Sensors and Materials, Vol. 37, No. 9 (2025) 4071–4085
MYU Tokyo

S & M 4168

Development of a Citizen-participatory Carbon Challenge Platform Based on the Carbon Spatial Information System

Kyo-Min Kim,[1] Seung-Su Lee,[1*] Song-Pyo Hong,[2] and Seung-Jun Lee[2]

[1]Department of Research & Planning, SPACE^N,
C 6 Floor, 242 Pangyo-ro, Bundang-gu, Seongnam-si, Gyeonggi-do, Republic of Korea
[2]Department of Digital Platform, SPACE^N,
C 6 Floor, 242 Pangyo-ro, Bundang-gu, Seongnam-si, Gyeonggi-do, Republic of Korea

(Received June 24, 2025; accepted September 8, 2025)

Keywords: carbon spatial information system, citizen participation, carbon challenge platform, business model canvas, data/API/sensor integration

In this paper, we propose a design and integration framework for transforming South Korea's Carbon Spatial Information System into a citizen-participatory geospatial platform, referred to as the Carbon Challenge Platform. Unlike existing carbon tracking services that mainly emphasize individuals' behavioral change through mobile applications or gamification, the proposed platform integrates geospatial carbon datasets with real-time sensor inputs and policy feedback mechanisms to enable localized and participatory climate action. In particular, the platform leverages sensors such as energy meters, mobility trackers, and environmental Internet of Things devices (e.g., CO_2 and temperature sensors) to provide real-time, detailed data for carbon footprint estimation. The system is designed around a layered architecture and ten core functions, supported by a modular data/Application Programming Interface (API)/sensor integration framework that links national geospatial datasets with third-party APIs, IoT devices, and policy databases. To ensure reliability, preprocessing techniques such as normalization, noise filtering, and temporal alignment are applied to handle sensor data variability and time-series resolution. From a citizen's perspective, the platform offers several anticipated benefits, including increased awareness of personal carbon impacts, motivation for sustainable behavior, and access to personalized feedback, thereby fostering proactive engagement in local climate initiatives. Beyond individual engagement, the aggregated data can guide municipal policy, strengthening participatory climate governance. The model thus provides a scalable and transferable template for climate-responsive digital governance. Future work will focus on pilot testing, refinement of spatial emission modeling, and alignment with international standards such as ISO 14068 and Open Geospatial Consortium (OGC) frameworks to ensure global interoperability and long-term policy integration.

[*]Corresponding author: e-mail: ss.lee@spacen.or.kr
https://doi.org/10.18494/SAM5828

ISSN 0914-4935

1. Introduction

In recent years, addressing the global climate crisis has increasingly emphasized not only top-down policy action but also bottom-up civic engagement.[1] Numerous digital platforms have emerged to track individual carbon footprints, encourage behavioral change, and gamify environmental responsibility.[2–4] Examples include JouleBug, Too Good To Go, and the CoolClimate Maps, all of which aim to visualize carbon emissions and promote individuals' contributions toward sustainability.

These platforms often adopt persuasive strategies such as personalized feedback, real-time tracking, and community challenges to drive user participation. However, despite their popularity, they typically lack a core element: geospatial intelligence. Most existing services do not contextualize user behavior within spatial environments, making it difficult to translate individuals' actions into localized climate relevance or spatial policy feedback.

This gap reveals a critical need for services that integrate behavioral data with location-aware spatial platforms.[5] Such integration would enable more accurate carbon accounting, improve citizen awareness, and support data-driven local governance.

In response to this need, in this paper, we present a comprehensive design framework for transforming South Korea's Carbon Spatial Information System (CSIS) into a participatory, citizen-oriented carbon engagement platform.

CSIS is a national-level geospatial platform originally developed to support carbon-related policy planning and spatial data visualization. While technically robust, its current structure is designed for institutional use and lacks mechanisms for direct public interaction, behavior logging, or personalized feedback. As a result, its potential to support civic climate engagement remains underutilized.

To address this challenge, we propose the Carbon Challenge Platform—a service architecture that builds on CSIS's spatial infrastructure but introduces citizen-facing functionalities such as activity logging, real-time emission calculation, geovisualization, gamification, and policy feedback mechanisms. By integrating spatial intelligence with behavioral engagement, we aim to bridge the gap between static national carbon datasets and dynamic, localized citizen action.

Unlike existing carbon tracking services focused on behavioral change through mobile apps or gamification, the proposed platform integrates geospatial carbon datasets with real-time sensor inputs and a policy feedback loop. This integration supports localized, data-driven, participatory climate action, addressing both individual engagement and spatial policy relevance. The research flow is illustrated in Fig. 1.

2. Background and Related Work

2.1 Global trends in citizen-participatory carbon platforms

Globally, digital platforms enabling individuals to track and reduce their carbon footprints have proliferated. Tools such as the JouleBug (USA),[6] Too Good To Go (Denmark),[7] and the CoolClimate Maps (USA)[8] illustrate how environmental data is being transformed into public-

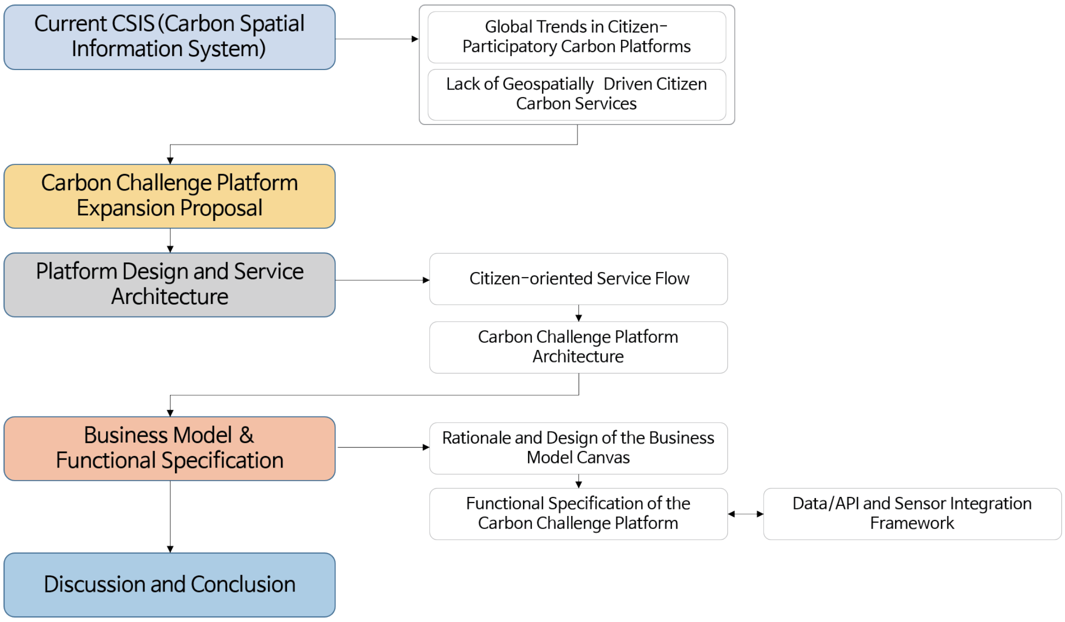

Fig. 1. (Color online) Research flow diagram.

friendly interfaces that drive awareness and voluntary climate action. These platforms often adopt strategies such as gamification, real-time feedback, and behavioral recommendations to promote user engagement.(9) However, these platforms generally lack robust geospatial capabilities. Although they offer individual-level carbon calculators or mobile apps, few incorporate location-based intelligence that contextualizes carbon activities within the urban fabric or natural environment.

2.2 Lack of geospatially driven citizen carbon services

While some smart city projects have explored environmental monitoring through IoT and sensor-based mapping, these initiatives often remain policy-centric or technical demonstrations.(10,11) They rarely offer citizen-facing tools that enable active participation in urban carbon management using spatial data. Moreover, prior academic literature has predominantly focused on carbon visualization, footprint estimation, or emission inventories,(12,13) with few studies proposing full-stack service designs for public engagement rooted in geospatial intelligence.

2.3 CSIS in Korea

In South Korea, the government has developed CSIS to support national climate policies (Fig. 2). The system integrates carbon-related spatial datasets—such as emissions, absorption, and land-use patterns—to provide spatial decision support for planners and policymakers.(14) However, this system remains government-centered, with no open interfaces or service models for direct public participation. Its design prioritizes top-down policy monitoring rather than interactive features for citizens.

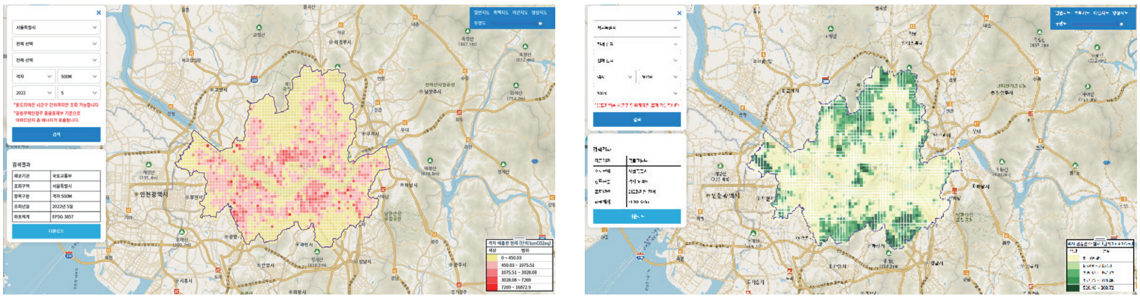

Fig. 2. (Color online) CSIS (Map Service).

3. Carbon Challenge Platform Design and Service Architecture

3.1 Motivation for platform expansion

CSIS in South Korea serves as a national geospatial infrastructure that integrates carbon-related data to support climate policy planning. However, the current system is government-centered and offers limited functionalities for public interaction or behavioral engagement.

This structure restricts its potential in the context of modern climate policy, which increasingly emphasizes bottom-up approaches and citizen participation.(15,16) While CSIS provides detailed spatial datasets, it lacks mechanisms to support individual- or community-level carbon reduction actions.

To address this gap, we propose the Carbon Challenge Platform, a citizen-participatory extension of CSIS. The platform enables users to set personal goals, record behavioral data, and receive spatially contextualized feedback, thereby transforming static carbon datasets into interactive and participatory services.

This expansion is justified by three core rationales, as follows:

- **Platform Compatibility**: The proposed platform can reuse existing CSIS datasets, classification logic, and geospatial infrastructure without requiring a complete system overhaul.
- **System Readiness**: National spatial data layers—such as land-type-based carbon emissions and regional energy usage statistics—provide a mature technical foundation for implementing real-time citizen-participatory services, particularly when supported by standardized data APIs.
- **Policy Relevance**: As policy emphasis shifts toward demand-side carbon mitigation, the platform bridges the gap between top-down carbon targets and bottom-up civic engagement, contributing to more responsive and effective climate governance.

Figure 3 illustrates the conceptual system architecture for transition from CSIS to the Carbon Challenge Platform. This transition shifts from government-led spatial data use (e.g., emissions, sequestration) to a citizen-participatory system incorporating behavioral input, sensor integration, and feedback mechanisms. It supports a closed-loop structure for real-time action tracking, analysis, and reward.

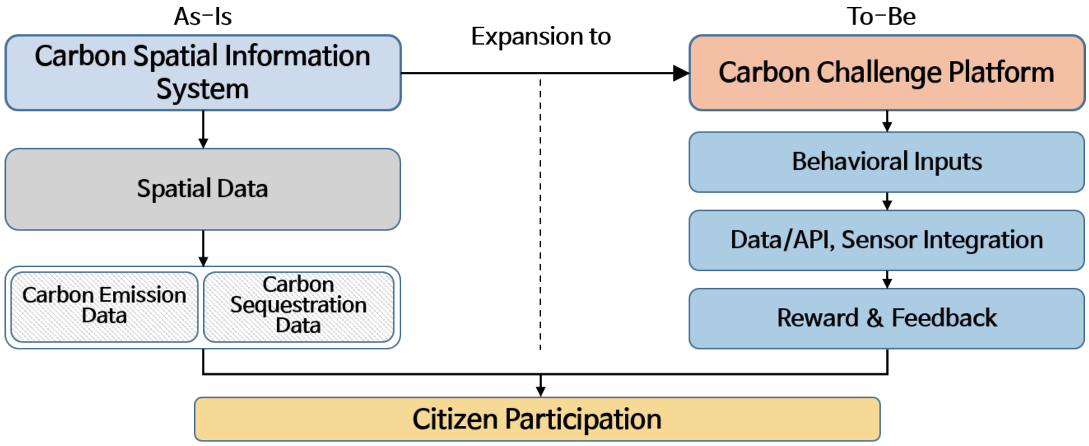

Fig. 3. (Color online) Conceptual system architecture for transision from CSIS to the Carbon Challenge Platform.

3.2 Citizen-participatory service flow

The Carbon Challenge Platform is designed to promote behavioral change through a closed-loop service flow that continuously engages users in carbon-conscious actions. This cyclical structure aims to convert passive awareness into proactive participation by integrating user behaviors, spatial analysis, and policy feedback mechanisms.

The service flow consists of five key stages, as follows:

Stage 1 – Action Registration

Users manually input or automatically synchronize their daily activities, such as transportation choices, household energy consumption, and dietary habits. The platform supports both direct data entry (e.g., via mobile app) and API-based integration with external services such as smart meters and fitness applications.

Stage 2 – Carbon Calculation

Each recorded activity is quantified into a carbon emission estimate using standardized emission coefficients. These values are further refined through spatial contextualization, taking into account factors such as urban density, building types, transportation infrastructure, and local energy sources.

Stage 3 – Visualization

The calculated emissions are displayed through an interactive carbon map interface. Users can view their emissions in relation to local and national averages, monitor progress toward individuals' or communities goals, and explore spatial variations in carbon intensity.

Stage 4 – Challenge Mechanism

The platform encourages user participation through individual- and community-based challenges. Gamification elements—including points, badges, levels, and leaderboards—are implemented to incentivize sustained engagement. Periodic campaigns (e.g., energy-saving week) are also integrated to align with national climate initiatives.

Stage 5 – Policy Feedback

Anonymized behavioral data are aggregated and analyzed to identify local trends, behavioral barriers, and opportunities for carbon reduction. These insights are delivered to local governments via real-time dashboards and analytical reports, providing evidence-based support for climate-responsive policymaking.

As illustrated in Fig. 4, the Carbon Challenge Platform operates through a five-stage closed-loop service flow, beginning with user behavior input and ending with feedback into local policymaking.

3.3 Platform architecture

To support the dynamic and interactive functionalities of the Carbon Challenge Platform, a modular and layered system architecture is proposed. This architecture ensures seamless data flow, scalable service delivery, and interoperability with both national spatial infrastructures and external services such as sensor networks and open APIs.

The architecture is composed of five functional layers (Fig. 5), each responsible for a distinct role while collectively enabling real-time interactions, carbon behavior analytics, and policy feedback mechanisms.

Layer 1 - User Interaction Layer

This layer provides intuitive user interfaces—accessible via mobile apps or web portals—that allow users to log behavior data, interact with carbon maps, participate in challenges, and receive personalized feedback. It also supports real-time data synchronization with external applications (e.g., smart meters, mobility apps) through API integration.

Layer 2 - Application Logic Layer

This layer hosts the platform's core computational logic, including the carbon footprint calculator, challenge and reward systems, behavior scoring algorithms, and user session management. It generates context-aware recommendations based on user profiles and activity patterns.

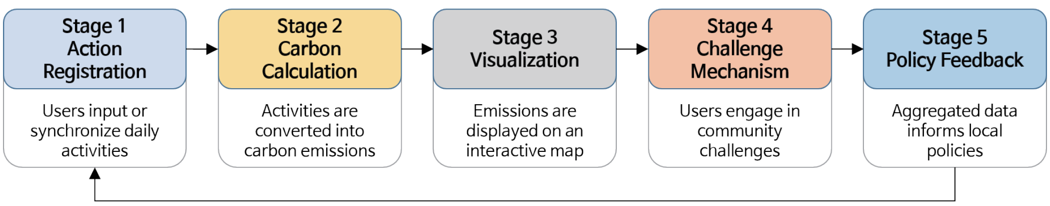

Fig. 4. (Color online) Citizen-participatory service flow.

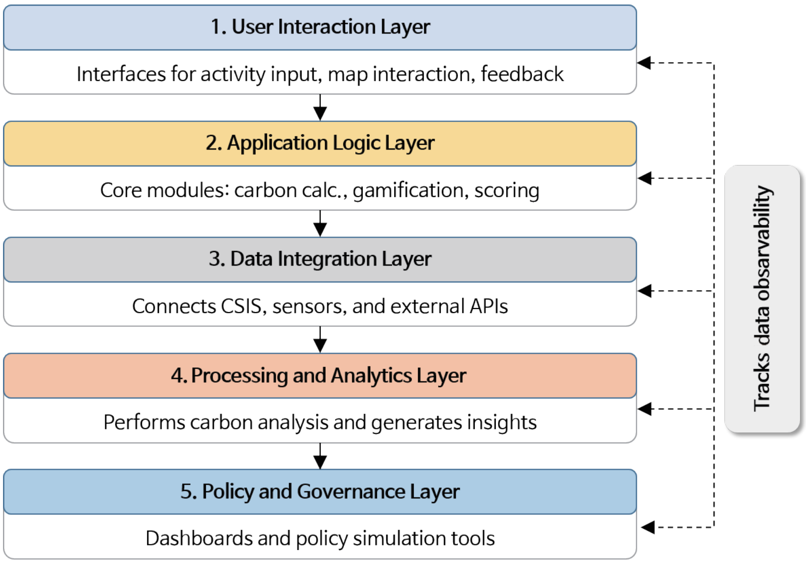

Fig. 5. (Color online) Platform architecture layers.

Layer 3 – Data Integration Layer

Responsible for connecting diverse data sources, this layer accesses spatial and carbon-related datasets from the national CSIS, including emissions, land use, and energy statistics. It also assimilates external behavioral and sensor data through standardized APIs, while supporting spatial rendering using publicly available national base maps.

Layer 4 – Processing and Analytics Layer

This layer executes spatiotemporal analyses by adjusting carbon emission factors according to contextual variables such as location characteristics, infrastructure, and behavioral trends. It generates aggregated indicators and regional benchmarks, providing meaningful feedback to both users and public authorities.

Layer 5 - Policy and Governance Layer

Designed to serve public-sector stakeholders, this layer offers dashboards and analytical tools for monitoring aggregated behavioral data, simulating climate policy effects, and incorporating citizen feedback into planning processes. It facilitates two-way communication between platform users and policymakers.

Together, these five layers form a flexible and interoperable architecture that not only delivers personalized carbon services to individuals but also facilitates evidence-based climate governance at the municipal level.

4. Business Model and Functional Specification

4.1 Rationale and design of the Business Model Canvas

The transformation of South Korea's CSIS into the Carbon Challenge Platform represents not just a technical extension, but a strategic shift toward a participatory service ecosystem. This transition necessitates a clear and scalable business model that defines how value is created, delivered, and sustained among key stakeholders—citizens, local governments, and policy makers.

While CSIS has primarily served as a government-focused tool for monitoring carbon-related spatial data, there is growing demand for platforms that support personalized, place-based climate action.[17] In response, the Carbon Challenge Platform is proposed as a geospatially grounded public service model that facilitates citizen engagement, behavioral change, and decentralized climate governance.

This model is structured using the Business Model Canvas (BMC), a widely adopted strategic framework that visualizes how value flows across nine components: customer segments, value propositions, channels, customer relationships, revenue streams, key resources, key activities, key partnerships, and cost structure.[18,19]

The platform delivers value by providing personalized carbon feedback to individuals, offering geospatial visualization of carbon behavior tailored to local conditions, and generating performance-based data insights that support evidence-informed climate policymaking at the local level.

Services are delivered through various channels, including mobile applications, web portals, and integration with public service platforms. Revenue is expected from national carbon programs, environmental social governance (ESG)-linked partnerships with the private sector, and potential engagement in carbon credit or offset markets.

Key resources supporting the platform include spatial datasets from CSIS, real-time data processing engines, and mapping APIs. Core activities involve behavior tracking, carbon footprint calculation, visualization, and policy-linked analytics. Strategic partnerships encompass the Ministry of Land, Infrastructure, and Transport, municipal governments, IoT sensor networks, and academic institutions. Costs are primarily associated with platform development, data integration, infrastructure maintenance, and user outreach or incentive programs.

Through this comprehensive framework, the Carbon Challenge Platform evolves from a static visualization system into a dynamic public infrastructure that empowers citizens to act and enables governments to make informed decisions based on real-time behavioral data. The BMC summarizing this value creation and delivery process is shown in Fig. 6.

4.2 Functional specification of the Carbon Challenge Platform

To operationalize the Carbon Challenge Platform, ten core functions were systematically defined on the basis of scenario-driven service flows, a layered system architecture, and the platform's role in supporting climate-responsive policy integration. These include key modules

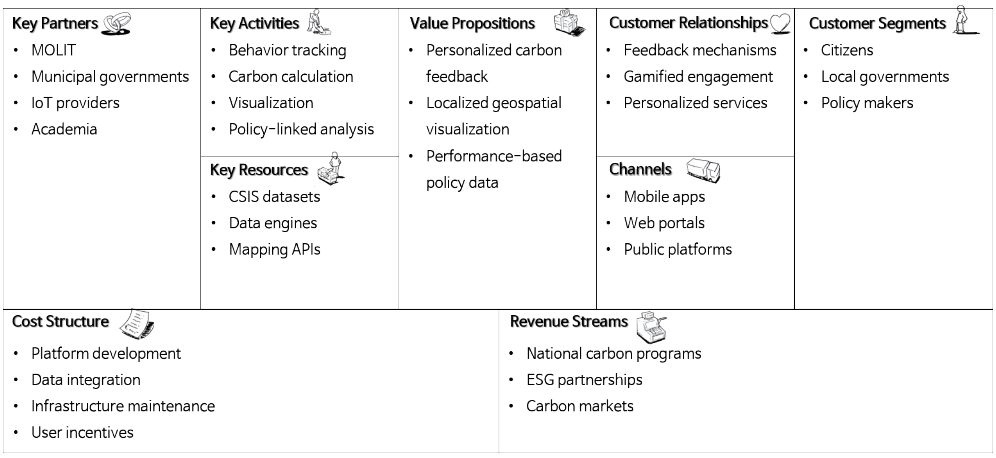

Fig. 6. Carbon Challenge Platform BMC.

such as the Personalized Carbon Dashboard Function, Daily Activity Input Function, and Carbon Footprint Calculation Function.

Each function was designed according to its specific purpose, required technical capabilities, and associated data sources. The architecture follows a modular structure, allowing individual functions to operate independently while ensuring interoperability within the broader system.

The Personalized Carbon Dashboard (F1), Daily Activity Input (F2), and Carbon Footprint Calculation (F3) functions collectively form the core service loop, enabling user engagement and behavioral data collection. Users can manually log or automatically synchronize their transportation patterns, energy usage, and dietary habits through API-integrated IoT services. This input is translated into carbon emission estimates using spatially adjusted coefficients and visualized on personalized dashboards, thereby reinforcing user awareness and low-carbon habits.

The Carbon Map Visualization (F4), Community Challenge Participation (F5), and Carbon Behavior Scoring (F6) functions enhance interaction and motivation. These modules enable the spatial comparison of emissions at the local and community levels, support gamified participation through points and leaderboards, and assess user performance based on behavioral consistency and effectiveness.

The Spatial Reward Distribution (F7), Policy Feedback Reporting (F8), Open Data Access (F9), and Geospatial Rendering (F10) functions expand the platform's utility to municipalities and third-party stakeholders. These modules enable real-time feedback loops for policymakers, transparent access to aggregated behavioral data, and integration with high-resolution national base maps for spatial analytics and simulation. The detailed specifications of all ten functions are summarized in Table 1.

Figure 7 illustrates the closed-loop functional architecture of the Carbon Challenge Platform, highlighting the logical flow and interconnections among its ten core modules.

The overall process begins with the Daily Activity Input Function (F2), where users can manually enter or automatically synchronize behavioral data related to transportation, energy consumption, and dietary habits via external services. The inputs are processed through the

Table 1
Core function specifications of the Carbon Challenge Platform.

Function ID	Function Name	Description
(F1)	Personalized Carbon Dashboard Function	Real-time visualization of personal emissions, target progress, and comparisons
(F2)	Daily Activity Input Function	Manual or automated input of transportation, energy use, and dietary habits
(F3)	Carbon Footprint Calculation Function	Conversion of behavioral data into CO_2 emissions with spatially adjusted coefficients
(F4)	Carbon Map Visualization Function	Geospatial display of emissions, targets, and benchmarks
(F5)	Community Challenge Participation Function	Gamified group activities with points, leaderboards, and challenge tracking
(F6)	Carbon Behavior Scoring Function	Evaluation of behavior by frequency, reduction impact, and consistency
(F7)	Spatial Reward Distribution Function	Allocation of differentiated rewards based on spatial emissions context
(F8)	Policy Feedback Reporting Function	Aggregation of anonymized data into municipal dashboards for policy support
(F9)	Open Data Access Function	Provision of data via APIs or downloads for researchers and external analysts
(F10)	Geospatial Rendering Function	High-resolution spatial visualization using national base maps and location APIs

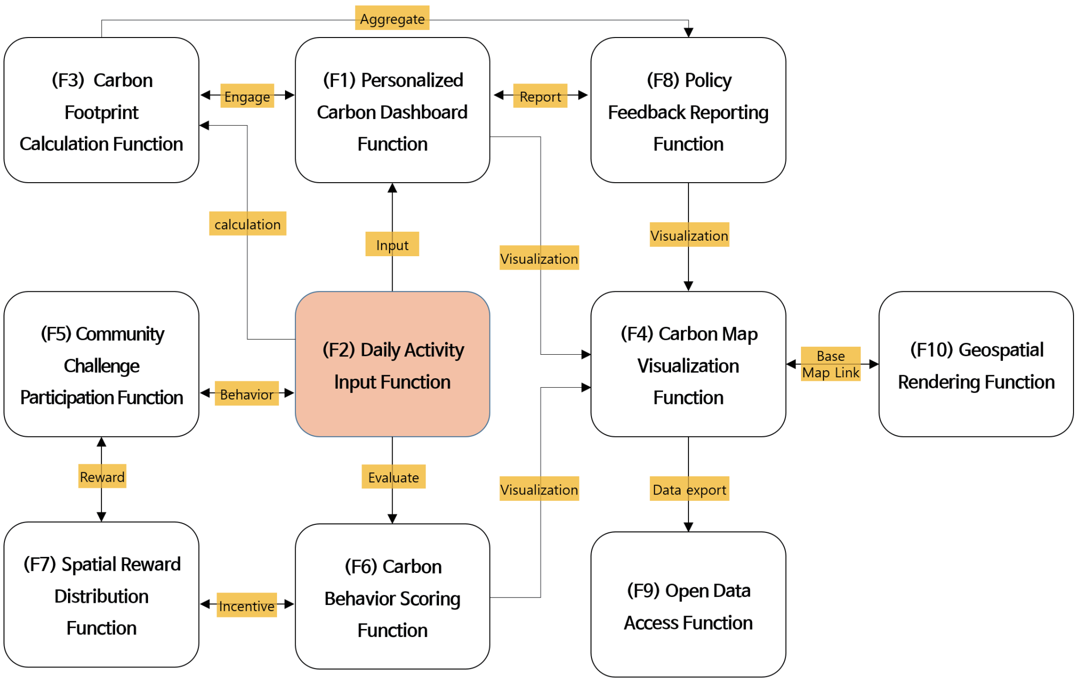

Fig. 7. (Color online) Functional interconnection structure of the Carbon Challenge Platform.

Carbon Footprint Calculation Function (F3), which converts behavioral data into carbon emissions contextualized by spatial factors. The aggregated emissions data is then delivered to the Policy Feedback Reporting Function (F8) to support climate-responsive policy planning and implementation at the municipal level. In parallel, user behaviors are evaluated on the basis of the Carbon Behavior Scoring Function (F6), and the resulting scores are linked to the Spatial Reward Distribution Function (F7) to provide regionally differentiated incentives based on local emission contexts. The outcomes from the Personalized Carbon Dashboard Function (F1), the Carbon Behavior Scoring Function (F6), and the Policy Feedback Reporting Function (F8) are visualized through the Carbon Map Visualization Function (F4), which integrates with the Geospatial Rendering Function (F10) to enable high-resolution mapping using national base maps. Finally, the visualized outputs and aggregated behavioral data are made accessible through the Open Data Access Function (F9) via APIs or downloadable formats, supporting academic research, policy analysis, and broader data-driven applications.

4.3 Data/API and Sensor Integration Framework

Building upon the functional specifications outlined in Sect. 4.2, the implementation of the Carbon Challenge Platform requires a seamless, real-time integration of diverse data sources. To support continuous user engagement, real-time carbon calculations, spatially contextualized visualizations, and data-informed policy feedback, the platform must assimilate, process, and connect behavioral, spatial, and sensor-based data efficiently and securely.

Conventional spatial data infrastructures often rely on static datasets or top-down government models, making them insufficient for dynamic, participatory climate services. To address this gap, we propose a multilayered Data/API and Sensor Integration Framework tailored to the platform's modular architecture.

This framework enables the convergence of five data domains—geospatial data, behavioral information, IoT sensor input, policy datasets, and system-level interfaces—thereby facilitating a full feedback loop from individuals' behavior to government responses. The proposed structure ensures high spatial granularity, scalability, and interoperability with national geospatial infrastructures such as CSIS, while also supporting third-party APIs and real-time sensor networks. To support system-level implementation, a comprehensive integration strategy was developed and categorized into five functional domains.

Table 2 provides a structured overview of the Data/API and Sensor Integration Framework that underpins the Carbon Challenge Platform. To support real-time behavioral tracking, spatial analysis, and policy feedback, the platform integrates multisource data across five categories: geospatial, behavioral, sensor-based, policy-related, and system-level information.

Geospatial datasets—such as carbon emissions, zoning, and land-use attributes—are sourced from the national CSIS and rendered using APIs connected to official base map services. Behavioral data is collected through mobility platforms and mobile health applications, whereas sensor inputs (e.g., energy meters and CO_2 and environmental sensors) provide contextual enrichment for individual activities.

To manage variations in sensor data quality and sampling intervals, the platform incorporates preprocessing techniques such as normalization, noise filtering, and temporal alignment. These methods ensure consistency and reliability before the data are integrated into the carbon estimation modules.

Table 2
Data/API and sensor integration structure for the Carbon Challenge Platform.

Category	Data/API type	Provider or source	Integration method	Use case & linked functions
Geospatial	Carbon emission / absorption spatial layers	CSIS	Internal DB linkage	Carbon Dashboard, Spatial Visualization (F1, F4)
	Zoning and land-use attributes	CSIS	API / DB synchronization	Challenge Context Adjustment, Incentive Logic (F5, F7)
	National spatial base map APIs	National Mapping Agency (e.g., NGII)	REST API	Map Rendering and Geolocation (F4, F10)
Behavioral	Transportation usage data	Mobility Platforms (e.g., Tmap, Government Portals)	Open API	Mobility Logging, Challenge Participation (F2, F5)
	Mobile activity data	Google Fit, Samsung Health	OAuth / Open API	Step Count, Active Mobility Scoring (F2, F6)
Sensor	Household energy meter data	Utility Providers (e.g., KEPCO), Smart Grid Networks	API / Data Sharing Agreement	Energy Behavior Input (F2, F5)
	CO_2 / temperature / light sensor data	Public IoT, Educational Sensors	IoT → API Gateway	Environmental Calibration, Gamification & Incentive System (F4, F5, F7)
	Indoor location sensors (BLE, etc.)	Public & Private Facilities	MQTT / LoRaWAN API	Indoor Activity Detection & Contextual Mobility Logging (F2, F5)
	Potential IoT extensions (smart appliances, wearables, mobility devices)	Consumer IoT Providers	API / IoT Gateway	Behavioral Enrichment, Advanced Emission Modeling (F2, F4, F6)
Policy	Local climate policy datasets	Local Governments, Statistics Korea	Public Open API	Policy Feedback, Regional Governance (F7, F8)
System	Identity & access control	CSIS, Gov SSO	Authentication API	Access Management, Privacy Protection (F9)

Policy datasets from local governments and national statistical agencies are accessed through open APIs to inform regional incentive structures and climate policy reporting. Finally, system-level interoperability is achieved through authentication APIs that enable secure identity and access control.

The integration of these diverse data streams ensures that the platform's modular components—particularly the core functions outlined in Sect. 4.2—can function reliably within a citizen-participatory framework that operates as a closed-loop feedback system to support localized climate action.

In addition to the sensor types listed in Table 2, the platform can be extended to incorporate IoT-based data sources such as smart appliances, wearable environmental monitors, and personal mobility tracking devices. These extensions would enrich user-level behavioral datasets and enhance the granularity and accuracy of spatial emission modeling.

5. Conclusions

5.1 Summary of contributions and implications

In this study, we presented a comprehensive design framework for expanding South Korea's CSIS into a citizen-oriented geospatial platform, termed the Carbon Challenge Platform. By integrating system architecture, the BMC, and functional specifications, we demonstrated the feasibility of transforming a traditionally top-down spatial data system into a participatory, bottom-up civic engagement infrastructure.

The key contributions of this research are as follows:

- **Conceptual Transition of CSIS**: We redefined CSIS not merely as a spatial data repository but as a platform that enables behavioral engagement. This positions CSIS as a foundation for evolving national geospatial systems into civic climate infrastructure.
- **Service and Technical Modeling**: The proposed platform features a citizen-centric service flow, a layered modular system architecture, and ten core functions—each systematically linked to spatial datasets, APIs, and sensor data. In particular, integrating smart meters, mobility trackers, and environmental IoT devices strengthens precise, real-time footprint estimation and reliable feedback.
- **Policy Integration and Utility**: Beyond personalized user services, the platform allows for aggregated behavioral data to inform and support municipal-level climate policy formulation and evaluation.

Furthermore, we emphasized the critical role of spatial intelligence in climate engagement. While many global carbon platforms lack meaningful geospatial integration, the Carbon Challenge Platform shows that localized spatial context enhances personalization, transparency, and behavioral accountability.

The design logic and system model proposed here are scalable and transferrable to other national settings, particularly where spatial infrastructures are underutilized in climate services. As such, the platform offers a replicable blueprint for the development of participatory, geospatially grounded climate platforms.

5.2 Limitations and future work

While this study presents a robust conceptual design, it remains at the planning and systems architecture stage, without empirical validation through pilot implementation or user testing. Several key areas for future development are identified:

- **Pilot Testing and Real-world Validation**: A demonstration involving real users and municipalities is required to assess the platform's usability, functional performance, and institutional integration in actual contexts.
- **Refinement of Carbon Calculation Models**: The current engine must be enhanced by incorporating more granular spatial attributes (e.g., microclimate zones, urban morphology) and diverse behavioral emission datasets, improving both precision and relevance.
- **Global Interoperability**: Follow-up research should align the platform with internationally recognized standards such as ISO 14068, Smart City Indicators, and Open Geospatial

Consortium frameworks. Such alignment would facilitate adaptation in diverse national contexts, ensure cross-border interoperability, and strengthen integration with international policy frameworks.

In sum, realizing the full potential of the Carbon Challenge Platform will require continued interdisciplinary collaboration, real-world testing, and policy-aligned system development to bridge the gap between top-down geospatial infrastructures and bottom-up climate action initiatives.

This study presents a foundational framework for transforming static geospatial carbon infrastructures into interactive, citizen-facing climate services. By explicitly incorporating diverse sensor inputs into its geospatial architecture, the platform advances beyond conventional calculators and provides more precise, actionable insights. In combining spatial intelligence with behavioral engagement, the Carbon Challenge Platform emerges as a scalable and adaptable model for climate-responsive digital governance.

Acknowledgments

This work was supported by the Korea Agency for Infrastructure Technology Advancement of Korea (KAIA) grant funded by the Ministry of Land, Infrastructure, and Transport of Korea (RS-2023-00242291).

References

1 K. Atzmanstorfer, M. Bartling, B. Haltofová, L. Zurita-Arthos, J. Grubinger-Preiner, and A. Eitzinger: ISPRS Int. J. Geo-Inf. **14** (2025) 153. https://doi.org/10.3390/ijgi14040153
2 T. Papadopoulos, K. Evangelidis, T. H. Kaskalis, and G. Evangelidis: ISPRS Int. J. Geo-Inf. **14** (2025) 126. https://doi.org/10.3390/ijgi14030126
3 E. Bąkowska-Waldmann: ISPRS Int. J. Geo-Inf. **12** (2023) 102. https://doi.org/10.3390/ijgi12030102
4 E. Bąkowska-Waldmann and T. Kaczmarek: ISPRS Int. J. Geo-Inf. **10** (2021) 581. https://doi.org/10.3390/ijgi10090581
5 W. Gao, N. Chen, J. Chen, B. Gao, Y. Xu, X. Weng, and X. Jiang: ISPRS Int. J. Geo-Inf. **13** (2024) 83. https://doi.org/10.3390/ijgi13030083
6 JouleBug: https://www.joulebug.com (accessed May 2025).
7 T. Good To Go: https://www.toogoodtogo.com (accessed May 2025).
8 CoolC. Maps: https://coolclimate.org/maps (accessed May 2025).
9 K. M. Kim, S. P. Hong, S. J. Lee, and S. S. Lee: J. K. Soc. Geospat. Inf. Sci. **33** (2025) 71. https://doi.org/10.7319/kogsis.2025.33.2.071
10 C. Wei, C. Jing, S. Wang, and D. Li: Sens. Mater. **33** (2021) 4579. https://doi.org/10.18494/SAM.2021.3461
11 J. Xu and X. Zhu: Proc. 2010 Int. Conf. Management and S. Science (ICMSS, 2010) 1–4.
12 T. Yixuan, S. Wang, S. Huang, M. Zhou, W. Zhang, Z. Li, and Q. Gao: Proc. 2023 5th Int. Conf. Circuits and Systems (ICCS, 2023) 253–257.
13 Y. Leung, K. S. Leung, M. H. Wong, T. Mak, K. Y. Cheung, L. Y. Lo, W. Y. Yi, and Y. L. Dong: Int. J. Geogr. Inf. Sci. **32** (2018) 1787. https://doi.org/10.1080/13658816.2018.1460752
14 M. S. Kim and S. H. Jung: Environ. Policy **32** (2024) 43. https://doi.org/10.15301/jepa.2024.32.2.43
15 N. M. Lima, M. Nygård, and M. P. Heris: Proc. 2023 Int. Conf. F. Energy Solutions (FES, 2023) 1–6.
16 H. J. Park, Y. H. Lee, and T. Lee: Futures **152** (2023) 103274. https://doi.org/10.1016/j.futures.2023.103274
17 H. S. Hwang, J. J. Joo, and J. H. Koh: Spat. Inf. Res. **20** (2012) 71. http://uci.or.kr/G704-000574.2012.20.1.003
18 T. J. Foxon, C. S. E. Bale, J. Busch, R. Bush, S. Hall, and K. Roelich: Infrastruct. Complex. **2** (2015) 4. https://doi.org/10.1186/s40551-015-0009-4
19 K. Sorri, M. Seppänen, K. Still, and K. Valkokari: J. Bus. Models **7** (2019) 1. https://cris.vtt.fi/en/publications/business-model-innovation-with-platform-canvas

About the Authors

Kyo-Min Kim received his B.S. and M.S. degrees from Anyang University, Korea, in 2007 and 2010, respectively, and his Ph.D. degree from the University of Seoul, Korea, in 2024. From 2011 to 2012, he was a researcher at the Korea Research Institute for Human Settlements (KRIHS). Since 2012, he has been working as a researcher at the Spatial Information Industry Promotion Agency (SPACEN), Korea. His research primarily focuses on spatial information and urban policy, emphasizing research and development activities within these domains. (km.kim@spacen.or.kr)

Seung-Su Lee received his B.S. and M.S. degrees from Anyang University, Korea, in 2002 and 2004, respectively, and completed his Ph.D. coursework at Anyang University in 2013. From 2005 to 2009, he was a researcher at the Korea Research Institute for Human Settlements (KRIHS). He worked at Segain Information Technology from 2009 to 2012. Since 2012, he has been working as a Team Head at the Spatial Information Industry Promotion Agency (SPACEN), Korea. His research interests include research and development related to spatial information.
(ss.lee@spacen.or.kr)

Song-Pyo Hong received his B.S. and M.S. degrees from Namseoul University, Korea, in 2017 and 2019, respectively, and completed his Ph.D. coursework at Seoul National University of Science and Technology, Korea, in 2022. From 2022 to 2025, he has been working as a researcher at the Spatial Information Industry Promotion Agency (SPACEN), Korea. His research interests are in photogrammetry and GIS. (sp.hong@spacen.or.kr)

Seung-jun Lee received his B.S. degree from Namseoul University, Korea, in 2020, and is expected to receive his M.S. degree from the University of Seoul, Korea, in 2025. He worked at Saehan Aerial Survey from 2019 to 2020 and at All For Land from 2020 to 2024. Since 2024, he has been working as a researcher at the Spatial Information Industry Promotion Agency (SPACEN), Korea. His research interests include research and development related to spatial information. (sj1.lee@spacen.or.kr)