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Assessing Strategies for Urban Climate Change Adaptation: The Case of Six Metropolitan Cities in South Korea

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Abstract: As interest in climate change adaptation grows, an increasing number of national and local governments are developing adaptation strategies. This study assesses the strategies for urban climate change adaptation of municipal governments in South Korea. The adaptation plans and budget expenditures of six metropolitan cities in South Korea were compared, based on the Implementation Plan for Climate Change Adaptation Strategy (IPCCAS) 2012–2016 and annual expenditure reports of each city. The results show that the actual implementation of these adaptation programs varied vis-à-vis the original plans, in terms of the level of overall expenditure and sector-specific expenditure. The following findings were drawn from the analysis: First, in most cases, the highest adaptation priorities were disaster/infrastructure, water management, and the health sector. Second, actual expenditure on climate change adaptation programs was smaller than the planned budget in the IPCCAS. Third, the prioritized sectors matched for planning and implementation in Seoul, Daegu, Daejeon, and Incheon, but not in Busan and Ulsan. Fourth, the adaptation programs of South Korean metropolitan cities do not seem to have been well-tailored to each case.

Keywords: climate change adaptation; climate-resilient city; metropolitan city; IPCCAS; South Korea

1. Introduction

The global urban population has grown from 2.3 billion in 1990 to about 4 billion in 2016, or 43% and 54.5% of the world's population, respectively. It is projected that 60% of the world's population will dwell in urban areas by 2030 [1,2]. Such rapid urbanization poses various social and environmental problems for cities, including insufficient housing, traffic congestion, increasing crime rates, environmental pollution, and inadequate sanitation services [3–7]. In addition to these "traditional" challenges, responding to climate change has emerged as an important task for municipal governments. Since anthropogenic greenhouse gas (GHG) emissions originating from cities account for up to 70% of global GHG emissions [8], cities can play a significant role in climate change mitigation by reducing fossil fuel consumption and promoting a low-carbon economy. Furthermore, cities themselves are under threat from the effects of climate change, such as sea-level rise, more frequent extreme weather events, and natural disasters, which negatively affect human health, water availability, and so on [9–11]. The number of natural disasters worldwide has quadrupled to around 400 a year since 1975 [12], and the economic loss resulting from natural disasters between 2005 and 2014 reached 1.5 trillion USD, a ten-fold increase from the previous decade [13]. In 2014, 87% of disasters were climate-related [2]. Although disasters can seriously threaten both urban and rural areas, cities are particularly vulnerable due to high population density as well as concentrated infrastructure and

assets [9,14–16]. Since it is expected that climate change will increase both the risk of disasters and loss from those disasters [17], cities must find ways to deal with climate hazards.

In this regard, the concept of the climate-resilient city has received increasing attention from municipal governments. The term "resilience" was originally used by physical scientists to indicate the characteristics of a spring and the resistance of materials to external shocks [18] (p. 300). The term was later introduced into ecology, where it is used to describe the capacity of a system to maintain its functions and controls when faced with disturbance [19] (p. 220). Based on this ecological interpretation, urban resilience is commonly defined as the ability of a system, a community, and a society within a city to resist, absorb, survive, adapt, and recover from the stresses and shocks to which they are exposed [6,19–21]. The concept of resilience has recently been used in diverse areas, including disaster management, urban security, and economic growth [19]. Since climate change tends to harm cities through causing an increase in natural disasters and extreme weather events, a climate-resilient city has many common features with a disaster-resilient city. According to Wamsler et al. (2013), a disaster-resilient city is one that decreases not only actual hazards, but also the susceptibility of individuals, communities, and institutions to hazards, and formalizes disaster recovery mechanisms [11]. Applying the definition of general urban resilience and disaster resilience, a climate-resilient city can be described as a city having the capacity to relieve and recover from climate-related shocks and stresses and reduce its vulnerability to climate change [21].

In the climate change policy context, efforts to build climate resilience can be understood as climate change adaptation strategies. The Intergovernmental Panel on Climate Change (IPCC, 2014) explains that "adaptation is the process of adjustment to actual or expected climate and its effects" [22] (p. 118). Adaptation is a more ambitious form of climate resilience including providing an alternative water supply, cooling services, flood protection, green infrastructure, and emergency preparedness mechanisms [23–25]. The growing realization that mitigation alone is not an effective response to climate change has created an opening for adaptation policy [26–28]. Consequently, increasingly more national and local governments around the world have developed various adaptation strategies. According to the Organisation for Economic Co-operation and Development (OECD), only five member countries had established specific adaptation policies in 2006, but, by 2012, that number had increased to 27 [29]. Many megacities such as New York, London, Mexico City, Seoul, and Sydney have also devised adaptation policies.

Despite the increased number of adaptation plans announced by municipal governments, analysis of their actual implementation is rare. Thus far, many studies have focused on the establishment of municipal adaptation strategies without assessing their performance. However, plans are not always implemented, and although governments adopt adaptation plans to improve climate-resilience, they may fail to implement those plans due to various political and financial factors. Therefore, monitoring implementation outcomes is important to assess cities' climate-resilience. One of the methods used to evaluate the efforts of a city to adapt to climate change is analyzing its financial report for adaptation measures [10].

This study therefore examines the implementation of the climate change adaptation strategies of six metropolitan cities in South Korea, i.e., all metropolitan cities except Gwangju. Since the establishment of the National Comprehensive Plan for Climate Change Adaptation in December 2008, the South Korean government has announced a series of national-level adaptation plans and encouraged local governments to develop their own adaptation plans. The Framework Act on Low Carbon Green Growth, enacted in 2009, mandates that every five years the national government must formulate an adaptation strategy and local governments must establish implementation plans for the adaptation strategy. Based on this provision, the South Korean government announced the National Climate Change Adaptation Strategy (NCCAS) 2011–2015 in 2010 and distributed a manual for the Implementation Plan for Climate Change Adaptation Strategy (IPCCAS) to help local governments devise their own plans. By 2012, all seven metropolitan governments in South Korea had established their IPCCAS 2012–2016. After the implementation periods of the first plans,

the second round of national strategy and implementation plans were established and implemented (NCCAS 2016–2020 and IPCCAS 2017–2021). Each IPCCAS contains specific adaption programs that the local government attempts to carry out and related budget plans. This study uses the first IPCCAS and annual expenditure reports of six metropolitan cities in South Korea to identify key characteristics of urban climate change adaptation and assess their implementation.

The remainder of this paper is structured as follows. The second section reviews the literature of urban adaptation strategies to climate change and the third Section explains the data and methods used in the analysis. The fourth Section presents our analysis of the climate change adaptation plans and expenditure schemes in the six metropolitan cities; it specifically examines which adaptation programs were devised, the budget allocated to those programs, and how much of that budget was actually spent for each city. The Conclusion summarizes the key findings of this study and outlines the implications for future urban adaptation plans.

2. Literature Review of Urban Climate Change Adaptation

2.1. Options for Climate Change Adaptation

Climate change adaptation includes both reducing damage from climate change and taking advantage of it where possible [22,30]. Since climate affects diverse economic and social sectors including agriculture, forestry, fisheries, housing, transport, and human health [27]. Adaptation options also cover a wide range of activities across all sectors of society. In addition to direct actions to reduce climate risks, adaptation options also include capacity building measures for individuals, communities, and organizations [30].

The classification of adaptation options varies. One of the most common way is categorizing adaptation options by sector. De Bruin et al. (2009) suggests 96 adaptation options for seven sectors (agriculture, nature, water, energy and transport, housing and infrastructure, health, and recreation and tourism) [31]. Moser and Satterthwaite (2008) divided adaptation options into four categories (protection, pre-disaster damage limitation, immediate post-disaster responses, and rebuilding) [32], while the Asian Cities Climate Change Resilience Network indicated four elements of resilience (infrastructure systems, ecosystems, agent capacities, and institutions) [33]. The IPCC sorted adaptation options into three main categories (structural/physical, social, and institutional) and ten sub-categories (engineered and built environment, technological, ecosystem-based, services, educational, informational, behavioral, economic, laws and regulations, and government policies and programs) [34]. The United Kingdom Climate Impacts Programme suggested adaptation options according to two categories (building adaptive capacity and delivering adaptation actions) and seven sub-categories (creating information, supportive social structure, supportive governance, accepting the impacts and bearing losses, preventing effects or reducing risks, offsetting losses by spreading or sharing risks or losses, and exploring positive opportunities) [35]. Examples of suggested adaptation options are listed in Table 1.

2.2. Cities' Climate Change Adaptation

Climate change mitigation has been dominant on cities' agendas for climate change response. Broto and Bulkeley (2013) reported that only 12% of 627 mitigation and adaptation practices of 100 global cities were adaptation programs [23], and Reckien et al. (2014) showed that only 28% of 200 European cities had adaptation plans, while 65% of the cities had mitigation plans [16]. Nevertheless, various adaptation strategies have been increasingly developed by national and local governments around the world [23,28,29,36], and investigation into the substance and consequence of urban climate adaptation has been initiated by a series of studies.

Table 1. Examples of climate change adaptation options (Source: [31–35]).

Source	Category		Examples of Adaptation Options
de Bruin et al. (2009)	Agriculture		• Adjusting crop rotation schemes and planting dates • Floating greenhouses
	Nature		• Establishment and management of protected areas • Artificial translocation of plants and animals
	Water		• Risk-based allocation policy • Regional water system/improving river capacity
	Energy and transport		• Modes of transport/more intelligent infrastructure • Reduce buildings' need for air-conditioning/heating
	Housing and infrastructure		• Sufficient cooling capacity/revision of sewer system
	Health		• Measures for preventing climate-related diseases
	Recreation and tourism		• Design infrastructure for recreation and tourism
Moser and Satterthwaite (2008)	Protection		• Adjusting official standards for building and land use • Risk-reduction investment and actions
	Pre-disaster damage limitation		• Temporary accommodation with relevant services • Disaster early-warning system
	Immediate post-disaster responses		• Rapid repairs to key infrastructure and services • Protection of physical capital to prevent further erosion
	Rebuilding		• Rebuilding infrastructure to more resilient standards
Tyler and Moench (2012)	Infrastructure systems		• Flood monitoring and early warning systems • Rainwater harvesting
	Ecosystems		• Mangrove restoration and protection • Watershed planning and forest protection
	Agent capacities		• Building awareness of climate risks • Training communities in disaster risk management
	Institutions		• Water demand management • Local government coordination and technical support
Intergovernmental Panel on Climate Change (2014)	Structural/physical	Engineered and built environment	• Sea walls and coastal protection structures • Storm and waste water management
		Technological	• New crop and animal varieties • Water saving technologies
		Ecosystem-based	• Ecological restoration • Community-based natural resource management
		Services	• Social safety nets and social protection • Essential public health services
	Social	Educational	• Awareness raising and integrating into education
		Informational	• Hazard and vulnerability mapping • Early warning and response system
		Behavioral	• Household preparation and evacuation planning
	Institutional	Economic	• Insurance/catastrophe bonds • Payments for ecosystem services
		Laws and regulations	• Building standards/land zoning laws
		Government policies and programs	• National and regional adaptation plans • Disaster planning and preparedness
United Kingdom Climate Impacts Programme (2008)	Building adaptive capacity	Creating information	• Research/data collection/awareness raising
		Supportive social structure	• Working in partnerships/organizational development
		Supportive governance	• Regulation/legislation/guidance
	Delivering adaptation actions	Offsetting losses by spreading or sharing	• Insurance • Sharing costs of response
		Preventing effects or reducing risks	• Changing use or location • Building resilience
		Exploiting opportunities	• New species • Developing previously limited activities
		Accepting the impacts and bearing loss	• Managing retreat from sea-level rise

The most prevalent type of study involves exploring and comparing the adaptation strategies of multiple cities. Broto and Bulkeley (2013) examined climate change policies of 100 global cities and concluded that adaptation programs were found most frequently in Oceania and least frequently in Europe [23]. Studies have varying results on the most popular adaptation options and sectors. Preston et al. (2011) identified 507 adaptation options in 57 adaptation plans from Australia, the United Kingdom, and the United States and found that capacity building programs accounted for 72% of

total adaptation options, outnumbering the delivery of specific vulnerability reduction programs [28]. Lesnikowski et al. (2014) reviewed 4104 adaptation initiatives communicated to the UNFCCC and found that the largest number of initiatives were related to infrastructure, technology, and innovation in the environmental, water, and agricultural sectors [37]. Wamsler et al. (2013) compared adaptation options found in developed and developing countries through meta-evaluation of multiple country studies [11].

Some studies found factors that enabled municipal governments to successfully adopt and implement adaptation policies [14,24,36,38]. Carmin et al. (2009) noted internal motivation, such as the need to protect property and lives from natural disasters, was a strong driver for Durban and Quito to develop adaptation planning far earlier than other cities [38]. In California, large population, high household income, and strong support from local leaders and the public were associated with adopting local climate change adaptation policies [36]. Another key success factor was the active participation of stakeholders, as shown in the cases of London and New York [14]. The commitment of local leaders, municipal expenditures per capita, and awareness of climate change were positively associated with engagement in adaptation planning [24]. On the other hand, potential obstacles to adopting climate change adaptation policies were also identified: difficulties in negotiation and coordination among various stakeholders, political change, lack of awareness, uncertainty, and complacency [39,40].

One recent study provides more specific results about cities' adaptation efforts by analyzing the disbursement for climate change adaptation in ten megacities—London, Paris, New York, Mexico City, São Paulo, Beijing, Mumbai, Jakarta, Lagos, and Addis Ababa. The results show that expenditure on adaptation accounted for as much as 0.33% of a city's gross domestic product. While cities in developed countries spend more money on energy and water, cities in developing countries tend to focus on adaptation options for the health and agricultural sectors [10].

Previous studies on urban climate change adaption have some limitations. Most of the studies investigated the establishment of adaptation policies rather than their implementation. The papers report which adaptation options are included in the adaptation plans of cities and what leads or impedes municipal governments to adopt adaptation strategies. However, adopting an adaptation policy is only the first step in municipal adaptation efforts. Therefore, it is necessary to monitor whether municipal governments implement the policy that they adopted and to evaluate how effective their adaptation is in enhancing climate resilience. Georgeson et al. (2016) analyzed cities' actual expenditure on climate change adaptation, but focused on only one fiscal year; moreover, they did not analyze whether the expenditure corresponded with the original budget. Given these previous limitations, this study attempted to assess whether cities have implemented their climate change adaptation policies in accordance with their original plans.

3. Materials and Methods

3.1. Scope of Analysis: Six Metropolitan Cities in South Korea

This study analyzed the budget and actual expenditure on climate change adaptation programs from 2012 to 2016 of six metropolitan cities in South Korea (Seoul, Busan, Daegu, Daejeon, Incheon, and Ulsan). The seventh metropolitan city, Gwangju, was excluded to enable more consistent analysis: while the other six cities have an annual budget plan for adaptation strategies, Gwangju provides only a five-year budget. The geographic location and general characteristics of each city are presented in Figure 1. The six cities have experienced gradual increases in annual average temperature and precipitation since the 1960s [41–46], and those tendencies are expected to continue [47–52]. Table 2 shows the change in annual average temperature and precipitation of each city under the Representative Concentration Pathways (RCP) 2.6 and RCP 6.0 scenarios presented in the Fifth Assessment Report of the IPCC.

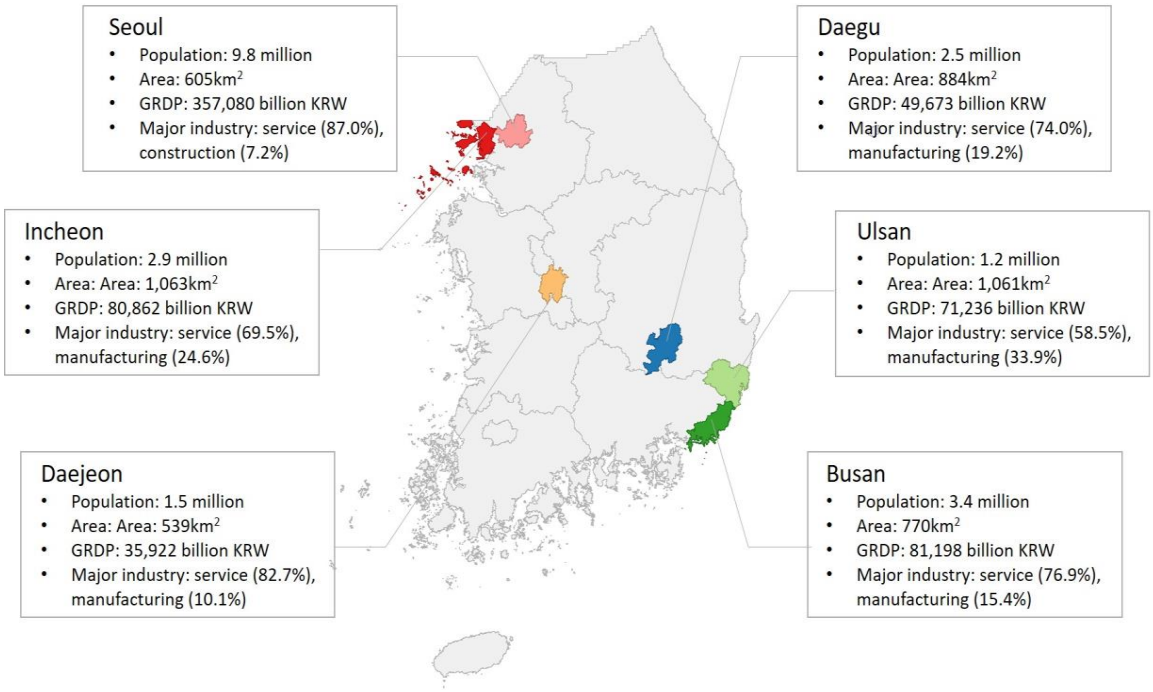


Figure 1. Location and characteristics of six South Korean metropolitan cities (Data source: [53]).

Table 2. Climate change projections of each city (Data source: [47–52]).

Element	Period	Scenario	Seoul	Busan	Daegu	Daejeon	Incheon	Ulsan
Average temperature (°C)	2001–2010	-	13.0	14.4	13.2	12.4	12.0	13.4
	2041–2050	RCP2.6	13.3	15.7	14.6	13.7	13.5	14.7
		RCP6.0	13.7	15.0	13.9	13.0	12.6	14.1
	2091–2100	RCP2.6	14.5	15.9	14.8	13.8	13.7	15.0
		RCP6.0	16.0	17.2	16.2	15.3	15.1	16.2
Average precipitation (mm)	2001–2010	-	1387.4	1532.9	1266.4	1285.0	1192.5	1446.0
	2041–2050	RCP2.6	1202.8	1552.7	1174.6	1226.4	1019.8	1442.4
		RCP6.0	1258.7	1560.6	1182.8	1301.7	1057.3	1367.3
	2091–2100	RCP2.6	1328.6	1552.3	1273.0	1293.5	1118.9	1479.3
		RCP6.0	1279.1	1695.4	1283.8	1250.8	1064.4	1642.4

3.2. Data Sources

Data on planning and implementation of adaptation measures for each city was required for this study. Adaptation planning data were collected from the IPCCAS of six metropolitan cities [41–46]. In South Korea, each local government must establish its own IPCCAS every five years, as mandated by the Framework Act on Low Carbon Green Growth that was enacted in 2009. All seven metropolitan governments in South Korea completed the establishment of their first IPCCAS (2012–2016) in 2012; they announced their second IPCCAS (2017–2021) in 2017. Smaller local governments have also developed IPCCAS. In this study, the adaptation efforts of municipal governments were identified and assessed using IPCCAS 2012–2016, since the IPCCAS 2017–2021 were still in the initial stage of implementation at the time of this study. To study implementation, this study measured the adaptation efforts of municipal governments based on their financial response. Expenditure reports for each city for fiscal years 2012–2016 [54–83] were used to assess actual expenditure on the adaptation programs suggested in IPCCAS.

3.3. Methods

The following approaches were applied to assess the adaptation efforts of the six metropolitan cities. First, all adaption programs described in the IPCCAS were identified and recategorized using a standardized typology. Since each city used its own criteria to categorize adaptation programs, it is difficult to directly compare sector-specific budget plans and expenditures among the cities. For instance, Seoul included a flood early-warning system in the disaster management sector of its IPCCAS, but the same measure was listed in the water management sector of Busan's IPCCAS. In addition, Busan put "creating urban forests" in the forest section, while Daegu included it under the health sector. Furthermore, Ulsan introduced unique criteria—healthy and safe city, water-circulating eco city, and climate-friendly city—while the other cities retained traditional criteria based on sectors such as health, disaster, agriculture, and forest. To resolve this issue of inconsistent classification, we reclassified the adaptation programs stated in the IPCCAS in accordance with the criteria used in NCCAS 2011–2015, which presented 29 strategies and 87 specific plans under ten sectors: health, disaster/infrastructure, agriculture, forest, ocean/fisheries, water management, ecosystem, climate change monitoring/projection, adaptation industry/energy, and education/promotion/international cooperation. Table 3 outlines the NCCAS classifications [84].

Table 3. National Climate Change Adaptation Strategy of South Korea, 2011–2015 (Source: [84]).

Sector	Strategy	Specific Plan
Health	(1) Heat wave and UV	• Health impact assessment resulting from heat waves and UV monitoring system • Reducing damages from heat waves and UV
	(2) Climate hazards	• Health impact assessment resulting from climate hazards, monitoring system, and reduction
	(3) Infectious diseases	• Health impact assessment resulting from ecosystem change and monitoring system • Infectious disease surveillance and management • R&D for infectious diseases
	(4) Air pollution and chemicals	• Health impact assessment of air pollution and monitoring system • Reducing damage from air pollution • Health impact assessment of movement of chemicals and monitoring system
	(5) Allergies (asthma, rhinitis, atopy)	• Managing allergenic environmental factors • Preventing and managing allergies
Disaster/ infrastructure	(1) Disaster prevention system	• Risk assessment of natural disasters caused by climate change • Strengthening standards and institutions • Disaster insurance
	(2) Infrastructure for disaster prevention	• Disaster prevention programs for high-risk areas • Early-warning and response system to disasters • Post-disaster recovery to prevent recurrent damages • Installation of rainwater runoff reduction facilities • Stable management and disaster prevention system of waste treatment facilities • R&D for climate control • Improvement of sewerage system
	(3) Infrastructure for society	• Identification of vulnerable areas to climate change and adaptation plan for those areas • Land use plans considering climate change • Improving adaptation capacity of cities • Building climate-resilient, disaster-preventive cities
Agriculture	(1) Climate-friendly agriculture and animal husbandry	• Crop yield estimation and prediction • Climate-adaptive species and new cultivars • Climate-adaptive cultivation techniques • Improvement and management of livestock • Forage supply • Efficient use and saving of agricultural water • Stable supply of agricultural water
	(2) Preventing damages	• Vulnerability assessment • Technology development to relieve climate hazards • Agricultural infrastructure to prevent damage from storms and floods • Disease and insect pest control system • Forecast of foreign diseases and insect pests • Prevention of animal diseases

Table 3. *Cont.*

Sector	Strategy	Specific Plan
Forest	(1) Improving resilience and function of forests	• Protecting plant species vulnerable to climate change • Forests for watershed conservation
	(2) Increasing forest productivity	• Impact and vulnerability assessment of forestry • Increasing forest productivity
	(3) Preventing forest damage	• Vulnerability assessment of forest disasters • Prevention and alleviation of forester disasters • Disease and insect pest control system • Climate-adaptive forest management
Ocean/fisheries	(1) Plans for coastal areas	• Vulnerability assessment of coastal areas to sea-level rise • Scientific management system to predict and respond to changing external forces • Coastal topography change and adaptation plan
	(2) Increasing productivity of fisheries	• Management of fishing conditions of littoral sea and fishery resources • Securing future fishery resources • Enhancing observation and management of coastal fisheries
	(3) Preventing damage to fisheries	• Management of infectious diseases in marine creatures • Reducing damage from ocean acidification • Alleviating fishery disasters
Water management	(1) Impact and vulnerability assessment	• Strengthening water management monitoring • Impact and vulnerability assessment
	(2) Flood and drought prevention	• Infrastructure for flood prevention • Demand management through efficient water use • Stable water resources • Developing alternative water sources • Maximizing adaptative capacity of rivers • Export of water management technologies
	(3) Management of water quality and aquatic ecosystems	• Management of water quality • Restoration of aquatic ecosystems
Ecosystem	(1) Monitoring and vulnerability assessment	• Monitoring ecosystems and vulnerable species • Impact and vulnerability assessment
	(2) Adaptation plan	• Conservation of biodiversity • Restoration of ecological axis • Management system for nonnative species • Governance for ecosystem management and promotion
Climate change monitoring/projection	(1) Monitoring climate change	• Three-dimensional observation system • Monitoring local climate
	(2) Producing projection data	• Standardized national climate change scenarios • Producing regional and extreme climate data
	(3) Korea-specific projection model	• Global climate change projection model • Regional climate model for Korean Peninsula
	(4) Application system of projection/monitoring data	• Technology development for early-warning of extreme climate • Integrated monitoring of climate and air pollution • Services to provide projection/monitoring data
Adaptation industry/energy	(1) Impact and vulnerability assessment	• Impact and vulnerability assessment
	(2) Risk management and taking advantage of opportunities	• Establishment of adaptation plan by industry • Developing and supporting new/promising industries • Stable energy supply
Education/promotion/ international cooperation	(1) Education and promotion	• Education and promotion to raise awareness • Infrastructure to build adaptative capacity
	(2) International cooperation	• International cooperation for adaptation

We estimated the planned budget and actual expenditure on adaptation programs based on the IPCCAS and annual expenditure reports of six cities. The budget data were acquired from the IPCCAS. However, there are no official data that show the exact amount of governmental spending on climate change adaptation programs. Annual expenditure reports provide the expenditure on specific programs undertaken by municipal government departments in the fiscal year. To estimate spending on adaptation, we selected the programs sharing common features with the IPCCAS from the annual expenditure reports and aggregated the expenses of those programs. For example, the expenditure on purchasing equipment to extinguish forest fires was used to estimate the expenditure on the "prevention and alleviation of forest disaster" program in the forest sector, and the expenditure on water reuse projects was used to estimate the expenditure on the "developing alternative water sources" program in the water management sector. In addition, we also calculated expenditure on programs

that were not included in that city's IPCCAS but were included in other cities' IPCCAS and NCCAS. After this adjustment process, we compared budget plans and actual expenditure.

There are a few limitations to this method. First, some programs that did not need money were excluded from evaluation since the expenditure reports only include programs in which budget was invested. For example, the IPCCAS include modifying rules and regulations, but most of these were not included in expenditure reports as the cities did not allocate a budget for these objectives because they are normal activities of the municipal government that require no direct cost. Instead, this study focused on comparing planned budget and actual expenditure on adaptation programs. Second, the expenditure on climate change adaptation programs may be overestimated. Adaptation programs are not undertaken in the name of climate change, but are often combined with existing development, disaster management, and welfare programs [23]. For instance, most cities' IPCCAS include river maintenance to adapt to climate change and visiting health services for people who are vulnerable to heat wave. However, the expenditure reports show the spending on general river maintenance and visiting health services since they are often not implemented with the only purpose of climate change adaptation. Nevertheless, it is not expected to hamper the validity of the results since the budget in the IPCCAS also does not seem to be confined to climate-specific programs.

4. Results

4.1. Climate Change Adaptation Plans of Six Metropolitan Cities

Seoul, the capital city of South Korea, was the first city to establish an IPCCAS. It announced its first IPCCAS in December 2011, while the other metropolitan cities did so in February 2012. In the IPCCAS, the cities presented specific adaptation programs in various sectors and developed annual budget plans to implement these programs. According to IPCCAS 2012–2016 of six cities, the cities planned to spend 10,425 billion KRW (approximately 9.9 billion USD) on over 900 adaptation programs across five years. The cities tended to prioritize disaster/infrastructure, water management, and the health sector. They planned to spend 3592 billion KRW on 161 programs to prevent and respond to disasters, 2333 billion KRW on 171 programs to manage water quantity and quality, and 1901 billion KRW on 158 programs to prevent and manage diseases caused by climate change (Figure 2). A larger budget was allocated to the disaster/infrastructure sector than to water management: although the former sector had fewer programs, these programs included high-cost projects such as maintaining and expanding drain pipes and constructing waste treatment facilities.

The climate change adaptation strategies of the cities, considered together, have similar tendencies to strategies examined in prior studies. The most prevalent adaptation measures are related to water management [11], and many adaptation programs are similar to disaster management programs [23,85]. On the other hand, the adaptation strategies we studied were more focused on health and the adaptation of industry than cities assessed in previous studies. This is more apparent at the specific plan level. Table 4 presents the top five plans by program number and budget. In terms of the number of programs, measures to "reduce damage from heat waves and UV" (77 programs) are most frequently found, followed by "development of new and promising industries" (44 programs), and water quality management (37 programs). In terms of planned budget, the biggest portion was earmarked for "improvement of sewerage system" (2634 billion KRW), followed by "reducing damage from heat waves and UV" (1721 billion KRW), and "development of new and promising industries" (1140 billion KRW). This distribution may be attributed to the typology and background of IPCCAS 2012–2016. First, according to the NCCAS 2011–2015, activities to increase urban green areas are categorized in the health sector ("reducing damage from heat waves and UV") rather than the forest sector. The NCCAS considers increasing urban green areas to be a key measure to mitigate urban heat island effects and provide shelter through shade. Municipal governments have conducted many projects to increase green spaces, not only to protect citizens' health, but also to improve urban landscapes. In this sense, it is unsurprising that the health sector has the largest number of programs

and one of the highest proportions of the budget. Second, most of the IPCCAS 2012–2016 were prepared with reference to the NCCAS 2011–2015, which was established based on the Framework Act on Low Carbon Green Growth. The Korean government regarded the green growth model as a new mechanism for national growth and emphasized that managing climate change risk should be treated as a new opportunity for economic growth. Consequently, the government promoted industries related to climate change, such as renewable energy, desalination, and climate-related financial services, which became a key element of its climate change adaptation strategy.

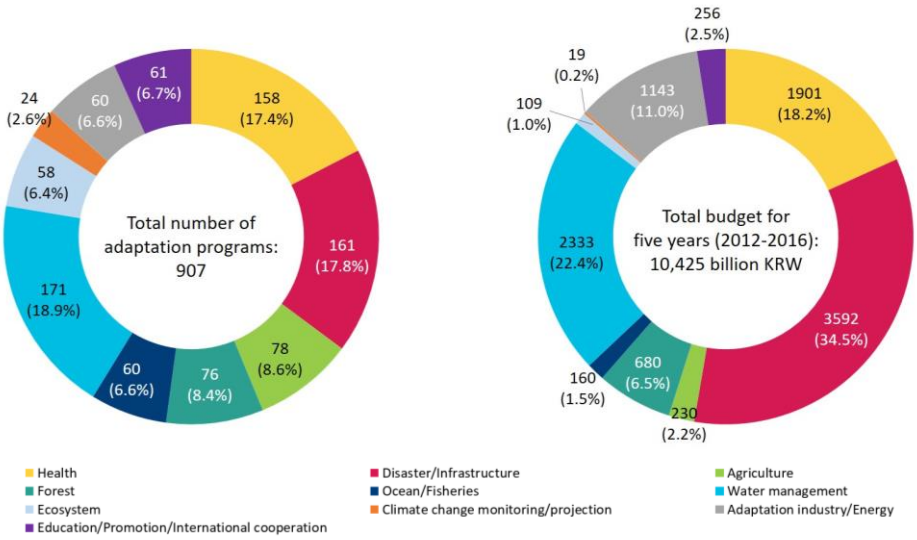


Figure 2. Climate change adaptation programs and budget plans divided by sector for six Korean cities, 2012–2016.

Table 4. Specific climate adaptation plans of six Korean cities, ranked by number of programs and allocated budget.

Category	Rank	Sector	Specific Plan	Program/ Budget
Number of programs	1	Health	Reducing damage from heat waves and UV	77
	2	Adaptation industry/energy	Developing and supporting new/promising industries	44
	3	Water management	Management of water quality	37
	4	Disaster/infrastructure	Early-warning and response system to disasters	36
	5	Disaster/infrastructure	Improvement of sewerage system	32
Budget (billion KRW)	1	Disaster/infrastructure	Improvement of sewerage system	2634
	2	Health	Reducing damage from heat waves and UV	1721
	3	Adaptation industry/energy	Developing and supporting new/promising industries	1140
	4	Water management	Developing alternative water sources	1013
	5	Water management	Management of water quality	509

The total planned budget of all six cities was 1448 billion KRW for adaptation programs in 2012, which would be expanded to 2666 billion KRW in 2016 (Figure 3). The budget for adaptation programs increased every year except between 2014 and 2015; this exception was mainly due to a large increase in the water management sector in 2014 and 2016. Incheon sharply increased its budget for several river maintenance projects in 2014, and Ulsan allocated a large budget for projects to reuse sewage and

waste water in 2016. The increase in the health sector budget between 2015 and 2016 is accounted for by Ulsan's large planned investment in urban parks and green spaces.

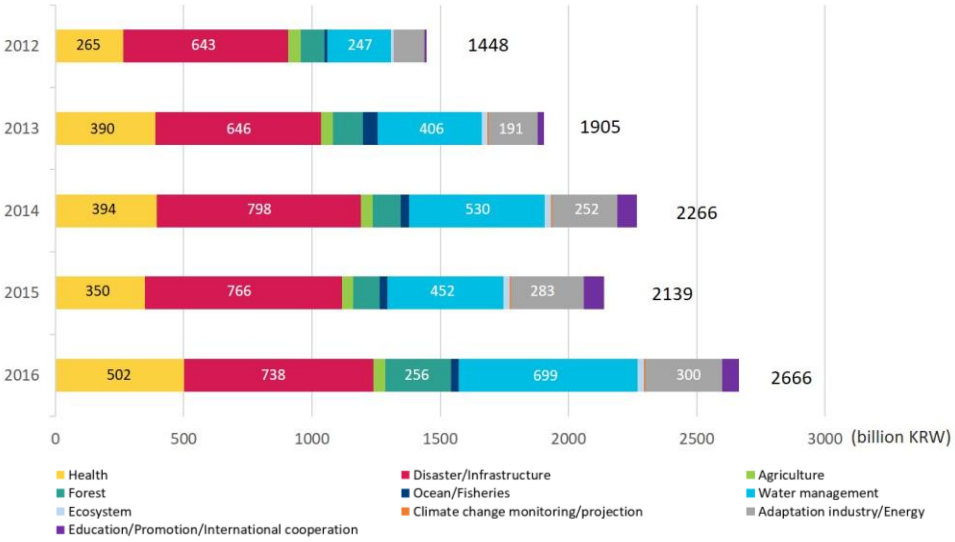


Figure 3. Total annual planned budgets for climate adaptation programs in six Korean cities, 2012–2016.

At the individual city level, Seoul allocated the largest budget (3619 billion KRW) to climate change adaption programs, of which it had 155. The next largest planned budget was in Daegu, where 1977 billion KRW was allocated to 235 programs, the highest number of programs among these six cities. Busan, Ulsan, and Daejeon planned to spend 1766 billion KRW on 211 programs, 1587 billion KRW on 118 programs, and 924 billion KRW on 125 programs, respectively. Incheon had the smallest budget (529 billion KRW) and number of programs (63) (Figure 4).

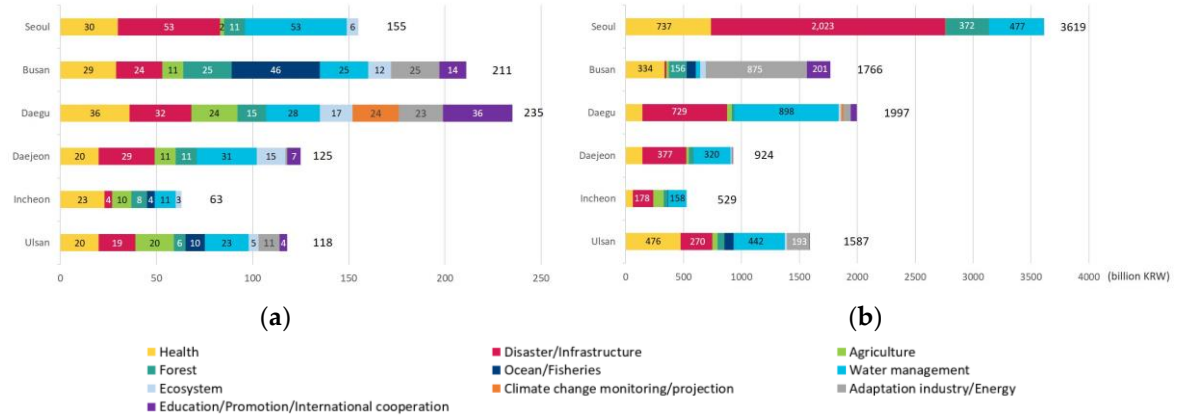


Figure 4. Planned climate change adaptation measures in six Korean cities for 2012–2016: (**a**) number of adaptation programs; and (**b**) allocated budget.

Figure 4 shows the number of programs and planned budget by sector in each city. Adaptation efforts seem comparatively well-distributed among sectors in terms of the number of programs, with some exceptions. First, Daegu is the only city that planned programs for climate change monitoring and projection. Since Korean cities tend to rely on nationally provided climate data and climate change scenarios, the other cities seemed unwilling to undertake programs for this sector. However, Daegu planned to develop systems to monitor its urban microclimate and produce city-specific climate data and scenarios. Second, the coastal cities—Busan, Incheon,

and Ulsan—prepared programs for the ocean/fisheries sector, whereas the inland cities—Seoul, Daegu, and Daejeon—presented no such programs. Third, Seoul did not include any programs for adaptation of industry/energy or the education/promotion/international cooperation sector, despite having the largest planned budget. One possible explanation is that Seoul did not consider educational and promotional programs to be adaptation options when it established IPCCAS, since its establishment preceded the national government distributing the IPCCAS writing manual.

The planned budgets show that the case cities have different predominant sectors, and the cities can be divided into four groups. First, the majority of cities prioritized the disaster/infrastructure and water management sectors: Daegu, Daejeon, and Incheon, respectively, allocated 81.5%, 75.4% and 63.5% of their total budgets for adaptation programs to these sectors. Second, Seoul planned to invest a very sizable portion of its budget, 2023 of 3619 billion KRW (55.9%), in only the disaster/infrastructure sector, with the aims of expanding sewer capacity and installing rainwater detention facilities to prevent flood damage. Third, Busan prioritized the climate change industry/energy sector more than the other cities. It planned to spend 49.5% of its budget (875 of 1766 billion KRW) on nurturing the marine bio industry, seawater desalination, and Green Port industry; developing renewable energy projects, including constructing off-shore wind farms; and developing hydrogen production and storage technology. By contrast, the other cities considered renewable energy projects as mitigation efforts rather than adaptation programs. Finally, Ulsan distributed its budget relatively evenly across diverse sectors compared to the other cities. Tables A1 and A2 present more detailed information about budget allocation by programs for each city.

4.2. Implementation of Climate Change Adaptation Measures in Six Metropolitan Cities

From 2012 to 2016, the six metropolitan governments spent 7988 billion KRW (approximately 7.6 billion USD) on climate change adaptation programs, falling short of the planned budget for the total period. In 2012, the cities' spending exceeded their planned budget, but in all other years they spent less money (Figure 5a). At the individual city level, all cities except Incheon spent less on climate change adaptation programs than they had planned in the IPCCAS (Figure 5b).

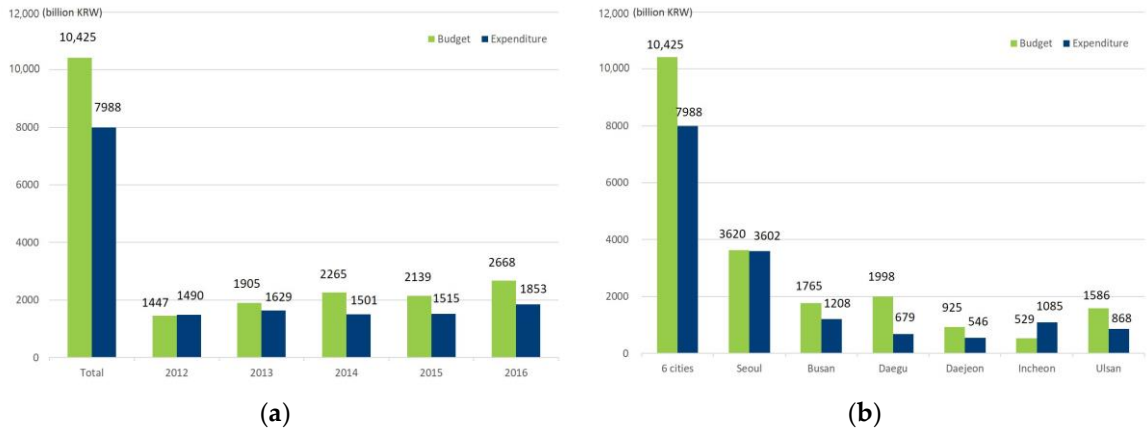
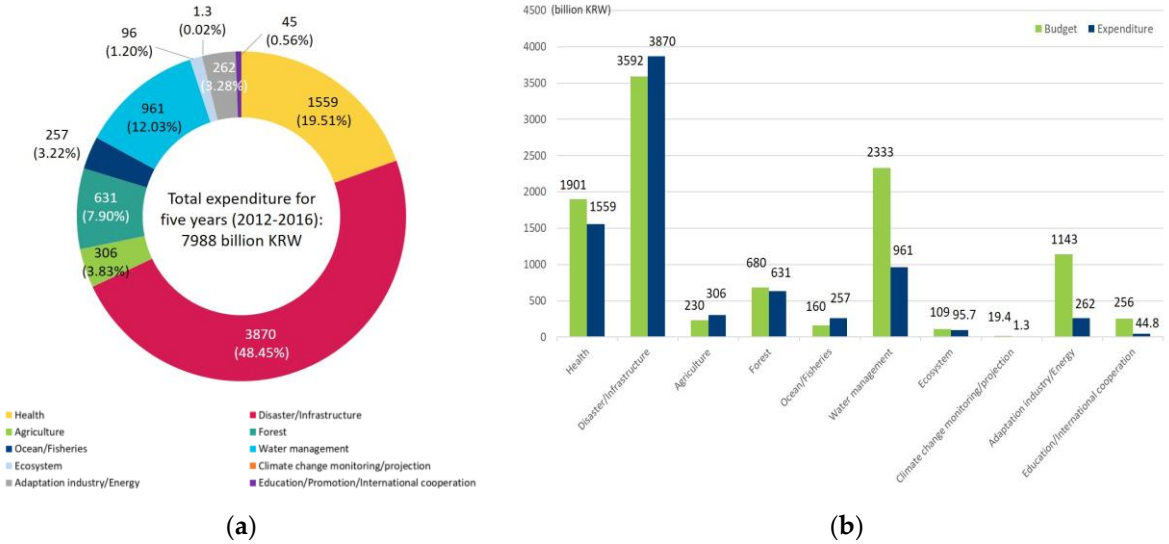


Figure 5. Planned budget vs. actual expenditure on climate change adaptation programs for 2012–2016 in six Korean cities: (**a**) by year; and (**b**) by city.

Figure 6 shows actual expenditure on adaptation programs by sector. The most money was spent on the disaster/infrastructure sector (3870 billion KRW, 48.4%), followed by health (1559 billion KRW, 19.5%), and water management (961 billion KRW, 12.0%). These three sectors also had the three highest planned budgets. However, expenditure on the water management and health sectors was lower than the respective planned budgets of 2333 and 1901 billion KRW for these sectors. In contrast, expenditure on the disaster/infrastructure sector exceeded the planned budget of 3592 billion KRW. Consequently, about half of total adaptation expenditure was concentrated on programs to prevent and

respond to disasters. In addition to exceeding the planned disaster/infrastructure sector budget, the six municipal governments spent more money than planned on the agriculture and ocean/fisheries sectors: 306 billion KRW rather than 230 for agriculture; 257 billion KRW rather than 160 for ocean/fisheries. A similar amount of money was spent on the ecosystem sector, while in other sectors the planned budget was not completely utilized.



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

Figure 6. Spending on climate change adaptation programs in six Korean cities, 2012–2016: (**a**) by sector; and (**b**) comparison between planned budget and actual expenditure by sector.

Table 5 outlines spending on specific plans. In the disaster/infrastructure sector, a significant amount of money was invested in programs to improve sewerage systems, including expanding sewer capacity and installing rainwater detention facilities to prevent flood damage (1514 billion KRW), to safely manage waste treatment facilities (1042 billion KRW), and to protect disaster-prone areas such as low-lying ground and slopes (541 billion KRW). Within the health sector, the six cities spent large amounts on programs to reduce damage from heat waves and UV (1001 billion KRW) and damage from air pollution (32 billion KRW). Among the five plans with the largest expenditures, only two—improvement of sewerage system and reducing damage from heat waves and UV—had been adequately budgeted for in the IPCCAS. More detailed information about expenditure by program for each city is presented in Tables A1 and A2.

Table 5. The five most costly specific plans for climate change adaptation in six Korean cities (2012–2016).

Rank	Sector	Specific Plan	Expenditure (billion KRW)
1	Disaster/infrastructure	Improvement of sewerage system	1514
2	Disaster/infrastructure	Stable management and disaster prevention system of waste treatment facilities	1042
3	Health	Reducing damage from heat waves and UV	1001
4	Disaster/infrastructure	Disaster prevention programs for high-risk areas	541
5	Health	Reducing damage from air pollution	32

The phenomenon of expenditure exceeding the budget in some sectors is made more obvious by scrutinizing the expenditure at the level of each city. Figure 7 presents the planned budget and actual expenditure by sector and year for each city. The bars indicate the planned budget

set out in the IPCCAS, and the lines show actual expenditure estimated from the expenditure reports. Although looking at all six cities together suggests that only the disaster/infrastructure, agriculture, and ocean/fisheries sectors exceeded the planned budget, looking at each city shows that expenditure also exceeded budget in other sectors. Seoul spent more money than planned in the health, ecosystem, climate change industry/energy, and education/promotion/international cooperation sectors; Busan in water management; Daegu in forest; Daejeon in ecosystem and education/promotion/international cooperation; Incheon in health, forest, climate change industry/energy, and education/promotion/international cooperation; and Ulsan in forest and education/promotion/international cooperation.

The reason for the variation between planned and actual expenditure may be municipal governments' different perceptions of climate change adaptation. Since adaptation policies overlap with disaster management and other environmental policies, the range of adaptation programs may depend on how climate change adaptation and climate-related risks are defined. This meant that certain programs were included in the IPCCAS of some cities but not others. For example, Seoul and Incheon did not recognize the international cooperation sector as an adaptation category and thus did not list any programs in this sector whereas Busan, Daegu, and Ulsan included various programs in this sector. According to the NCCAS, programs falling under the international cooperation sector could include holding international conferences and exhibitions about climate change adaptation, exchanging knowledge with foreign governments and institutions, and participating in international adaptation projects. Seoul and Incheon spent a substantial amount of money on this sector: Seoul held the International Council of Local Environmental Initiatives (ICLEI) World Congress in 2015 and operates the ICLEI East Asia Secretariat; Incheon also supported international organizations located in its territory, such as the Green Climate Fund. Similarly, Daegu, Daejeon, and Incheon spent money on programs to reduce air pollution even though they did not present those programs as adaptation programs in the IPCCAS. Expenditure on such "unrecognized" adaptation programs ranged from 4.9% to 60.8% of individual cities' total expenditure on adaptation programs (Table 6).

Table 6. Cities' expenditure on climate change adaptation (2012–2016) that was not planned in their Implementation Plans for Climate Change Adaptation Strategy.

	Seoul	Busan	Daegu	Daejeon	Incheon	Ulsan
Unplanned expenditure (million KRW)	377,055	222,297	98,786	71,110	659,354	42,544
Unplanned expenditure (% of total adaptation expenditure)	10.5	18.4	14.6	13.0	60.8	4.9

Figure 7. *Cont.*

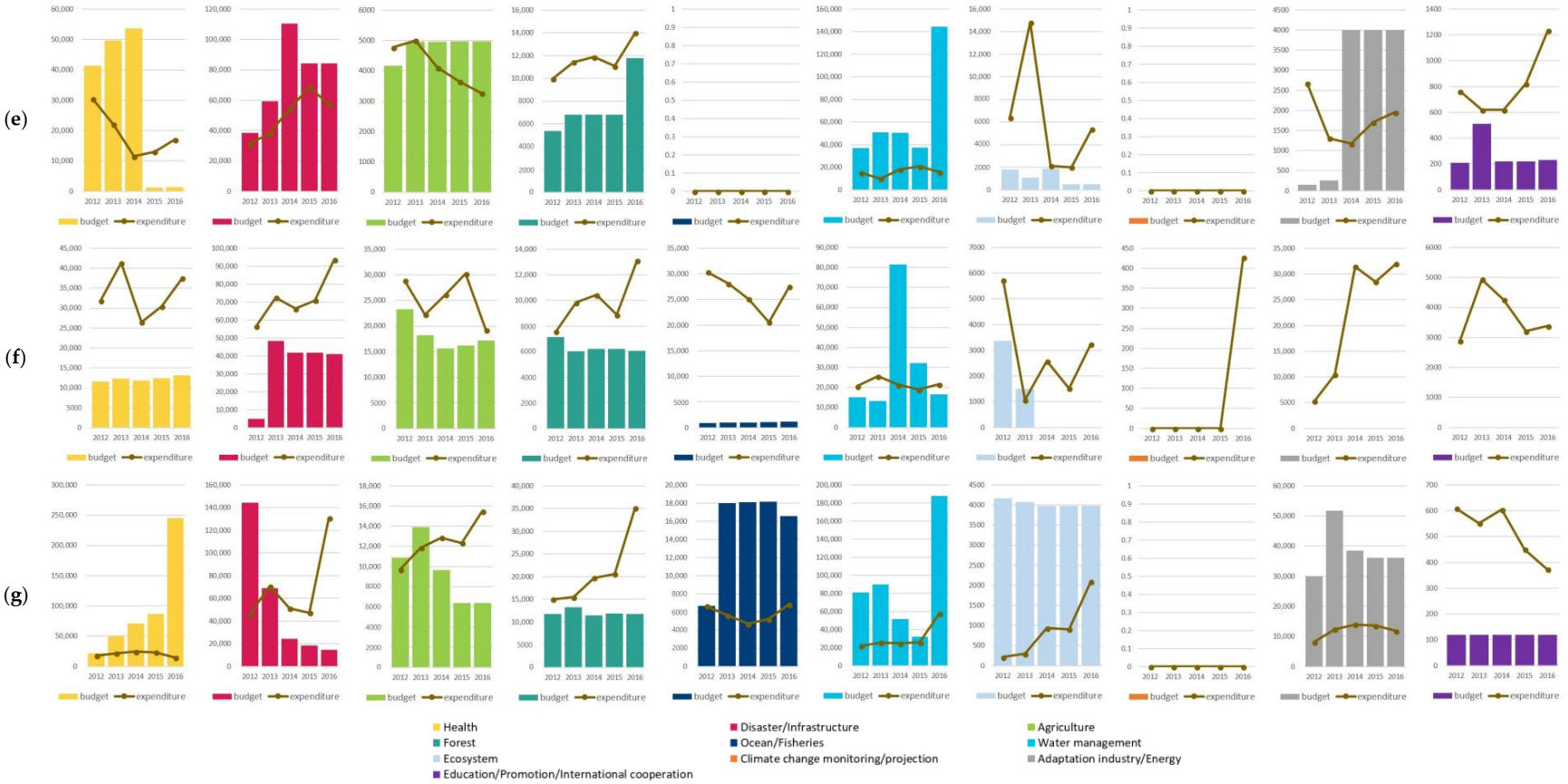


Figure 7. Annual planned budget and actual expenditure on climate change adaptation programs by sector for: (**a**) all six cities; (**b**) Seoul; (**c**) Busan; (**d**) Daegu; (**e**) Daejeon; (**f**) Incheon; and (**g**) Ulsan.

5. Discussion

The analysis showed that the South Korean metropolitan cities taken as case studies varied in implementing the strategies for climate change adaptation that were indicated in their IPCCAS. Figure 8 summarizes these outcomes. Seoul shows almost the same shape for both budget (blue dotted line) and expenditure (green solid line), which means it implemented the adaptation programs that it planned. In Daegu and Daejeon, the shapes of budget and expenditure are similar, but the budget is bigger than the expenditure. This means that these cities distributed their actual expenditure as planned in the budget, but the absolute level of expenditure was lower than planned. Incheon also has relatively similar shapes for budget and expenditure, but the budget is smaller than the expenditure. This indicates that Incheon concentrated its actual expenditure on the sectors that were prioritized in the IPCCAS, and the actual expenditure surpassed the allocated budget. Finally, in Busan and Ulsan, the shapes and sizes of the budget and expenditure are different from each other, which suggests that these cities implemented their adaptation programs differently from the original plans.

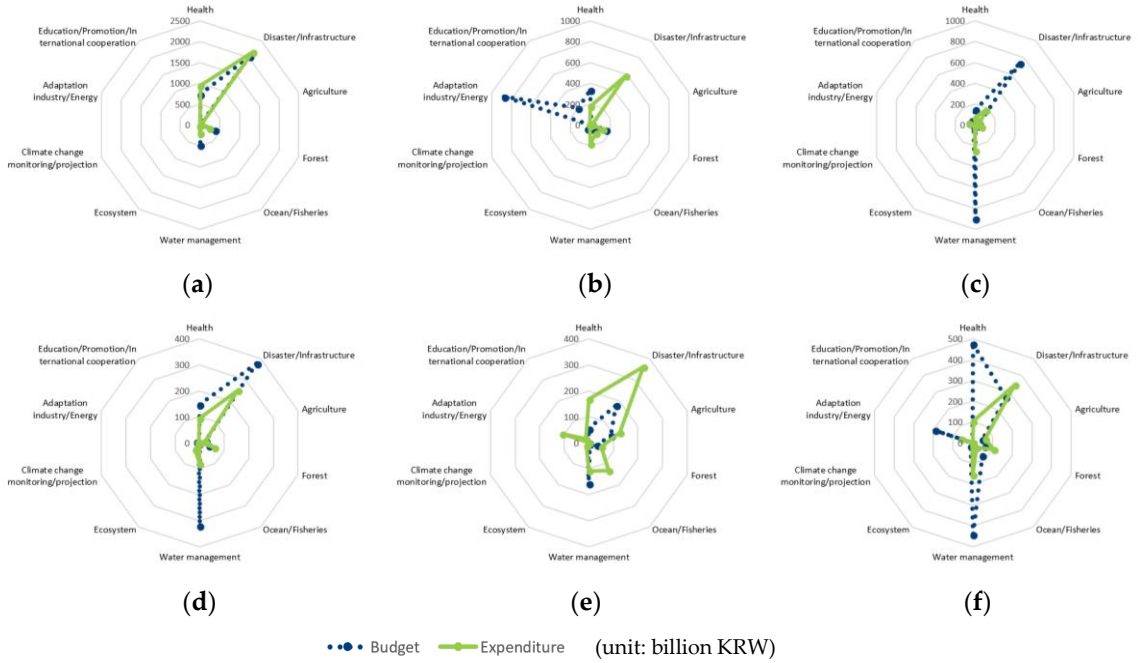


Figure 8. Comparison between planned budget and actual expenditure on climate change adaptation programs by sector from 2012–2016 for: (**a**) Seoul; (**b**) Busan; (**c**) Daegu; (**d**) Daejeon; (**e**) Incheon; and (**f**) Ulsan.

Despite their overall tendency to spend less than budgeted, it can be argued that metropolitan cities in South Korea have been implementing various climate change adaptation programs. However, it may be too early to assert that the programs are fully developed to enable climate change adaptation in individual cities. First, most of the IPCCAS adaptation programs came from the NCCAS; consequently, the programs are quite similar across cities, although climate change adaptation itself is "highly context-specific because it depends on the climatic, environmental, social, and political conditions in the target region and sector" [27] (p. 273). Although the NCCAS provides a good catalogue of diverse adaptation options, it does not offer specific, locally-customized adaptation programs since it was prepared in the national context. Given this limitation, municipal adaptation plans should fully consider local conditions and include numerous unique programs that the NCCAS could not provide. However, IPCCAS 2012–2016 showed a substantial overlap with the NCCAS and the overlapping programs appear to be general programs applicable to most cities, for example reducing damage from heavy snow and strong winds; promoting urban farming; managing street

trees; maintaining mountain trails; and developing technology to store, process, and distribute marine products. The expenditure on such programs is classified under "Etc." for each sector in Tables A1 and A2 in the appendix.

The amount of unutilized budget also shows that municipal governments were not fully able to develop an effective IPCCAS. According to Table 7, 343 billion KRW (3.3% of total planned budget) was not spent, because not all programs to which a budget was allocated were implemented. This seems to be a small proportion of the total budget, but the majority of the unimplemented programs were vulnerability assessments and advanced monitoring to predict the effects of climate change on various sectors.

Table 7. Unspent climate change adaptation budget (2012–2016) allocated in the Implementation Plans for Climate Change Adaptation Strategy of six Korean cities.

	Seoul	Busan	Daegu	Daejeon	Incheon	Ulsan
Unspent budget (million KRW)	3938	64,754	33,299	12,502	158,914	69,589
Unspent budget (% of total adaptation budget)	0.1	3.7	1.7	1.4	30.4	4.4

Finally, a question about the effect of adaptation programs arises. If adaptation programs do not appropriately reflect local conditions, are they effective in mitigating the adverse effects of climate change and making cities more climate-resilient? The six case study cities still spent large amounts of money on post-disaster restoration. For example, Busan's annual expenditure between 2012 and 2016 on restoring damaged areas and supporting people damaged by floods and landslides was 1186, 203, 8011, 1107 and 3003 million KRW. In Ulsan, annual expenditure amounted to 3184, 1484, 6408, 1698, and 53,531 million KRW. Considering that implementing policies and spending large amounts on programs does not always guarantee the expected outcomes, future research should focus on evaluating the actual effect of adaptation programs on individual cities [28]. Moreover, if adaptation programs do not have a significant effect, research should address why the programs are not working.

6. Conclusions

Through analyzing budgets and actual expenditure on climate change adaptation programs in six metropolitan cities in South Korea, this study found that these cities have implemented various programs to adapt to climate change, but the cities' expenditure varied to different degrees from their original IPCCAS in terms of both level of overall expenditure and specific expenditure by sector. More specifically, we discovered the following: First, most cities prioritized the disaster/infrastructure, water management, and health sectors for adaptation. Second, actual expenditure on climate change adaptation programs was less than the budget planned in the IPCCAS. Third, some cities (Seoul, Daegu, Daejeon, and Incheon) prioritized the sectors similarly in both the planning and implementation stages, whereas some cities (Busan and Ulsan) had different priorities in the two stages. In other words, the former cities spent more money on the sectors to which more budget had been allocated, but the latter cities did not distribute their money as planned in the IPCCAS. Fourth, it is difficult to assert that the current adaptation programs of South Korean metropolitan cities are well-tailored to each city.

This study is the first to compare the planning and implementation stages of adaptation at the level of municipal governments in South Korea in terms of budget and expenditure. It has important implications for many other local governments that are preparing to establish an IPCCAS, as well as the six metropolitan governments implementing their second IPCCAS. The findings suggest that, to improve consistency between planning and implementation, municipal governments should consider local conditions and develop locally required programs rather than broadly accepting and emulating the NCCAS. Successfully implementing climate change adaptation programs at the city level not only protects citizens from climate hazards, but also contributes to global efforts to achieve Sustainable Development Goals (SDGs), such as Good Health and Well-being (SDG 3); Clean Water and Sanitation (SDG 6); Affordable and Clean Energy (SDG 7); Industry, Innovation and Infrastructure

(SDG 9); Sustainable Cities and Communities (SDG 11); Climate Action (SDG 13); Life Below Water (SDG 14); and Life on Land (SDG 15). Since these goals can be achieved only if they are supported by local efforts and cooperation, it is very important for local governments to create and implement well-tailored climate change adaptation plans. Furthermore, since implementing adaptation programs does not reduce the negative effects and risks of climate change, monitoring and evaluation systems for adaptation programs are still required.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Climate change adaptation programs, planned budget, and actual expenditure of three metropolitan cities in South Korea (Seoul, Busan, and Daegu), 2012–2016.

Sector/Specific Plan	Seoul			Busan			Daegu		
	Programs (#)	Budget (million KRW)	Expenditure (million KRW)	Programs (#)	Budget (million KRW)	Expenditure (million KRW)	Programs (#)	Budget (million KRW)	Expenditure (million KRW)
Total	155	3,620,143	3,602,143	211	1,765,486	1,208,395	235	1,998,212	678,538
Health	30	737,324	946,464	29	333,650	176,666	36	146,407	72,573
• Health impact assessment resulting from heat waves and UV monitoring system	2	0	0	5	8100	0	0	0	0
• Reducing damage from heat waves and UV	17	676,299	690,541	9	317,700	104,005	23	140,843	33,658
• Health impact assessment resulting from climate hazards, monitoring system, and reduction	2	9620	4217	0	0	4633	3	3471	3466
• Health impact assessment resulting from ecosystem change and monitoring	0	0	0	0	0	7	0	0	0
• Infectious disease surveillance and management	3	5180	5575	6	700	4482	5	393	830
• R&D for infectious diseases	0	0	0	0	0	0	2	1070	0
• Health impact assessment of air pollution and monitoring system	0	0	0	0	0	0	0	0	0
• Reducing damage from air pollution	2	300	242,891	9	7150	62,287	2	100	33,794
• Health impact assessment of movement of chemicals and monitoring system	0	0	0	0	0	0	0	0	0
• Managing allergenic environmental factors	1	1100	0	0	0	0	0	0	0
• Preventing and managing allergies	3	44,825	3240	0	0	1251	1	530	825
Disaster/infrastructure	53	2,023,172	2,157,140	24	15,584	581,080	32	728,524	175,488
• Risk assessment of natural disasters caused by climate change	0	0	0	3	1600	0	2	100	0
• Strengthening standards and institutions	1	0	0	0	0	0	4	6300	0
• Disaster insurance	1	0	65	2	1584	0	2	26,250	287
• Disaster prevention programs for high-risk areas	3	19,957	48,769	4	600	347,255	2	84,393	60,824
• R&D for climate control	14	15,966	18,534	0	0	36,281	11	8994	37,174
• Early-warning and response system to disasters	5	1500	94,024	3	4500	19,672	3	80	0
• Post-disaster recovery to prevent recurrent damages	2	94,190	91,850	8	6700	52,234	0	0	500
• Installation of rainwater runoff reduction facilities	0	0	322,915	0	0	122,891	2	0	38,728
• Stable management and disaster prevention system of waste treatment facilities	0	0	0	0	0	0	0	0	0

Table A1. *Cont.*

Sector/Specific Plan	Seoul			Busan			Daegu		
	Programs (#)	**Budget (million KRW)**	**Expenditure (million KRW)**	**Programs (#)**	**Budget (million KRW)**	**Expenditure (million KRW)**	**Programs (#)**	**Budget (million KRW)**	**Expenditure (million KRW)**
Total	155	3,620,143	3,602,143	211	1,765,486	1,208,395	235	1,998,212	678,538
• Improvement of sewerage system	12	1,699,686	1,356,684	4	600	2502	2	602,000	35,213
• Identification of vulnerable areas to climate change and adaptation plan	0	0	0	0	0	0	0	0	0
• Land use plans considering climate change	0	0	0	0	0	0	0	0	0
• Improving adaptation capacity of cities	0	0	2103	0	0	244	0	0	0
• Building climate-resilient, disaster-preventive cities	1	590	1112	0	0	0	0	0	1876
• Etc. (responding to heavy snow and strong wind)	14	191,283	221,084	0	0	0	4	407	884
Agriculture	2	3060	29,824	11	22,040	20,558	24	42,999	45,794
• Crop yield estimation and prediction	0	0	0	2	0	0	1	0	0
• Climate-adaptive species and new cultivars	0	0	0	2	8000	0	2	7796	3295
• Climate-adaptive cultivation techniques	0	0	971	2	200	5074	3	5830	9474
• Improvement and management of livestock	0	0	0	0	0	155	0	0	4067
• Forage supply	0	0	0	0	0	16	0	0	77
• Efficient use and saving of agricultural water	0	0	0	0	0	0	3	170	0
• Stable supply of agricultural water	0	0	0	0	0	0	2	19,243	300
• Vulnerability assessment	0	0	0	0	0	0	3	100	0
• Technology development to relieve climate hazards	0	0	9	4	13,840	5079	3	2445	6194
• Agricultural infrastructure to prevent damage from storms and floods	0	0	0	0	0	3620	2	5210	11,339
• Disease and insect pest control system	0	0	196	1	0	98	3	50	5
• Forecast of foreign disease and insect pest	0	0	0	0	0	0	0	0	100
• Prevention of animal diseases	0	0	1101	0	0	2727	2	2155	6525
• Etc. (promotion of urban farming)	2	3060	27,547	0	0	3789	0	0	4417
Forest	11	372,371	227,662	25	155,900	127,696	15	22,002	61,385
• Protecting plant species vulnerable to climate change	0	0	0	4	67,600	30,702	2	450	9386
• Forests for watershed conservation	0	0	0	3	2600	0	4	5693	7251
• Impact and vulnerability assessment of forestry	0	0	0	2	1000	0	0	0	0
• Increasing forest productivity	1	2578	0	2	0	256	0	0	256
• Vulnerability assessment of forest disasters	1	0	0	0	0	330	3	185	235
• Prevention and alleviation of forester disasters	4	329,932	107,687	8	65,500	34,308	3	12,389	17,086

Table A1. *Cont.*

Sector/Specific Plan	Seoul			Busan			Daegu		
	Programs (#)	**Budget (million KRW)**	**Expenditure (million KRW)**	**Programs (#)**	**Budget (million KRW)**	**Expenditure (million KRW)**	**Programs (#)**	**Budget (million KRW)**	**Expenditure (million KRW)**
Total	155	3,620,143	3,602,143	211	1,765,486	1,208,395	235	1,998,212	678,538
• Disease and insect pest control system	0	0	14,159	2	0	30,148	3	3285	5481
• Climate-adaptive forest management	0	0	140	0	0	0	0	0	12
• Etc. (Management of street trees/maintenance of mountain trails)	3	39,861	105,676	4	19,200	31,952	0	0	21,679
Ocean/fisheries	0	0	0	46	77,700	96,615	0	0	0
• Vulnerability assessment of coastal areas to sea-level rise	0	0	0	4	1500	0	0	0	0
• Scientific management system to predict and respond to changing external forces	0	0	0	14	18,300	173	0	0	0
• Coastal topography change and adaptation plan	0	0	0	6	8250	35,897	0	0	0
• Management of fishing condition of littoral sea and fishery resources	0	0	0	5	1300	90	0	0	0
• Securing future fishery resources	0	0	0	7	2350	11,395	0	0	0
• Enhancing observation and management of coastal fisheries	0	0	0	3	1000	0	0	0	0
• Management of infectious diseases in marine creatures	0	0	0	0	22,500	162	0	0	0
• Reducing damage from ocean acidification	0	0	0	0	0	0	0	0	0
• Alleviating fishery disasters	0	0	0	3	0	12,226	0	0	0
• Etc. (technology to store, process, and distribute marine products)	0	0	0	4	22,500	36,672	0	0	0
Water management	53	476,810	192,835	25	37,650	177,204	28	898,436	247,943
• Strengthening water management monitoring	1	0	2879	3	1250	671	2	0	466
• Impact and vulnerability assessment	1	0	0	4	2000	0	0	0	0
• Infrastructure for flood prevention	7	22,200	42,565	8	2000	0	3	6800	11,635
• Demand management through efficient water use	4	0	0	0	0	61	2	1600	43
• Stable water resources	4	2313	3442	0	0	3	4	0	27
• Developing alternative water sources	12	33,628	37,151	3	30,700	0	9	782,913	5885
• Maximizing adaptative capacity of rivers	3	76,564	48,424	3	1200	71,559	6	106,148	112,538
• Export of water management technologies	0	0	0	0	0	0	0	0	29,440
• Management of water quality	20	292,865	30,447	0	0	49,164	2	975	51,546
• Restoration of aquatic ecosystems	1	49,240	27,927	4	500	55,747	0	0	36,361

Table A1. *Cont.*

Sector/Specific Plan	Seoul			Busan			Daegu		
	Programs (#)	**Budget (million KRW)**	**Expenditure (million KRW)**	**Programs (#)**	**Budget (million KRW)**	**Expenditure (million KRW)**	**Programs (#)**	**Budget (million KRW)**	**Expenditure (million KRW)**
Total	155	3,620,143	3,602,143	211	1,765,486	1,208,395	235	1,998,212	678,538
Ecosystem	6	7406	25,861	12	47,300	9879	17	23,495	10,651
• Monitoring ecosystems and vulnerable species	3	1177	586	0	0	0	3	1080	149
• Impact and vulnerability assessment	0	0	0	5	4300	0	0	0	0
• Conservation of biodiversity	2	5969	12,129	3	500	7538	4	5358	2581
• Restoration of ecological axis	0	0	12,987	4	42,500	1589	3	17,008	7921
• Management system for nonnative species	1	260	0	0	0	752	0	0	0
• Governance for ecosystem management and promotion	0	0	159	0	0	0	3	49	0
Climate change monitoring/projection	0	0	0	0	0	0	24	19,350	0
• Three-dimensional observation system	0	0	0	0	0	0	3	5700	0
• Monitoring local climate	0	0	0	0	0	0	4	7450	0
• Standardized national climate change scenario	0	0	0	0	0	0	2	500	0
• Producing regional and extreme climate data	0	0	0	0	0	0	6	1000	0
• Global climate change projection model	0	0	0	0	0	0	0	0	0
• Regional climate model for Korean Peninsula	0	0	0	0	0	0	2	1000	0
• Technology development for early-warning of extreme climate	0	0	0	0	0	0	0	0	0
• Integrated monitoring of climate and air pollution	0	0	895	0	0	0	0	0	0
• Services to provide projection/monitoring data	0	0	0	0	0	0	7	3700	0
Adaptation industry/energy	0	0	0	25	874,860	12,742	23	63,544	63,166
• Impact and vulnerability assessment	0	0	0	1	0	0	2	600	0
• Establishment of adaptation plan by industry	0	0	0	2	1370	0	6	1030	0
• Developing and supporting new/promising industries	0	0	9459	21	873,490	12,742	15	61,914	63,166
• Stable energy supply	0	0	0	1	0	0		0	0
Education/promotion/international cooperation	0	0	11,961	14	200,802	5955	36	53,455	1538
• Education and promotion to raise awareness	0	0	1461	8	850	2122	18	8305	1412
• Infrastructure to build adaptative capacity	0	0	3673	3	150,500	7	12	40,700	126
• International cooperation for adaptation	0	0	6828	3	49,452	3826	6	4450	0

Table A2. Climate change adaptation programs, planned budget, and actual expenditure of three metropolitan cities in South Korea (Daejeon, Incheon, and Ulsan), 2012–2016.

Sector/Specific plan	Daejeon			Incheon			Ulsan		
	Programs (#)	Budget (Million KRW)	Expenditure (Million KRW)	Programs (#)	Budget (Million KRW)	Expenditure (Million KRW)	Programs (#)	Budget (Million KRW)	Expenditure (Million KRW)
Total	125	925,255	546,253	63	529,345	1,084,965	118	1,586,432	867,899
Health	20	147,320	94,113	23	61,100	167,599	20	475,575	101,578
• Health impact assessment resulting from heat waves and UV monitoring system	0	0	0	0	0	0	0	0	0
• Reducing damage from heat waves and UV	14	145,868	70,218	7	14,596	29,100	7	425,680	73,377
• Health impact assessment resulting from climate hazards, monitoring system, and reduction	4	1360	2741	4	36,502	32,300	1	1620	2191
• Health impact assessment resulting from ecosystem change and monitoring system	0	0	0	6	0	0	0	0	0
• Infectious disease surveillance and management	2	92	6374	0	7449	16,259	6	3465	3563
• R&D for infectious diseases	0	0	0	0	0	0	0	0	0
• Health impact assessment of air pollution and monitoring system	0	0	0	0	0	0	0	0	0
• Reducing damage from air pollution	0	0	14,755	0	0	89,837	3	42,160	22,448
• Health impact assessment of movement of chemicals and monitoring system	0	0	0	0	0	0	0	0	0
• Managing allergenic environmental factors	0	0	0	0	0	0	0	0	0
• Preventing and managing allergies	0	0	25	6	2553	102	3	2650	0
Disaster/infrastructure	29	377,047	249,903	4	177,808	360,169	19	270,343	346,258
• Risk assessment of natural disasters caused by climate change		0	0	0	0	0	0	0	0
• Strengthening standards and institutions	6	1700	108	0	0	813	0	0	2350
• Disaster insurance	2	15	56	1	0	75	1	60	0
• Disaster prevention programs for high-risk areas	0	0	5928	1	4708	35,267	3	16,823	42,722
• R&D for climate control	8	45,624	35,204	0	0	34,804	3	255	31,174
• Early-warning and response system to disasters	0	0	4033	0	0	10,275	2	0	66,304
• Post-disaster recovery to prevent recurrent damages	2	482	0	0	0	0	0	0	1272
• Installation of rainwater runoff reduction facilities	6	324,379	203,478	0	0	185,290	2	54,992	168,618
• Stable management and disaster prevention system of waste treatment facilities	0	0	0	0	0	0	0	0	0
• Improvement of sewerage system	5	4847	0	2	173,100	88,550	7	153,439	31,023
• Identification of vulnerable areas to climate change and adaptation plan	0	0	0	0	0	0	0	0	0

Table A2. *Cont.*

Sector/Specific plan	Daejeon			Incheon			Ulsan		
	Programs (#)	**Budget (Million KRW)**	**Expenditure (Million KRW)**	**Programs (#)**	**Budget (Million KRW)**	**Expenditure (Million KRW)**	**Programs (#)**	**Budget (Million KRW)**	**Expenditure (Million KRW)**
Total	125	925,255	546,253	63	529,345	1,084,965	118	1,586,432	867,899
• Land use plans considering climate change	0	0	0	0	0	0	0	0	0
• Improving adaptation capacity of cities	0	0	0	0	0	0	1	44,774	0
• Building climate-resilient, disaster-preventive cities	0	0	0	0	0	2341	0	0	2794
• Etc. (Responding to heavy snow and strong wind)	0	0	1096	0	0	2753	0	0	0
Agriculture	11	24,004	20,765	10	90,439	126,657	20	47,249	62,240
• Crop yield estimation and prediction		0	0	0	0	0	1	34	0
• Climate-adaptive species and new cultivars		0	0	0	0	1009	1	170	3212
• Climate-adaptive cultivation techniques	6	18,806	10,636	4	0	24,596	11	39,569	20,152
• Improvement and management of livestock	0	0	1294	0	0	2493	0	0	63
• Forage supply	0	0	483	0	0	1090	0	0	12,546
• Efficient use and saving of agricultural water	0	0	441	0	0	0	0	0	0
• Stable supply of agricultural water	2	4200	0	1	0	20,984	1	0	0
• Vulnerability assessment		0	0	0	0	0	0	0	0
• Technology development to relieve climate hazards	3	998	317	1	32,664	5636	1	0	3724
• Agricultural infrastructure to prevent damage from storms and floods	0	0	1300	1	57,760	51,466	1	1679	9389
• Disease and insect pest control system	0	0	100	3	15	1324	1	0	140
• Forecast of foreign diseases and insect pests		0	0	0	0	0	0	0	0
• Prevention of animal diseases	0	0	2845	0	0	10,716	3	5797	10,954
• Etc. (Promotion of urban farming)	0	0	3351	0	0	7343	0	0	2061
Forest	11	37,628	58,373	8	31,717	49,827	6	60,108	105,967
• Protecting plant species vulnerable to climate change	0	0	10,447	0	0	0	0	0	721
• Forests for watershed conservation	4	2091	10,310	2	14,831	13,140	0	0	12,981
• Impact and vulnerability assessment of forestry	0	0	0	0	0	0	0	0	0
• Increasing forest productivity	0	0	2815	0	0	7011	0	0	476
• Vulnerability assessment of forest disasters	0	0	0	0	0	0	0	200	591
• Prevention and alleviation of forester disasters	7	16,886	14,194	3	12,710	21,646	1	32,833	35,098
• Disease and insect pest control system	0	0	1550	3	4176	3463	2	25,545	39,302
• Climate-adaptive forest management	0	0	4	0	0	230	2	0	2797
• Etc. (Management of street trees/ maintenance of mountain trails)	0	18,651	19,052	0	0	4337	0	1530	14,002

Table A2. *Cont.*

Sector/Specific plan	Daejeon			Incheon			Ulsan		
	Programs (#)	**Budget (Million KRW)**	**Expenditure (Million KRW)**	**Programs (#)**	**Budget (Million KRW)**	**Expenditure (Million KRW)**	**Programs (#)**	**Budget (Million KRW)**	**Expenditure (Million KRW)**
Total	125	925,255	546,253	63	529,345	1,084,965	118	1,586,432	867,899
Ocean/fisheries	0	0	0	4	5123	131,724	10	77,503	29,054
• Vulnerability assessment of coastal areas to sea-level rise	0	0	0	0	0	0	1	33	0
• Scientific management system to predict and respond to changing external forces	0	0	0	0	0	0	0	0	0
• Coastal topography change and adaptation plan	0	0	0	0	0	92	0	0	2905
• Management of fishing conditions of littoral sea and fishery resources	0	0	0	0	0	0	1	33	0
• Securing future fishery resources	0	0	0	0	0	45,876	4	13,187	12,005
• Enhancing observation and management of coastal fisheries	0	0	0	0	0	8408	1	700	0
• Management of infectious diseases in marine creatures	0	0	0	0	0	187	1	150	322
• Reducing damage from ocean acidification	0	0	0	0	0	0	0	0	0
• Alleviating fishery disasters	0	0	0	4	5123	71,786	2	63,400	12,310
• Etc. (technology to store, process, and distribute marine products)	0	0	0	0	0	5374	0	0	1511
Water management	31	319,693	79,501	11	158,291	108,036	23	442,220	155,811
• Strengthening water management monitoring	0	0	1604	0	0	1399		0	0
• Impact and vulnerability assessment	0	0	0	0	0	270	1	200	3299
• Infrastructure for flood prevention	0	0	19,037	0	0	1668	2	700	0
• Demand management through efficient water use	0	0	3	0	0	0	3	250	0
• Stable water resources	8	685	1345	0	0	16,241	4	135,231	9135
• Developing alternative water sources	2	0	0	0	0	16,829	5	166,240	3142
• Maximizing adaptative capacity of rivers	6	107,860	38,982	0	0	65,427	3	126,140	115,329
• Export of water management technologies	3	50	60	0	0	0		0	0
• Management of water quality	11	201,740	3489	0	0	6262	4	13,209	5591
• Restoration of aquatic ecosystems	1	9358	14,981	11	158,291	0	1	250	19,315
Ecosystem	15	5773	30,728	3	4867	14,141	5	20,155	4450
• Monitoring ecosystems and vulnerable species	4	2973	0	1	623	0	1	83	0
• Impact and vulnerability assessment	1	0	0	0	0	0	1	0	0
• Conservation of biodiversity	1	0	6777	0	0	4174	1	44,774	4450
• Restoration of ecological axis	8	2800	23,951	2	4244	9917	2	20,072	0
• Management system for nonnative species	1	0	0	0	0	50	0	0	0
• Governance for ecosystem management and promotion	0	0	0	0	0	0	0	0	0

Table A2. *Cont.*

Sector/Specific plan	Daejeon			Incheon			Ulsan		
	Programs (#)	**Budget (Million KRW)**	**Expenditure (Million KRW)**	**Programs (#)**	**Budget (Million KRW)**	**Expenditure (Million KRW)**	**Programs (#)**	**Budget (Million KRW)**	**Expenditure (Million KRW)**
Total	125	925,255	546,253	63	529,345	1,084,965	118	1,586,432	867,899
Climate change monitoring/projection	0	0	0	0	0	0	0	0	0
• Three-dimensional observation system	0	0	0	0	0	0	0	0	0
• Monitoring local climate	0	0	0	0	0	0	0	0	0
• Standardized national climate change scenarios	0	0	0	0	0	0	0	0	0
• Producing regional and extreme climate data	0	0	0	0	0	0	0	0	0
• Global climate change projection model	0	0	0	0	0	0	0	0	0
• Regional climate model for Korean Peninsula	0	0	0	0	0	0	0	0	0
• Technology development for early-warning of extreme climate	0	0	0	0	0	0	0	0	0
• Integrated monitoring of climate and air pollution	0	0	0	0	0	427	0	0	0
• Services to provide projection/monitoring data	0	0	0	0	0	0	0	0	0
Adaptation industry/Energy	1	12,400	8811	0	0	107,713	11	192,679	59,950
• Impact and vulnerability assessment	0	0	0	0	0	0	1	0	0
• Establishment of adaptation plan by industry	0	0	0	0	0	0	2	200	0
• Developing and supporting new/promising industries	1	12,400	8811	0	0	107,713	7	192,479	59,950
• Stable energy supply	0	0	0	0	0	0	1	0	0
Education/Promotion/International cooperation	7	1390	4059	0	0	18,673	4	600	2591
• Education and promotion to raise awareness	2	90	3890	0	0	5052	2	500	2374
• Infrastructure to build adaptative capacity	5	1300	169	0	0	1361	0	0	69
• International cooperation for adaptation	0	0	0	0	0	12,260	2	100	148

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