership. The trend that Gu governments having more homeowners show better performance on mini-PV plant installation infers that some people do not install mini-PV plants, even if they have a preference for renewable energy, and want to install mini-PV plants only because they have leases on their houses.



(**a**) (**b**)

Figure 9. Scatter plots of the number of mini-PV plants installed and demographic and socioeconomic factors of Gu governments: (**a**) the elderly; (**b**) household owning a house.

5. Conclusions

This paper found the gaps in policy implementation and performance among Gu governments under the SMG in the case of the mini-PV plant and tried to explain the causes of these differences by testing the eight hypotheses. Among the outcomes following the tests of the different hypotheses, an interesting phenomenon was found in the aspects of the financial capacity, which would distinguish SMG from other country cases. It was also found that some factors, such as home ownership and the number of the elderly, that the policy diffusion theory hardly involves may have a correlation with the expansion of renewable energy.

As the history of the mini-PV plant program is still short, the finding of this study might inevitably be limited. In addition, the lack of full data and the short history of the program led to methodological limitations and a reliance on descriptive statistics. Future, carefully executed studies should focus on monitoring and robust quantitative re-evaluation of this program based on more accumulated data to supplement current study findings.

However, the exploration of the initial stage of local energy transition in SMG is still important to gauge the future progress of ONLPP and other sustainable development measures in SMP. Furthermore, analyzing the relationship between city- and district-level governments, which attracted less attention in the policy diffusion research, may open more opportunities for future research. Shipan and Volden [32] argue that policy diffusion is also affected by the visibility of the actual policy. If the effects of a policy are clear and highly observable, the policy will spread much faster. In order to achieve the goal of SMG to spread energy transition through renewable energy dissemination, the effects and benefits of mini-PV plants need to be fully shared among residents and mayors of Gu governments. Finally, institutional improvement to lower barriers that impede mini-PV plant installation by tenants, such as reinstallation after moving, should also be considered as a future task.

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