# Smart Energy Transition: evaluation of cities in South Korea

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**Abstract:** One of the major objectives of smart city development is achieving energy efficiency and moving towards a low-carbon energy society. The idea is that ICT-embedded urban infrastructure can enable efficient energy management and contribute to reducing CO2 emission. In that sense, a smart city can play an important role in the energy transition. In South Korea, the government plays a major role in smart city development. Since the 2000s the governments implemented informatization and digitalization and since 2008 they started smart city implementation across the country. Then how these government-led smart city initiatives perform in the energy transition? The purpose of this paper is to discover the contribution of government-led smart city initiatives in the energy transition. After building a conceptual framework on smart city and energy transition, we develop a Smart Energy Transition Index. The 161 cities in South Korea are grouped into three categories: 1st and 2nd wave smart cities and non-smart cities. The index score is compared among the groups and the analysis showed that there is a significant difference between 2nd wave smart cities and the 1st and the non-smart cities. The analysis provided empirical evidence of the smart city's contribution to the energy transition.

**Keywords**: smart city; energy transition, smart energy transition index (SETI), South Korea

## Introduction

Rapid urbanization and urban population growth have been accelerating greenhouse gas (GHG) and climate change. Currently, more than half of the world population reside in the urban area and according to the UN's prospect, the urban population will be 68% by 2050 (UN, 2018). These people's daily life cannot be separated from energy consumption and GHG emission. According to the Intergovernmental Panel on Climate Change (IPCC), cities consume around 67% to 76% of energy and produce three-fourths of GHG emissions (IPCC, 2015). Therefore, the factors that influence GHG emission in cities need to be managed for sustainable energy consumption. Those factors include population density, economic activity, climate variables such as heating degree days, household size, and urbanization rate (Creutzig *et al.*, 2015). Since urban infrastructures such as buildings and roads are the main place of energy consumption (Calvillo, Sánchez-Miralles and Villar, 2016), urban form and activities (economic activity, heating, and transport) should be considered in urban energy management.

To ensure environmental sustainability, it is important to manage the aforementioned urban attributes, but also change in the energy system. Today the main energy source is fossil fuel, which is a major contributor to CO2 emission and climate change. If we use energy at a business-as-usual level, the energy consumption will be triple of 2005 by 2050 (Creutzig *et al.*, 2015). Energy transition becomes an important topic because the growing urban population and urbanization rate will increase energy demand. Energy transition means a drastic change in energy consumption and production pattern to a more effective and sustainable way (Rutherford and Coutard, 2014). It represents moving to a low carbon energy system (Bridge *et al.*, 2013). It is derived by both supply and demand, but the most important driver is the end-users (Grubler, 2012). Therefore, both energy production and consumption need modification.

The smart city literature argues that smart cities can contribute to reducing energy consumption and CO2 emission (Debnath *et al.*, 2014; Snow, Hakonsson and Obel, 2016). The buildings can be designed energy-efficiently in the first place to automatically reduce energy consumption. ICT can be used to sense and monitor energy use in the building so that people can alter their behavior to reduce energy consumption (Navarro, Ruiz and Peña, 2017). On the road, a major difference can be made by the Automatic Vehicle Location System. This system is implemented in public transportation and help reducing fuel consumption and travel time (Debnath *et al.*, 2014). Sharing transport data can also reduce congestion (Snow, Hakonsson and Obel, 2016) and reduce CO2 emission. In regard to CO2 emission reduction, alternative or renewable energy sources are introduced, developed, and applied to generate cleaner energy (Zygiaris, 2013). The use of ICT can relieve the environmental burden (Hara *et al.*, 2016) and smart cities have a high possibility in contributing to the energy transition.

Many countries are interested in the idea of a smart city. The Indian government announced an ambitious goal of making 100 smart cities (Datta, 2015), and many other countries already initiated smart city projects. Especially in South Korea, the government has been investing in digitalization and ICT infrastructure since the early 2000s, and promoted smart city development since 2006. The effort of developing smart cities has been continuous: the government announced Ubiquitous-City (U-City) plan in 2004, established the first smart city (u-eco city) in Songdo in 2009, designated Jeju island as a test bed for smart grid system in 2010, and now develop Busan and Sejong as smart city since 2018. Then how these government-led smart cities are different from regular, ordinary cities? Do they perform better in terms of the energy transition? These questions are valid to check the effectiveness of government-led smart city projects.

The purpose of this study is to analyze the government-led smart city's achievement in terms of the energy transition. The remainder of this paper consists of the following. First, we build a conceptual framework on smart city and energy transition. After reviewing the definition of smart city and energy transition we make the link between them and develop evaluation criteria to evaluate government-led smart cities in terms of the energy transition. Second, we introduce South Korean planning history and policies regarding smart city development and energy transition. Then we move on to the analysis, introducing the data collection, analysis methods, and the results. Finally, we conclude with a summary of the analysis and discussion.

**Smart City and Smart Energy Transition**

After reviewing 78 academic paper on smart city framework, Yigitcanlar et al. (2018) developed a comprehensive conceptual framework for the smart city following the input-process-output model as shown in **오류! 참조 원본을 찾을 수 없습니다.**. To this framework, the city itself is an asset (input). Technology, community, and policy are the main drivers (process) that produce desired outcomes (output) in fields of economy, society, environment, and governance. These desired outcomes eventually make the city smart. This framework does not perceive the smart city as an end result per se, rather as a process to achieve balanced and sustainable development through three drivers. To put it differently, a smart city is a vision to achieve sustainability (Trindade *et al.*, 2017). Therefore, smart communities, technology, and innovative policies are important features in the smart city. The smart community identifies what they need and encourage developing better services and citizen-centric decision making through online platforms (Romanelli, 2013). The smart city provides an environment that citizens can participate through a various channel and enables mutual communication between citizens and the governments through technology (Moss Kanter and Litow, 2009; Bakici, Almirall and Wareham, 2013; Gil-Garcia, Zhang and Puron-Cid, 2016). Policy paves environments for technology to be applied and implemented in desired places.

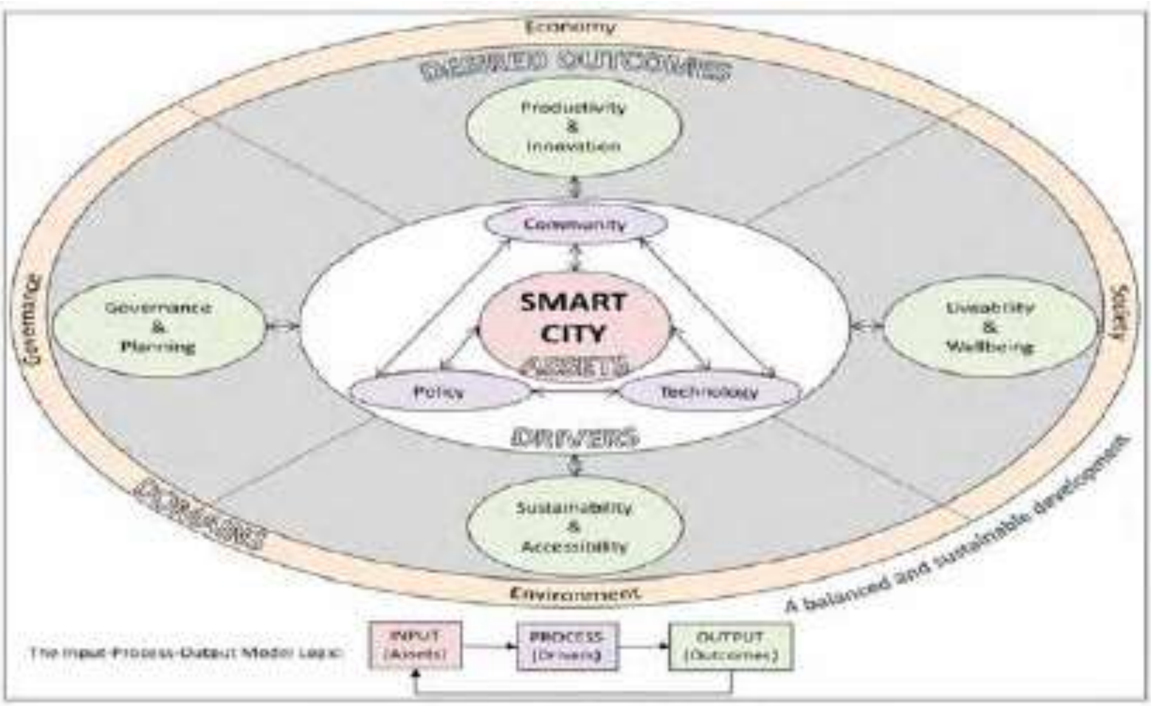



*Figure 1 Smart City Framework (source: Yigitcanlar et al., 2018)*

Technology in a smart city is mainly ICT such as sensors, broadband, and wireless networks, and mobile devices (Washburn *et al.*, 2009; Schaffers *et al.*, 2011). ICT functions as enabler and facilitator of various actions and innovations in the smart city (Nam and Pardo, 2011b). ICT-embedded infrastructures enable gathering, processing, storing and sharing of real-time information. It creates a ubiquitous connection not only among people, firms, and governments but also with the hard infrastructures (Nam and Pardo, 2011b; Cimmino *et al.*, 2014). Internet of Things (IoT), Cyber-Physical Systems (CPS), and big data are major examples of ICT in a smart city. Technology is a prerequisite that facilitates collaboration and cooperation among actors in the city so that they can find an innovative solution to local problems and pursue sustainable growth (Nam and Pardo, 2011b). In that sense, community and policy take an important role in shaping a city into a smart one.

A smart community is operated with creativity, social learning, and life-long education and pursuit inclusiveness, cooperation, and democratic decision making (Nam and Pardo, 2011b). Urban Living Lab is an example of innovative community involvement which is public, private and people partnership (4P) model, a user-driven innovation (Schaffers *et al.*, 2011). At the same time, citizens can be empowered and participate more in public decision making in smart cities by providing a communication platform with ICT infrastructure (Stratigea, 2012). It supports prompt communication and higher accessibility to information and data that are needed to solve local social and economic problems (Nam and Pardo, 2011b). Inevitably, the citizens need to have the ability to exploit ICT infrastructure (Stratigea, 2012), and because of this age and socioeconomic difference can create a digital divide (Mcallister *et al.*, 2005). To prevent further gaps, inclusive policy intervention is needed.

The policy represents a favorable governance environment for smart city development. In the smart city, e-governance is highlighted because it creates a connection among departments, civil society, and private entities (Nam and Pardo, 2011b). E-governance is the capacity of the government to communicate with citizens via on-line participatory tools regarding public services and satisfying citizens' needs (Odendaal, 2003; Barns *et al.*, 2017). The policies in favor of smart city development include investment in R&D for ICT infrastructure, providing learning programs for citizens who are not used to the ICT devices, and maintaining a good relationship with communities and businesses. Strong leadership, clear goal, appropriate planning, and commitment can encourage and accelerate the smart city development process (Stratigea, 2012). Finally, the government needs to consider what society wants, citizens' ability to exploit ICT infrastructures, and jurisdiction (Odendaal, 2003; Barns *et al.*, 2017).

The three drivers of the smart city do not act separately but they work together to achieve the best results in economic, social, and environmental sustainability (Yigitcanlar *et al.*, 2018). Especially, these drivers can contribute to energy transition. The energy transition can be defined as changing energy production and consumption pattern to a low-carbon society (Grubler, 2012). Low-carbon means producing renewable energy sources that emit less CO2 emission, storing and distributing electricity according to the supply and demand, and consuming less energy in daily life (Bridge *et al.*, 2013). A radical change in the energy system has been highlighted because of two major trends: technological lock-in to the current unsustainable energy system and the limited amount of fossil fuel that the current energy system relies on upon (Seyfang and Haxeltine, 2012). System-wide change is desired and the smart city can be one of the solutions because the smart city itself is a comprehensive change in the urban system.

In a smart city, ICT-embedded urban infrastructure and open data sharing can enable efficient energy management and optimize energy consumption which can lead to less CO2 emission (Debnath *et al.*, 2014; Snow, Hakonsson and Obel, 2016). According to Nielsen, Amer, & Halsnæs (2013 p.3), smart energy city means a city with greater energy efficiency using ICT and promoting renewable energy so that it provides a sustainable living environment. Parallel to this definition, Mosannenzadeh, Nucci, and Vettorate (2017) provided a holistic definition based on 5W1H (who, when, where, what, how, and why), in relation to smart city and sustainable city. They define smart energy city as "a component of smart city development aiming at a site-specific continuous transition towards sustainability, self-sufficiency, and resilience of energy systems, while ensuring accessibility, affordability, and adequacy of energy services, through optimized integration of energy conservation, energy efficiency, and local renewable energy sources (Mosannenzadeh and Vettorato, 2014, p.57)." They also mention ICT and collaboration among stakeholders are important to keep energy transition on-going. In their definition, we could find three drivers of smart city, ICT as technology, major stakeholders including community (civil and private firms) and government (policy).

The energy system follows a procedure of energy production, distribution and storage, and consumption (Calvillo, Sánchez-Miralles and Villar, 2016). In the traditional energy system, there was a clear distinction between who produces and distributes (a government agency) and who consumes (civil society). The traditional energy system involves mass production and distribution of power which needed large infrastructures and investments govern by the government. In a transitioning system, this centralized energy system changes into a more decentralized one, where individuals can become energy producers (Mah *et al.*, 2013). People can install small scale energy production plants such as solar panels to their homes and offices (Mosannenzadeh *et al.*, 2017). Moreover, it is possible to save the residual electricity and sell it to local power plants. The smart grid enables real-time and interactive information sharing on energy production and consumption while the energy storage system (ESS) enables optimizing energy use on demand and enhance stable energy distribution. Also, technological development can increase energy efficiency, meaning using less amount of power to generate the same performance. For example, the household appliance can be designed energy efficiently, so that people can save energy while doing the usual house chore. Energy conservation activities can be promoted by actively involving citizens. For example, people can share cars and bikes and use more public transportation (Geels *et al.*, 2018). As the system changes, the stakeholders' role in energy systems is changing. The government's role is expanded from energy producer to comprehensive system manager. The government produces energy, promotes innovation in technology, and facilitates citizens' participation for a sustainable energy system. The community's role is also expanded from energy consumer to energy producer using a smart grid system.

*Table 1 Theoretical framework*

| Drivers | Energy Production | Energy Distribution & Storage | Energy Consumption |
|---|---|---|---|
| Technology | Renewable energy | Smart grid, ESS | - |
| Community | Civil initiatives in renewable energy sector | | Energy consumption level |
| Policy | Supporting technological development<br>Rules and regulations for energy transition | | |

The main hypothesis is that there is a difference between smart and none-smart cities regarding performance in the energy transition. To check the hypothesis, evaluation criteria are developed as shown in Table 1. The contribution of smart city elements in each process of the energy system is stated in each cell. Technological development enabled more energy production with renewable energy, energy distribution, and storage with a smart grid system including an energy storage system. It also influenced energy consumption by providing energy efficient gadgets and facilities, but we omitted this in the table because those are included in the community's energy consumption behavior. The community's contribution is represented as installing small-scale on-site energy generation for energy production, distribution, and storage. For energy consumption, energy conservation behavior and energy consumption level are evaluated. Finally, the policy here means the government's activities in regard to the energy transition. It includes the rules, regulations, the legislation's on energy systems, energy conservation campaigns, and supporting technological development in general.

**Smart City Development in South Korea**

Smart city development is one of the national development strategies in President Moon's administration (Baek, 2017). Smart city development in South Korea started with informatization and digitalization following the introduction of the Internet in the early 2000s. The government then initiated U-Korea Plan (2006~2010) and U-City Plan (2009~2012) and launched 55 U-city projects (45 cities if deducting duplicated projects in the same cities). 'U' stands for Ubiquitous technology that enables unlimited network accessible anywhere and anytime. The main focus of U-city was on technology and infrastructure such as Ubiquitous Sensor Network (USN), Wireless Sensor Network (WSN), CCTV, fast internet network, mobile environment, and public wi-fi. The sensors are implemented in roads, rivers, and major facilities for the management. U-city provides service mainly on transportation information and security (surveillance through CCTV & emergency response). U-city is a prototype of a smart city.

At the same time, the government started to prepare for energy transition under the 'Low Carbon Green Growth' agenda. Phasing with the global trend to low-carbon economy and emphasis on green growth, the government focused on sustainable economic development, especially focusing on green and eco-friendly transportation. The government launched the Guideline for Low-carbon Green City (2009.8) focusing on developing low-carbon green cities to overcome climate change crisis and Low-carbon Green Growth Law (2010.4) regulating compact city, mixed land use, public transportation, new and renewable energy use, water and resource cycle. Also, the government initiated the National Smart Grid Vision (2009), and National Smart Grid Roadmap (2010). At glance, the government's efforts on smart city and energy transition seem to be separated. They both are under the Low-carbon Green City agenda but U-city is rather focused on cutting-edge technology and infrastructure on transportation and security while the low-carbon green city projects focus on purifying and restoring the natural environment and renewable energy. Also, the government used energy transition as a means of economic development, ignoring actual energy transition in general society (Yun, 2009).

Table 2 summarizes the major difference between the U-city and the smart city. Both U-city and Smart city utilize the technology but u-city focus on the technology itself while the smart city focuses on its functionality. U-city focuses on connected infrastructure while the smart city pays attention to human and social capital. The u-city's goal is urban informatization which is implementing technology for efficiency while that of the smart city is urban intelligence, which is making the technology more accessible to the general public. When there is an urban problem, u-city tends to follow ready-made procedures, but smart city diagnoses the problem and prescribes solution based on the data. The initiatives changed from a government-led, city-focused, top-down manner to multi-stakeholder and citizen participation, bottom-up manner. Citizens' role is also expended from mere service users to active service developers. This was administratively assisted by the government as they initiated Open Government 2.0 which is a platform for open administration data service so that people can access to the government data with ease in 2012. The smart city provides more comprehensive and multiple urban services. Based on the lessons from u-city development, South Korean smart city now tries to provide multiple urban services and include citizens and other parties.

*Table 2 Difference between U-city and Smart city*

| Category | U-City | Smart City |
|---|---|---|
| Major Focus | Connected Infrastructure (network)<br>Focus on technology | Social Infrastructure (Human & social capital)<br>Focus on functionality |
| Goal | Urban informatization (efficiency) | Urban intelligence (usability) |
| Solution to urban problems | Ready-made procedure | Prescription based on data |
| Initiative | Top-down<br>City focused & Government-led<br>Vertical collaboration | Bottom-up<br>Citizen's participation & Multi-stakeholders<br>Horizontal collaboration |
| Implementation/ Operation | Limited urban services in telecommunication, security, and disaster prevention<br>Mostly implement in newly developed cities<br>Citizens adapt to provided urban services | Various urban services in administration, transportation, energy, water management, welfare, environment<br>Can be implemented in both new and old cities<br>Provide citizen-centered urban services |

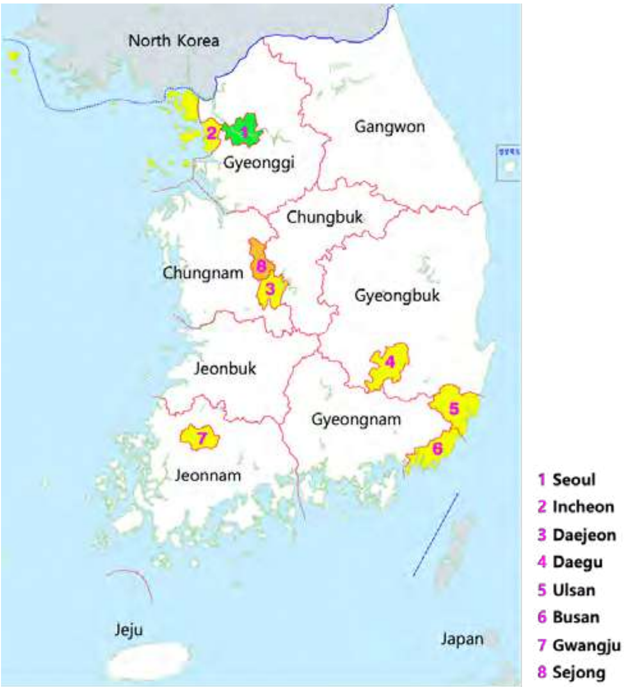
Source: Adopted and translated from (Park, Gang and Lee, 2018)

For the analysis, cities in South Korea is categorized into three as the following:

1. First wave smart city (n=34): U-city (u-eco city) and smart city projects by LH and local governments focusing on Transportation and Security (CCTV)
2. Second wave smart city (n=11): Smart city projects providing comprehensive urban management services, including transportation information, facility management, security and disaster prevention, health and welfare, administration, and environment (projects finished by 2016, not including on-going smart city projects)
3. Non-smart cities (n=116): None of the above

**Methodology**

Administrative districts in South Korea consist of one special city, six metropolitan cities, eight provinces, one special autonomous city, and one special autonomous province (see Figure 2). Including Seoul, Sejong, and Jeju, six metropolitan cities, and 75 Si and 77 Gun, a total of 161 areas are considered as cities for data analysis.




| Districts | Name | No. of sub district |
|---|---|---|
| Special City | Seoul (si) | 25 (gu) |
| Metropolitan Cities | Incheon (si) | 8 (gu) & 2 (gun) |
| | Daejeon (si) | 5 (gu) |
| | Daegu (si) | 7 (gu) & 1 (gun) |
| | Ulsan (si) | 4 (gu) & 1 (gun) |
| | Busan (si) | 15 (gu) & 1 (gun) |
| | Gwangju (si) | 5 (gu) |
| Special Autonomous City | Sejong (si) | - |
| Provinces | Gyeonggi (do) | 28 (si) & 3 (gun) |
| | Gangwon (do) | 7 (si) & 11 (gun) |
| | Chungbuk (do) | 3 (si) & 8 (gun) |
| | Chungnam (do) | 8 (si) & 7 (gun) |
| | Gyeongbuk (do) | 6 (si) & 8 (gun) |
| | Gyeongnam (do) | 5 (si) & 17 (gun) |
| | Jeonbuk (do) | 10 (si) & 13 (gun) |
| | Jeonnam (do) | 8 (si) & 10 (gun) |
| Special Autonomous Province | Jeju (do) | 2 (si) |
| Total | 9 (do), 83 (si), 82 (gun), & 69 (gu) | |

*Figure 2 Administrative districts in South Korea*

Smart Energy Transition Index (SETI) is developed based on the theoretical framework in Table 1, and the indicators are shown in Table 3. The following indicates how the data was collected and treated for each indicator.

- Renewable energy production: There are provincial level data on renewable energy production, but not on city level. Instead we use ratio of employment in renewable energy power generation to total number of employments. Renewable energy includes solar and hydro.
- Smart grid: The DOE Global Energy Storage Database provides ESS projects around the world. They provide which projects are installed where so that it is possible to establish city-level data.
- Citizen initiatives in the energy sector: There are three forms of the civil initiative that are available as dataset: cooperatives, social enterprise, and town enterprise. It is possible to access to full list of these initiatives and extract the ones specialized in the renewable energy sector. Most of them support local residents in installing or renting solar-panel.
- Energy conservation behaviors: It represents how much people try to reduce energy consumption in their daily lives. The data is from the social survey, which asks whether people try to use public transportation, participate in recycling, use fewer disposable goods, buy eco-friendly goods, and participate in energy conservation campaigns. These are asked on a scale of 5; from 5 (always participating) to 1 (never or not interested). Provinces except for Gangwon, Chungnam, Jeonnam, and Gyeongnam have city-level data on each energy conservation behaviors (n=87). Gangwon, Chungnam, Jeonnam, and Gyeongnam (n=74) only provide provincial level data. It is risky to remove all missing cases so we used provincial level data as each city's data since the provincial data is average of city-level data. The analysis was performed with and without this indicator for sensitivity analysis.

- Energy consumption level: Energy consumption means electricity use. The Korea Statistical Information Service (KOSIS) provides city-level data on electricity use, which is divided into four purposes of the use: home, public, service, and industry. We excluded industrial (agriculture, fisheries, forestry, and mining, and manufacture) electricity use because those facilities are usually built outside of the city. Only home, public and service are considered. The total amount of electricity consumption is divided by the population.
- Financial support: Financial support for technological development is represented with percent of the budget for technology (technology development, R&D, and scientific technology in general) in the local government's annual budget.
- Rules and regulations: Elis.go.kr provides a full list of each cities' current ordinance, rules, and regulations. We count the number of ordinances and rules that are related to energy. The title of frequently appeared includes 'Energy Basic Ordinance', 'Ordinance on Green Roof', 'Ordinance on Response to Climate Change', 'Ordinance on Low-carbon Green Growth', and 'Ordinance on Renewable Energy Provision'.

*Table 3 Indicators of smart energy transition index*

| Dimensions | Category | Indicator | Year | Unit | Weight |
|---|---|---|---|---|---|
| Technology | Renewable energy production | The ratio of employees in solar and hydro energy production | 2016 | % | 0.5 |
| | Smart Gird | No. of gov't projects supporting ESS installation | Up to 2018 | unit | 0.5 |
| Community | Citizen initiatives in energy sector | No. of civil initiatives specialized in renewable energy | Up to 2018 | unit | 0.33 |
| | Energy conservation behavior | Average energy conservation behavior in using public transportation, recycling, using fewer disposable goods, buying eco-friendly goods, and participating in energy campaign | 2016 | score | 0.33 |
| | Energy consumption | Total amount of electricity use in houses, service sector, and public sector per capita | 2016 | MWh | 0.33 |
| Policy | Financial support | % of the budget for technology (scientific development) | 2016 | % | 0.5 |
| | Rules and regulations on energy sector | No. of local gov't's regulations, laws, or legislation regarding energy sector | 2016 | unit | 0.5 |

The indicators are normalized and accumulated with equal weighting as shown in Figure 3. We choose equal weighting because three dimensions of smart cities are equally highlighted in the literature (Yigitcanlar *et al.*, 2018).

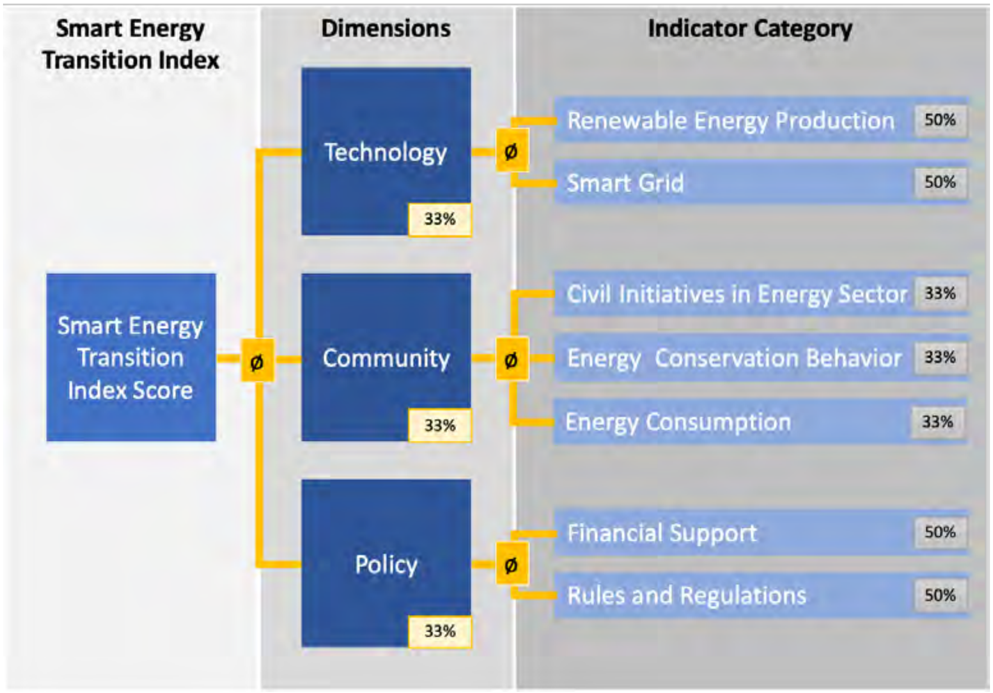



*Figure 3 Framework of smart energy transition index*

Before normalizing and accumulating indicators into one index, correlation analysis has been carried out to check the suitability of indicators. As shown in Table 4, the smart grid has a positive correlation with community initiatives, technology budget, and energy regulations. The community initiatives are promoting renewable energy use and installing small scale solar panels at houses and both technology budget and rules and regulations represent the government's efforts on energy transition. Therefore, the smart grid has a positive correlation with these three indicators. Rules and regulations on the energy sector have a positive correlation with community initiatives and technology budget. This means the government's effort and communities' effort sync for the energy transition.

*Table 4 Correlation among the indicators*

| | Renewable energy employment | Smart grid | Community initiatives | Energy conservation behavior | Electricity Consumption | Technology budget | Rules and Regulations on Energy sector |
|---|---|---|---|---|---|---|---|
| Renewable energy employment | 1 | -.052 | -.011 | -.111 | -.055 | -.052 | -.051 |
| Smart grid | | 1 | .585* | .073 | -.048 | .373** | .408** |
| Community initiatives | | | 1 | -.041 | -.037 | .046 | .427** |
| Energy conservation behavior | | | | 1 | -.100 | .008 | -.070 |
| Electricity Consumption | | | | | 1 | -.036 | .021 |
| Technology | | | | | | 1 | .249** |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| budget | | | | | | | |
| Rules and Regulations on Energy sector | | | | | | | 1 |

**. Correlation is significant at the 0.01 level (2 -tailed)

Since the indicators have different measuring units, the indicators are normalized by using z-score and percentile. This way the indicators are on the same scale and they can reveal each city's relative position. Then the equal weight was given to the accumulating total SETI score.

<Smart Energy Transition Index> <Smart Cities in Korea>

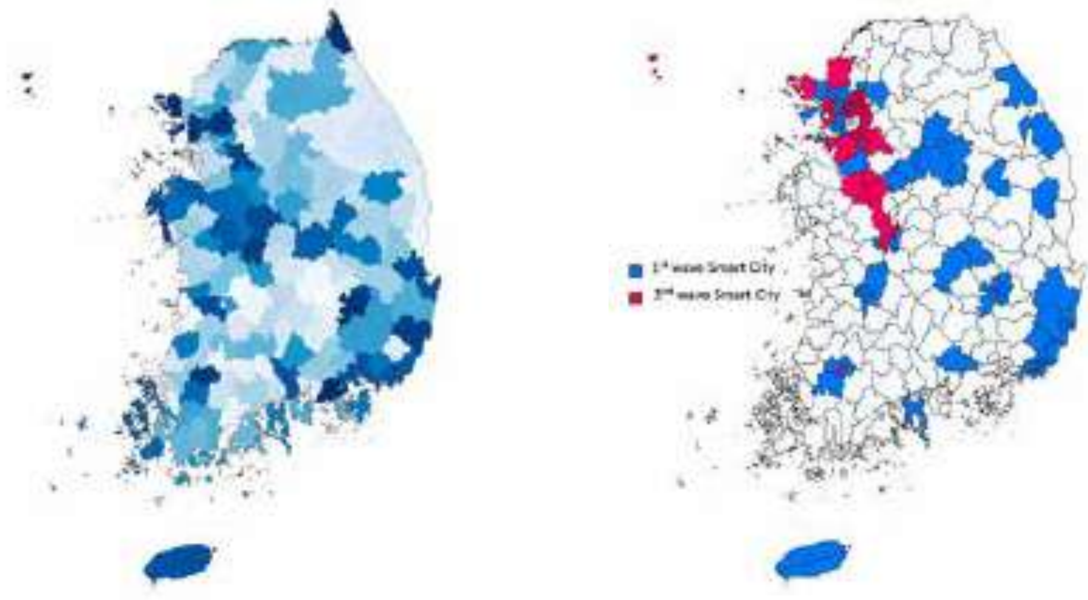


*Figure 4 Smart energy transition index scores*

The SETI score ranges from 100% being the highest to 0% being the lowest. Figure 4 shows the result of the SETI score and the city categories. Darker blue means a high level of the SETI score. In general, smart cities in South Korea have a higher level of SETI score than non-smart cities. The 10 cities with the highest and lowest score are shown in Table 5. Top 10 cities are mostly smart cities (1st and 2nd wave) and the top six cities are all metropolitan or special cities. The bottom 10 cities are mostly non-smart cities and 'gun' area. However, there are two non-smart cities in the top 10 list and two 1st wave smart cities in the bottom 10 lists.

*Table 5 List of top and bottom 10 cities*

| Top 10 cities with highest SETI score | | | | Bottom 10 cities with lowest SETI score | | | |
|---|---|---|---|---|---|---|---|
| Rank | City Name | SETI score | City Category | Rank | City Name | SETI score | City Category |
| 1 | Incheon | 78.9 | 2nd wave smart city | 161 | Seongju-gun | 29.3 | Non-smart city |
| 2 | Daegu | 71.8 | 1st wave smart city | 160 | Goryeong-gun | 31.5 | Non-smart city |
| 3 | Gwangju | 70.8 | 1st wave smart city | 159 | Buan-gun | 32.1 | Non-smart city |
| 4 | Seoul | 70.7 | 2nd wave smart city | 158 | Gimcheon-si | 32.4 | 1st wave smart city |
| 5 | Daejeon | 68.1 | 2nd wave smart city | 157 | Wanju-gun | 32.5 | 1st wave smart city |
| 6 | Ulsan | 65.7 | 1st wave smart city | 156 | Jinan-gun | 32.8 | Non-smart city |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 7 | Yongin-si | 62.3 | 2nd wave smart city | 155 | Yeongdeok-gun | 34.5 | Non-smart city |
| 8 | Taean-gun | 60.3 | Non-smart city | 154 | Gurye-gun | 34.6 | Non-smart city |
| 9 | Cheongju-si | 60.1 | Non-smart city | 153 | Boseong-gun | 34.6 | Non-smart city |
| 10 | Bucheon-si | 59.6 | 1st wave smart city | 152 | Damyang-gun | 35.8 | Non-smart city |

Table 6 shows the results of the descriptive analysis of each city category and SETI score. The 1st wave smart city is 34 cities, and their mean smart energy transition index score is 47.4, the minimum is 32.4 and the maximum is 71.8. Number of the non-smart city is 115 and their mean score is 44.9, the minimum and the maximum score is 29.3 and 60.3 respectively. The 2nd wave smart city is 11 cities where the mean score is 57.4 and the maximum score is 78.9. The mean score is highest in the 2nd wave smart city and the non-smart city is the lowest. Figure 5 shows the boxplot and histogram of the SETI score by the city category. The 2nd wave smart city has a higher mean and range than non-smart city or 1st wave smart city. The 1st wave smart city and the non-smart city are similar in their position and range but the mean of 1st wave smart city is slightly higher than the non-smart city. In the 1st wave smart city, two cities seem to be outliers: Daegu and Gwangju.

*Table 6 Result of descriptive analysis*

| City | No. | Mean | Standard Deviation | Min | Max |
|---|---|---|---|---|---|
| 1st wave Smart City | 34 | 47.4 | 9.73 | 32.4 | 71.8 |
| 2nd wave Smart City | 11 | 56.9 | 12.2 | 39.2 | 78.9 |
| Non-Smart City | 116 | 44.9 | 7.08 | 29.3 | 60.3 |
| Total | 161 | 46.2 | 8.61 | 29.3 | 78.9 |

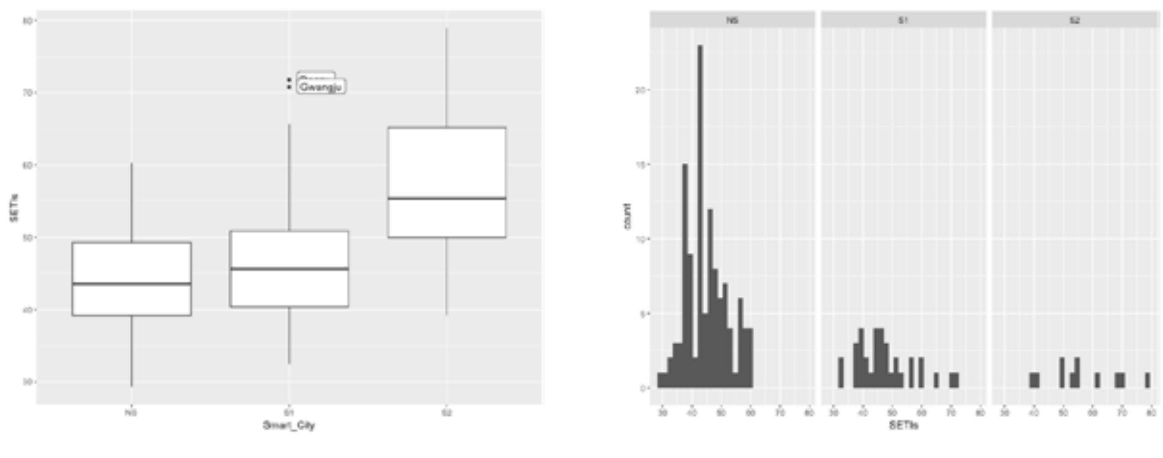


*Figure 5 Boxplot and distribution of smart energy transition index score*

First, including the outliers, one-way ANOVA is performed to check the hypothesis. One-way ANOVA is useful to check whether there is a significant difference among groups in their mean. Before performing ANOVA, the following assumptions were checked:

1. The data of each group is normally distributed (normality)
2. The data of each group has a common variance (homogeneity in variance)

For the normal distribution test, Shapiro-Wilk test is performed. Non-smart city and 1st wave smart city's p-value are 0.024 and 0.027 respectively which is lower than significant level ($p < 0.05$) which means they are not normally distributed. On the other hand, 2nd wave smart city's p-value is 0.848 and it is normally distributed. Table 7 summarizes the results of the analysis. Levene's test shows homogeneity of variance. The p-value is 0.0605 which is higher than the significance level ($p < 0.05$) so the null hypothesis cannot be rejected. This means the variance is homogeneous. However, since the normality assumption is not satisfied, nonparametric test was performed instead of one-way ANOVA. Since the number of the group is three, we adopted Kruskal-Wallis test. The p-value is 0.004235 which is less than the significance level 0.05, we can conclude that there are significant differences between the city categories. To find which pair of city category has a difference, we performed pairwise comparisons using the Wilcoxon rank sum test. The 2nd wave smart city is significantly different from the 1st wave smart city and non-smart city ($p <0.05$). However, there is no significant difference between the 1st wave smart city and non-smart city.

*Table 7 Results of the analysis*

| Data: Smart Energy Transition Index score by city categories | | | |
|---|---|---|---|
| Levene's test | Df | F-value | P-value |
| | 2 | 2.8556 | 0.0605 |
| Kruskal-Wallis | Chi-squared | df | P-value |
| | 10.929 | 2 | 0.004235 |
| Pairwise comparison | | 1st wave smart city | 2nd wave smart city |
| | 2nd wave smart city | 0.0291 | - |
| | Non-smart city | 0.2495 | 0.0041 |

Since the data on energy conservation behavior is imputation, we exclude this indicator for sensitivity analysis. The adjusted smart energy transition index score is summarized in below. Boxplot and distribution charts are similar to the original (see Figure 6) and the result of the Kruskal-Wallis test and post hoc test is similar to the original (see

Table 8 and Table 9). All in all, there is a significant difference between the 2nd wave smart city and 1st and non-smart city in the mean of smart energy transition index score.

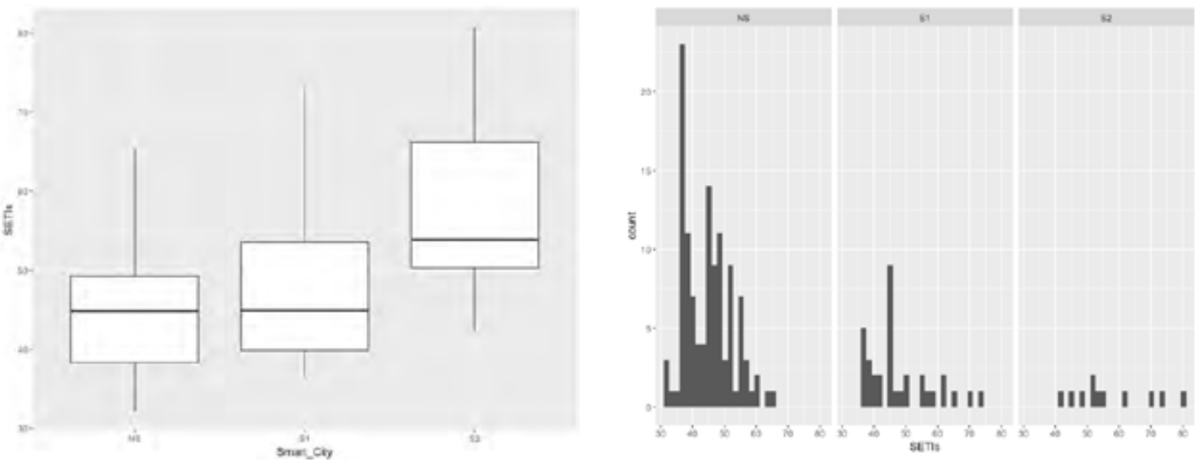


*Figure 6 Boxplot and distribution of adjusted smart energy transition index scores*

*Table 8 Descriptive analysis of adjusted smart energy transition index scores*

| City | No. | Mean | Standard Deviation | Min | Max |
|---|---|---|---|---|---|
| 1st wave Smart City | 34 | 47.6 (47.4) | 9.99 (9.73) | 36.5 (32.4) | 73.0 (71.8) |
| 2nd wave Smart City | 11 | 57.8 (56.9) | 12.3 (12.2) | 42.3 (39.2) | 80.7 (78.9) |
| Non-Smart City | 116 | 44.6 (44.9) | 7.43 (7.08) | 32.2 (29.3) | 65.3 (60.3) |
| Total | 161 | 46.1 (46.2) | 9.02 (8.61) | 32.2 (29.3) | 80.7 (78.9) |

* value within the bracket is the original

*Table 9 Adjusted Levene's test for homogeneity of variance*

| Data: Smart Energy Transition Index score by city categories | | | |
|---|---|---|---|
| Levene's test | Df | F-value | P-value |
| | 2 | 2.1121 (2.8556) | 0.1244 (0.0605) |
| Kruskal-Wallis | Chi-squared | df | P-value |
| | 13.688 (10.929) | 2 | 0.001066 (0.004235) |
| Pairwise comparison | | 1st wave smart city | 2nd wave smart city |
| | 2nd wave smart city | 0.012 (0.0291) | - |
| | Non-smart city | 0.206 (0.2495) | 0.001 (0.0041) |
| | 2nd wave smart city | 0.012 (0.0291) | - |
| | Non-smart city | 0.206 (0.2495) | 0.001 (0.0041) |

P-value adjustment method: BH

**Discussion and Conclusion**

There are some findings from the analysis. First, the indicators showed a correlation. The smart grid has a positive correlation with community initiatives, technology budget, and energy regulations and the energy regulations have a positive correlation with community initiatives and technology budget. This shows smart city drivers (technology, community, and policy) are interacting with each other. The community (community initiatives) and policy (technology budget and energy regulations) promote the technology (smart grid). The community initiatives represent cooperatives and social enterprises that are specialized in renewable energy. The policy (energy regulations) provides a favorable environment for those communities to participate in the energy sector. Second, the results of the analysis showed that there is a significant difference between the 2nd wave smart city and the 1st and non-smart cities in the smart energy transition index. This supports the hypothesis of this paper that smart cities perform better than non-smart cities in the energy transition. However, the 1st and non-smart cities do not have a significant difference. This shows the limitation of the 1st wave smart city. The 1st wave smart cities (u-city) focus on implementing connected infrastructure in limited sectors (transportation & security) (Park, Gang and Lee, 2018). On the other hand, the 2nd wave smart cities account the role of community and provide a comprehensive urban management service. This can be supporting evidence of the argument that a smart city is more than a technology (Hollands, 2008). Third, the SETI score is higher in smart cities (the 1st and 2nd wave smart city) than non-smart cities. However, there are non-smart cities that scored higher than smart cities (Taean-gun and Cheongju-si). Taean-gun has a higher ratio of renewable energy employees (61%) and community initiatives (77%). And both cities have a higher score in energy conservation behavior (93%, each), energy consumption level (56% each), and rules and regulation on energy transition (79%, each). The community initiatives and the energy conservation behavior are direct participation of the community, which sometimes initiated without the government's intervention. When we look into bottom the 10 cities, where two 1st wave smart cities are included (Gimcheon-si and Wanju-gun). Even though these cities have government initiatives, their performance in community initiative (33%) and energy conservation behavior (3%) are way below the average. This shows the community plays a critical role in the smart energy transition. Finally, the smart energy transition index score is higher in metropolitan cities (including special cities) than Si or Gun area. Special cities (Seoul & Sejong) and metropolitan cities are considered as the same administrative level (political power) with provinces ('Do') and their population is more than one million. Among eleven 2nd wave smart cities, four are special or metropolitan cities. Perhaps the reason why the 2nd wave smart city performs better than 1st and the non-smart city is that the smart cities are already advanced cities that have more political power and population. Strong political power and leadership ease the implementation (Nam and Pardo, 2011a) and certain population threshold needs to be satisfied to implement a large ICT infrastructure.

The purpose of this paper is to find empirical evidence of a smart city's contribution to the energy transition. We developed an index with seven indicators that represent the possible contribution of three drivers of the smart city (technology, community, and policy) in the energy transition. This study provides an overview of the smart energy transition in South Korea and compares smart and non-smart cities. As the result shows, there is a significant difference between the 2nd wave smart city and 1st and non-smart cities. This reveals the limitation of 1st wave smart cities which mainly focuses on technology implementation. A smart city is more than a technology implemented city (Hollands, 2008), and community and policy also play important roles.

The limitation of this study is that we have used an existing dataset that is available at the city level. Because of this, we used alternative indicators for some of the indicators. For example, renewable energy production is replaced with the ratio of the employees in renewable energy production, smart grid implementation is replaced with the number of ESS projects. Another limitation is that the paper provides only an overview of the smart energy transition. Why and how 2nd wave smart cities perform better than 1st and non-smart cities are not thoroughly studied in this paper. We leave this for further study, where specific case studies can be carried out to examine success and failure stories of smart cities in the energy transition.

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