KEI
Research Report
2025-05

Comparative Study on Urban Planning Elements and Policy Acceptability to Reduce Residents' Carbon Footprint

Targeting Korea and Germany

주민 탄소발자국 감축 도시계획요소 및 정책 수용성 비교 연구: 한국과 독일을 대상으로

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Publisher	Hongkyun Kim
Published by	Korea Environment Institute 370 Sicheong-daero Sejong-si, 30147, Republic of Korea Tel: +82-44-415-7777, Fax: +82-44-415-7799 www.kei.re.kr
Publication Date	April 2025
ISBN	979-11-5980-995-8

Foreword

Achieving carbon neutrality for sustainable development is a global challenge, and the policy efforts of individual nations to address this issue are becoming increasingly important. In particular, carbon emissions from urban areas have been identified as a major contributor to climate change, making urban planning and policy essential components of climate response strategies. This study aims to provide fundamental data for effective policy formulation by comparing and analyzing urban planning elements and policy acceptability for reducing residents' carbon footprints in South Korea and Germany.

Although South Korea and Germany differ in their levels of economic and social development, they share a common goal of sustainable urban development and carbon neutrality. This study compares the urban planning elements of both countries and analyzes differences in policy acceptability to derive policy implications for each. The findings from this multinational collaborative research will serve as a valuable resource for policymakers in designing and implementing carbon neutrality policies in their respective countries.

We extend our deepest gratitude to the researchers and advisory committee members who have provided unwavering support and valuable guidance throughout the completion of this study. We also sincerely appreciate the cooperation of the institutions and individuals who contributed to the research process. It is our hope that this study will serve as a foundational resource for sustainable urban development and the realization of carbon neutrality goals, fostering further in-depth research and policy discussions in the future.

Hongkyun Kim,
President,
Korea Environment Institute

Executive Summary

Comparative Study on Urban Planning Elements and Policy Acceptability to Reduce Residents' Carbon Footprint
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Kim, Taehyun et al.

1. Introduction: Research Background and Purpose

To achieve the goal of limiting rising global average temperatures to just 1.5°C higher than pre-industrial levels, governments worldwide have placed growing emphasis on the need to transform urban systems in the pursuit of decarbonization. However, decarbonization efforts face numerous scientific, economic, political, and even social challenges. For example, European farmers have protested the European Union (EU)'s greenhouse gas (GHG) emissions reduction policies and rising electricity prices associated with the transition to cleaner forms of energy. As such, it is essential to approach decarbonization policies through the lens of a just transition—one that considers public acceptance and aims to ensure fairness and equity throughout the process.

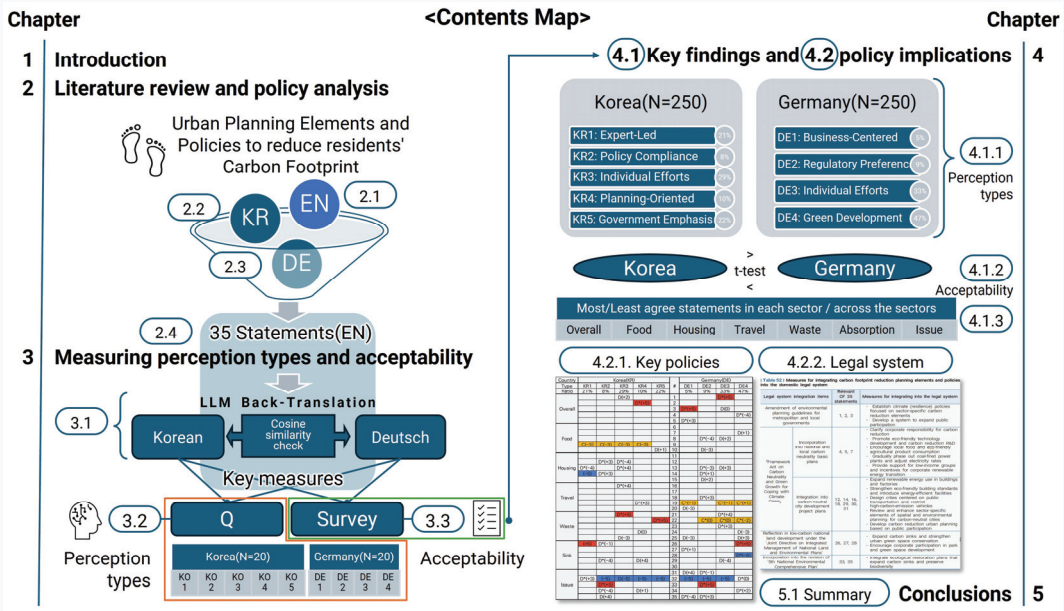
In particular, while national plans typically focus on reducing emissions associated with the energy, power generation, and industrial sectors, is also crucial to address more localized emissions. These include emissions from commercial activity, as well as from the household, transportation, and waste sectors, which typically fall under the jurisdiction of local governments. Although direct industrial emissions dwarf direct emissions from the household sector, it is demand from the latter for food housing, travel, goods, and services that indirectly drives emissions in the former, as well as nearly all other sectors, including the energy, commerce, and waste sectors. Understanding emissions in this way is the essence of the carbon footprint (CF) framework.

Reducing carbon footprints in consumption sectors such as food, housing, transportation, and waste requires taking a two-pronged approach. The first task is to address spatial and structural issues that influence behavior. The second task is to address the behaviors themselves. Governments around the world are promoting carbon neutrality policies and pursuing decarbonization efforts, including South Korea and Germany. However, these two large, manufacturing-based economies differ markedly in terms of how far they have come with regards to the energy transition and the level of public awareness. This study is a product of efforts to better understand these differences, and the implications carried by its conclusions carry meaningful implications for urban planning policy designed to advance global decarbonization efforts.

This study aims to compare the acceptance of urban planning policies aimed at reducing the carbon footprint of the average household among Koreans and Germans. Based on this comparison, it identifies policy implications that can support the global pursuit of carbon neutrality. Figure ES1 below visualizes the structure of the report.

First, we review existing literature on carbon footprint (CF) reduction policies in Germany and Korea, including policies currently in effect. Second, we identify key planning elements for CF reduction in major consumption sectors, such as food, housing, and transportation. Third, we investigate and analyze public awareness of CF reduction policies and their acceptability. Finally, we present strategies for policy application based on a comparative analysis of survey results on levels of public awareness and policy acceptability in both countries.

Figure ES 1 **Contents map**



Source The authors.

2. Urban Planning Elements and Policies for CF Reduction

2.1 Theoretical background

The food, energy, and other resources consumed by city dwellers are almost always brought in from outside the city, which is why residents of urban areas often have relatively large carbon footprints (CFs). Since the oil crisis of the 1970s, urban planners have debated how to best reduce energy consumption and increase efficiency. Various theories have been proposed: center urban development around public transit, promote mixed-use neighborhoods, and encourage high-density

development, among others. However, some studies have shown that some mixed-use and high-density development can actually increase residents' CFs by affecting food consumption patterns.

Recently, scholars have begun to look at the relationship between various urban characteristics and carbon footprints, such as the difference in the CFs of single-person and multi-person households in the residential sector, the difference in CFs by season depending on the type of apartment, and the effect suburban sprawl on carbon footprints. As an actual example, the state of California in the United States maps the average CF of each household through a CF-based urban planning model. This data is used to establish spatial planning strategies for reducing greenhouse gas (GHG) emissions.

2.2 South Korea

In Korea, urban planning and CF reduction policies emphasize improving energy efficiency—through measures such as zero-energy building certification and the adoption of smart city technologies—expanding green infrastructure, and establishing sustainable transportation systems. These efforts support broader initiatives to cut GHG emissions and pursue carbon neutrality.

To guide these initiatives, key urban planning elements have been identified based on research that outlines principles and strategies for the integrated management of spatial and environmental plans at the municipal level, as well as specific planning techniques aligned with carbon neutrality objectives. One related study took a CF reduction inventory linked to regional carbon neutrality implementation strategies.

In examining policies for reducing CFs, we reviewed the GHG reduction strategy proposed by the Ministry of Environment, which accounts for differences in city types and characteristics. We also analyzed local government-level CF reduction policies identified in previous studies, categorizing them by sector and region. In addition, we explored why the concept of carbon neutrality has not been fully integrated into national land use plans, drawing on insights from various research reports on GHG reduction and carbon neutrality.

Our review also included implementation strategies from the Saemangeum Smart Waterfront City Carbon Neutral Master Plan, as well as programs related to energy transition, carbon sink expansion, resource circulation, climate change adaptation, and social transition found in carbon-neutral green city initiatives in Suwon and Chungju.

2.3 Germany

To examine the landscape of CF and GHG emissions reduction policies in Germany, we first reviewed the legal and policy foundations of CF reduction initiatives, CF-related urban planning measures, energy transition procedures, sector-specific reduction measures, and the level of public participation in urban planning processes.

Germany has set its climate protection goals in close alignment with the European framework, and has taken numerous measures to achieve these goals, including passing legislation, developing strategies, and establishing funding programs. The government is also closely monitoring developments for undesirable trends.

The multi-tiered German planning system and the existing strategies of the federal government all support efforts to achieve climate neutrality. Numerous basic principles and specific goals of spatial planning support the reduction of GHG emissions. Citizens can also influence planning processes at the municipal and neighborhood levels through participation processes. The data show that Germany has started to make real progress toward its climate goals, but that carbon neutrality remains a major challenge.

2.4 Key measures to reduce CF

To develop a list of key strategies for reducing CFs, we drew on the theoretical background, identified the major elements of CF reduction plans in Korea and Germany, surveyed relevant policies and case studies, and referred to international sources of relevant data, such as the United Nations' (UN) 170 Actions for Climate Change Response and the Reduction Elements for a Green, Low-Carbon Built Environment.

To address limitations of the literature review, which relied on the research team's existing knowledge, we used a large language model (LLM) to generate 25 draft statements designed to measure two aspects: the levels and types of awareness of CF-reduction urban planning, and the acceptability of CF-reduction related urban planning policies.

After collecting opinions from 20 experts on the validity of each item in the draft statements and the appropriateness of the Korean, English, and German expressions, we revised and supplemented them, ultimately arriving at a final set of 35 statements.

The statements were divided evenly into seven sector-based groups: overall CF reduction, food, housing, transportation, waste, sinks, and miscellaneous issues. The individual draft statements are related to one of three broad categories: planning and design; policies, programs, and business; and actions and initiatives. See Figure ES 2.

Figure ES 2 **Comparison of response ratios by perception type and key statements**

Country		Korea(KR)					Germany(DE)			
Type	Statements	KR1	KR2	KR3	KR4	KR5	DE1	DE2	DE3	DE4
Ratio		21%	8%	29%	10%	22%	5%	9%	33%	47%
Overall	1. Individuals should make an effort to reduce their consumption of food, housing, transportation, and goods and services.			D(+2)					D*(+5)	
	2. Urban planning and design is needed to reduce the carbon footprint of city dwellers.				D*(+5)					
	3. The government and local authorities should roll out policies, programs, and initiatives to reduce their carbon footprint.						D*(+5)		D(0)	
	4. Companies need to take steps to reduce their carbon footprint in their manufacturing processes.									D*(−4)
	5. I support increased investment and support for research and development of technologies that reduce our carbon footprint.						D*(+3)			
Food	6. I support expanding and revitalizing local farmers markets.									
	7. The government and local authorities should promote the certification and consumption of low-carbon, eco-friendly, and organic agricultural products.									D(+1)
	8. Individuals should make an effort to reduce their consumption of meat and imported/packaged/processed foods.							D*(−4)	D(+2)	
	9. Companies should ramp up efforts to expand plant-based options in restaurants and stores, along with developing meat alternatives.	C(−3)	C(−3)	C(−3)	C(−3)					
	10. I support plans that reduce transportation distances by producing and consuming food within cities, like urban farming.					D(+1)		D(−3)		
Housing	11. I support green remodeling efforts that improve the energy efficiency of existing buildings.									
	12. I support installing renewable energy sources like solar panels and solar thermal systems on buildings and homes.		D*(+3)	D*(−4)						
	13. Individuals should make an effort to conserve electricity, gas, and water at home.	D*(−4)		D*(+4)				D*(−3)	D(+3)	
	14. Require buildings or factories to install green roofs or solar panels.	(−5)	D*(+3)					D*(+1)		
	15. Require new buildings to be designed to be zero energy, meaning they don't rely on outside energy sources.							D(+2)		
Travel	16. Individuals should make an effort to use public transportation, such as buses, trains, or bikes, instead of driving their own cars.			D*(+4)						
	17. I support expanding bike lanes and pedestrian walkways.									
	18. I support limiting the use of high carbon-emission vehicles.							D*(+3)		
	19. I support plans and designs that increase the proportion of residential areas and population density within cities to reduce urban sprawl through mixed-use development.				D*(+3)		C*(−1)		C*(−1)	C*(+1)
	20. I support expanding the infrastructure for electric vehicle charging and dedicated parking spaces.						D(−3)			
Waste	21. We all need to do our part to reduce food and general waste and increase recycling and reuse.			D*(+5)					D*(+4)	
	22. The government and local authorities should implement policies to reduce single-use items in places like stores and hotels.					D*(+5)		C*(0)	C*(0)	C*(−2)
	23. I support policies that discourage single-use products and mandate reusable containers.								D*(+3)	
	24. Companies need to cut back on product packaging and create reusable containers.				D(0)					D(−3)
	25. I support the plan to build a biogas facility with organic waste such as food waste, livestock manure, and sewage sludge.			D(−3)			D(−3)			D(+3)
Sink	26. I support increasing the amount of green space and parks in urban areas.	(+5)	D*(−1)							D*(+5)
	27. Companies should get involved in programs and initiatives that expand carbon sinks, such as creating parks and planting trees.						D*(+1)			
	28. I support expanding the greenbelt designation, which limits development on existing green spaces.									D*(−5)
	29. The government should invest more in research and development to boost the carbon-absorbing capacity of our forests and green spaces.		D*(−4)		D(+4)				D(−4)	
	30. We need an ecological restoration plan that includes green spaces and biotopes that take biodiversity into account.									
Issue	31. Citizen engagement should be fully integrated into city planning, policies, programs, and procedures that aim to reduce carbon footprint.						D(+4)	D*(−1)		
	32. I support putting small modular reactors (SMRs) in cities that need a lot of electricity.	D*(+3)	(−5)	D(−5)	(−5)	(−5)	(−5)	(−5)	(−5)	D*(0)
	33. I support phasing out coal-fired power plants, even if it means paying more for electricity.		D*(+5)					D*(+5)		
	34. The government and local authorities should expand their social media campaigns to reduce their carbon footprint.		D*(−4)		D(+1)					D*(+2)
	35. I support raising electric rates to encourage the energy transition and to reduce our carbon footprint.		D(+4)				D*(−4)	D*(+3)		

Note
1) Red – Most agreed statement (+5), Blue – Least agreed statement (-5), Yellow C (Consensus) – Statement showing no difference from other types, D (Distinguish) – Statement. distinguishing from other types ($P<0.05$; * indicates significance level $P<0.01$), Numbers in parentheses represent factor Q-sort scores.
2) KR1: Expert-Led, KR2: Policy Compliance, KR3: Individual Efforts, KR4: Planning-Oriented, KR5: Government Emphasis.
3) DE1: Business-Centered, DE2: Regulatory Preference, DE3: Individual Efforts, DE4: Green Development.

Source The authors.

3. Measuring Perception Types and Acceptability of Key Measures to Reduce CF

3.1 Multilingual translation using LangChain

To ensure consistent understanding between South Korean and German respondents on statements measuring awareness and acceptability of carbon-footprint (CF) reduction strategies, a multilingual translation application was developed using LangChain, an LLM-based open source framework. For policy-related survey questions, we performed cross-language validation to ensure the consistency of results.

In the LangChain-based application, statements originally written in English were translated into Korean and German using LLMs such as ChatGPT-3.5, ChatGPT-4o, Gemini, Claude 3, and DeepL. These translations were then back-translated into English and evaluated using cosine similarity scores to assess how closely they matched the original text. The version with the highest similarity was selected as the most accurate translation.

To validate back-translated statements, linguists (experts) and native laypeople in both languages were consulted. Their evaluations were used to confirm whether or not the translated sentences accurately expressed the content of the statement.

3.2 Measuring perception types: Q methodology

The Q methodology was used to measure of major CF reduction strategies. Unlike expert-led decision-making techniques, such as the Analytic Hierarchy Process (AHP), the Q methodology is a qualitative-quantitative mixed methodology that is useful for systematically exploring the subjective views and judgment criteria of the general public. The Q Methodology can be used to identify the subjective judgment criteria of respondents that report different levels of acceptance across sectors and CF reduction factors. This makes it possible to pinpoint what kinds of perceptions and opinions to consider in the policy making process.

The 35 finalized statements as seen in Figure ES 2 were used in an 11-point Q classification survey, conducted both in-person and online with 40 total participants from Germany and Korea (20 from each country). The participants included experts in urban planning, the environment, and energy, as well as civil servants, private sector employees, and other members of the general public. The collected data were subjected to factor analysis through principal component analysis and varimax rotation using the PQ Method KADE program.

The Korean side categorized the survey data on policy acceptability into five perception types: expert-led (KR1), policy compliance (KR2), individual efforts (KR3), plan-centered (KR4), and government emphasis (KR5). The German side did the same, ultimately settling on four perception types: business-centered (DE1), regulatory preference (DE2), individual efforts (DE3), and green development (DE4). We then analyzed the commonalities and differences among these perception types and identified some of the basic characteristics of each type.

3.3 Measuring acceptability: Online survey

In order to measure the policy acceptability of CF reduction strategies, we administered an online survey based on a structured questionnaire. A population-proportional quota sampling was conducted to reflect the demographics of Korea and Germany. A total of 500 responses were collected (250 from each country).

The questionnaire included items on: awareness of and agreement with the CF concept; awareness of CF reduction strategies; and agreement with strategic CF reduction proposals in various sectors. In addition, the statements with the most/least agreement were selected in each sector, and the selected statements were prioritized again to identify differences in acceptability between key

means of reducing carbon footprints. We then identified the statements with which respondents indicated the highest and lowest levels of agreement. These statements were reorganized to discern differences in acceptability between major CF reduction strategies. In addition, additional items were added to ask about the degree of implementation of activities to reduce consumption by carbon footprint reduction sector, social necessity, personal will, and realistic effectiveness. Additional questions were included to assess the extent of CF reduction in each sector, as well as perceptions of social necessity, personal willingness, and practical effectiveness. We also included questions on awareness of the energy transition and certain respondent characteristics, such as environmental awareness and social awareness, along with the level of understanding and support for carbon neutrality goals, the importance and performance of energy transition policies, and other questions related to the energy transition.

4. Key Findings and Policy Implications

4.1 Perception types and acceptability in South Korea and Germany

For the main analysis of the study, we explored the similarities and differences in perception types between South Korea and Germany across several dimensions: approaches to CF reduction, the roles of government, companies, and individuals, attitudes toward renewable energy, and willingness to bear economic burdens. While some perception types exhibited similarities—particularly in relation to the roles and levels of intervention by each actor—many notable differences also emerged.

By perception type, Korean responses were fairly balanced across the board, and no one perception type was overrepresented. Individual efforts (KR3, 29.2%), government emphasis (KR5, 22%), and expert-led (KR1, 21.2%) were the top three. In contrast, German perception types were more clustered, with green development (DE4 46.8%) ranking first, followed by individual efforts (DE3, 33.2%).

The statistical differences between CF reduction strategy-related survey items measured on the Likert scale were compared using a t-test between Korean and German respondents. Korean respondents exhibited a higher level of agreement on the CF concept and the need to reduce consumption activities, but Germany had a higher level of awareness of CF reduction strategies.

Comparing average acceptability by sector, we observed notable differences between Korean and German respondents. However, we observed no significant differences in opinions on practical measures such as reducing personal food consumption (#8), promoting zero-energy buildings in the residential sector (#15), reducing personal consumption (#1), and reducing waste (#21). In comparing acceptability rankings by sector, Korean respondents indicated they agreed the least

with the need to reduce their personal carbon footprint (#1) and food consumption (#8). Coincidentally, these were among the items for which German respondents indicated a high level of agreement. The items with the highest levels of agreement varied. For Korean respondents, the most widely accepted items were the role of government in addressing overall CF (#3) and the role of companies in the production process (#24). In contrast, German respondents showed the highest acceptability for voluntary individual actions in the waste (#21) and household (#13) sectors. The item with the lowest level of agreement in both countries was the proposal to increase electricity rates (#35).

In conclusion, we find significant differences in perception types between Germany and Korea. This well illustrates the need for customized approaches to carbon footprint reduction policy and carbon footprint awareness-raising strategies. Our findings suggest that public policy should consider the specific characteristics of each perception type, and attempt to strike a balance between the appropriate roles of companies, the government, and individuals. Meanwhile, Korea and Germany show differences in their approaches to CF reduction, and it was confirmed that the social and cultural backgrounds of each country have a significant impact on policy acceptance.

Table ES 1 **Climate Policy Perceptions and Approaches in Korea and Germany**

Classification	Korea	Germany
Policy acceptability	Preference for government and corporate-led intervention	Emphasis on voluntary individual actions
Government and corporate roles	Government and corporate-centered policy implementation	Citizen and local government-centered policies
Individual roles	Strong resistance to changes in individual consumption and lifestyle	Recognition of individual actions (e.g., food consumption reduction, recycling, energy conservation) as key factors
Environmental protection approach	Corporate responsibility and policy intervention-focused approach	Focus on individual lifestyle changes and energy conservation
Major policy measures	Combination of regulations and incentives (promoting corporate innovation)	Encouraging behavioral change through campaigns, education, and infrastructure improvements
Financial support methods	Tax benefits, subsidies, and technology development support	Active utilization of subsidies and tax incentives
Social acceptability	Strong resistance to policies with high economic burdens, such as electricity price increases	Resistance exists to policies involving economic burdens
Community roles	Relatively low, as policies are government and corporate-centered	Activation of community-led projects
Commonalities	• Resistance to policies with high economic burdens exists • Customized strategies needed to offset economic burdens (subsidies, tax benefits, gradual price increases, energy efficiency policies) • Sustainable CF reduction policies required	

Source The authors.

4.2 Policy recommendations for CF reduction

Based on the Q methodology and the results of the survey analysis, we propose that policymakers in both Korea and Germany should consider the composition of perception types in each country identified in this study when setting overall directions for CF reduction policies. Figure ES 2 shows where Koreans and Germans agreed and disagreed with regards to CF reduction strategies. These findings carry the following implications for policy.

When comparing consensus and distinguishing statements across perception types in each country, we can see differences in policy acceptability, the differences in attitudes toward the appropriate roles of government, companies, and individuals, approaches to environmental protection, major policy tools, financial support methods, social acceptability, and community roles, as shown in Table ES 1. We can also confirm that responses from both countries indicated a resistance to policies that imply a significant economic burden.

Based on our comparison of policy receptivity in Korea and Germany, we categorized CF reduction policy strategies into five groups: 1. Strengthening government-led policies and providing incentives, 2. Accelerating the transition to eco-friendly transportation, 3. Reinforcing circular economy initiatives in the waste sector, 4. Expanding carbon sinks and urban green space, 5. Taking a cautious approach to electricity rate hikes. See Table ES 2 for key priorities and recommendations.

Table ES 2 **Key priorities and recommendations for carbon footprint reduction**

Key priorities	State ments	Recommendations
1. Strengthening government policies and incentives	3, 29, 31	• Establishing and legislating carbon footprint reduction targets • Supporting research and technology for carbon absorption • Expanding citizen and corporate participation
2. Accelerating eco-friendly transportation	16, 18, 20	• Expanding public and low-carbon transportation • Supporting EV and eco-friendly vehicle transition • Providing CF reduction incentives in transportation
3. Enhancing waste management and circular economy	22, 24, 25	• Strengthening regulations on corporate packaging and disposables • Expanding the use of organic waste • Improving recycling and resource circulation systems
4. Expanding carbon sinks and urban green spaces	26, 27, 28	• Expanding urban green spaces and carbon sinks • Encouraging corporate and private green space initiatives • Strengthening green space conservation and ecosystem restoration
5. Cautious approach to electricity price increases	33, 35	• Gradually implementing electricity price increases • Supporting coal phase-out and renewable energy expansion • Expanding subsidies and incentives to ease economic burdens

Source The authors.

In order to enhance the implementation of CF reduction policies, it is necessary to ensure that CF reduction plans and policies stand on sound legal and institutional footing. We propose several measures to incorporate CF reduction planning elements and policies into Korea's legal and institutional framework, as outlined in Table ES 3.

These measures include revising guidelines for establishing environmental plans at the basic local government level, developing implementation plans under the Framework Act on Carbon Neutrality and Green Growth for Coping with Climate Crisis and national land and environmental plans, and revising the draft of the Fifth National Comprehensive Territorial Plan (2020-2040).

Table ES 3 **Measures for integrating carbon footprint reduction planning elements and policies into Korea's legal system**

Legal system integration items		Statements	Measures for integrating into the legal system
Amendment of environmental planning guidelines		1, 2, 3	- Establish climate (resilience) policies focused on sector-specific CF reduction elements - Develop a system to expand public participation
Framework Act on Carbon Neutrality and Green Growth for Coping with the Climate Crisis	Incorporation into national and local carbon neutrality basic plans	4, 5, 7	- Clarify corporate responsibility for CF reduction - Promote eco-friendly technology development and CF reduction R&D - Encourage local food and eco-friendly agricultural product consumption - Gradually phase out coal-fired power plants and adjust electricity rates - Provide support for low-income groups and incentives for corporate renewable energy transition
	Integration into carbon-neutral city development project plans	12, 14, 16, 18, 29, 30, 31	- Expand renewable energy use in buildings and factories - Strengthen eco-friendly building standards and introduce energy-efficient facilities - Design cities centered on public transportation and restrict high-carbon-emission vehicles - Review and enhance sector-specific elements of spatial and environmental planning for carbon-neutral cities - Develop CF reduction urban planning based on public participation
Reflection in low-carbon national land development under the Joint Directive		26, 27, 28	- Expand carbon sinks and strengthen urban green space conservation - Encourage corporate participation in park and green space development
Revision of the Fifth Comprehensive National Territorial Plan		33, 35	- Integrate ecological restoration plans that expand carbon sinks and preserve biodiversity

Source The authors.

5. Conclusion

This study holds both academic and policy significance by presenting a rigorous analytical methodology and highlighting the importance of stakeholder identification based on different types of awareness and acceptability related to urban planning and policy implementation for reducing carbon footprints. Future research should build on these findings through deeper analysis, such as examining the interactions among policy acceptability factors to support the development of more tailored and effective CF reduction policies.

Keywords Carbon Footprint Reduction, Sustainable Urban Planning, Policy Acceptability, Q Methodology, Online Survey

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Chapter 1
Introduction

1.1 Research background and objectives

1.1.1 Global climate challenges and the role of urban planning

(1) Global context and climate challenges

Decarbonization is urgently needed to to keep global average temperature increases under the Paris Agreement target of 1.5°C above pre-industrial levels.

The World Meteorological Organization (WMO), part of the United Nations (UN), predicts that the global average annual temperature increase could be more than 1.5°C above pre-industrial levels by 2027. September 2023 was the hottest September on record for Europe and the world, with one-third of all days exceeding the 1.5°C threshold, and 2024 was even hotter.[1)]

A lack of forward-thinking urban planning at all levels of government has resulted in urban infrastructure (railroads, streets, and airports) buckling under the weight of the climate crisis. Additionally, consistently extreme temperatures above the normal expected range (heat waves) have had major impacts on public health, and have also contributed to more frequent and damaging natural disasters such as wildfires. The majority of homes in major European cities are designed to maximize heat retention and lack ventilation. Air conditioning is still relatively uncommon in the UK (installed in around 5% of homes), and cities packed with skyscrapers often lack green space, exacerbating the

1) BBC NEWS Korea (October 7, 2023), "Climate Change: 1.5℃ Climate Catastrophe Threshold Now Likely to be Breached", accessed on March 24, 2024.

urban heat island effect.[2)]

To decarbonize the economy, urban systems must be completely transformed. The Sixth Synthesis Report of the Intergovernmental Panel on Climate Change (IPCC), released on March 20, 2023, emphasizes climate resilient development that features both mitigation and adaptation measures.[3)]

According to the IPCC report, short-term policy measures should reflect the importance of climate-resilient development pathways, integrating adaptation and mitigation measures in the pursuit of sustainable development. It also assesses adaptation and mitigation options in the short term (until 2040) and proposes ways to expand them.

We are running out of time to secure a sustainable future. Governments, civil society, and the private sector all have a role to play in facilitating a transition to a climate-resilient development path, and must do so urgently, as viable opportunities for climate-resilient development are fewer and fewer every day.

(2) Urban planning and carbon footprint management

Consumption-based carbon footprint management is inevitable at the municipal level. This is because national-level plans promulgated by the central government focus on energy, power generation, and industrial policies based on production that local governments do not have authority over.

Therefore, policies to reduce the carbon footprints of residents in the commercial, household, transportation, and waste sectors based on consumption that local governments have management authority over are important.[4)]

The IPCC's Climate Change: 2022 Mitigation of Climate Change report presents Consumption-Based Carbon Footprint (CBCF) (Wiedmann and Minx, 2008, pp. 1-11) accounting as an important element in the framework for calculating urban greenhouse gas (GHG) emissions.[5)]

The CBCF considers not only the force chain-related GHG emissions of infrastructure, but also the emissions associated with all goods and services in a city (Wiedmann et al., 2021, pp. 735-750).

The share of direct emissions from the household sector may seem relatively small compared to the industrial sector, but it is the consumption of food, housing, transportation, goods, and services in the

2) Yonhap News (July 21, 2022), "London Scrambles to Cope with 40-Degree Heatwave...Exposing Lack of Warming Preparedness", accessed on March 24, 2024.
3) Joint Press Release by the Ministry of Foreign Affairs (March 20, 2023), "IPCC Approves the Synthesis Report of the 6th Comprehensive Report", accessed on March 24, 2024.
4) Park, Kim, and Lee (2022).
5) IPCC (2022a), pp. 871-873.

household sector that drives emissions in nearly all other sectors, including the energy, power generation, industrial, commercial, transportation, and waste sectors.

In order to reduce the carbon footprint in each of these sectors, it is necessary to simultaneously address spatial and structural issues that influence consumption behavior as well as the consumption behaviors themselves.

To do so will require a firm grasp of spatial carbon emissions. This in turn necessitates a basic survey of emissions. The data from such a survey would greatly inform carbon neutrality policies and contribute to the pursuit of a carbon-neutral urban environment.

Kim and Noh (2024) is a recent study on the relationship between urban planning and the carbon footprint of city dwellers. The study's key findings are of particular interest:

Differences in urban and residential density and accessibility to service facilities have various effects on residents' travel carbon footprints (TCFs), which mean fossil fuel use due to passenger cars and use of public transportation, and smaller TCFs appear due to suburbanization, urban density in outlying areas, and improved accessibility.

- Urban density does not necessarily lead to smaller TCFs in cities where residential space accounts for little of the available land. In fact, high levels of residential density increase TCFs by 11% in areas with a low percentage of residential space.
- The effect of residential density on housing carbon footprints (HCFs), which mean electricity and heat energy use, varies depending on the season, with the effect being greater in winter than in summer, and the contribution of HCFs to the residential sector's total CF is also greater in winter than in summer.

1.1.2 Comparative analysis: Approaches to urban planning in South Korea and Germany

(1) Korea's approach

Korea declared that it would achieve a 40% reduction in national GHGs by 2030 compared to 2018 levels, and achieve carbon neutrality by 2050.

Among the current government's 120 national policy tasks, Task 86 (Green Economy Transition through the Establishment of a Scientific Carbon Neutrality Implementation Plan) sets out the goal of actively promoting carbon neutrality policies in response to global decarbonization initiatives. Efforts

are underway to promote carbon neutrality at all levels of government, as well as in spatial planning and mobility systems.

In order to achieve these goals, the Korean government specifically calls for establishing and expanding the operation of local government carbon neutrality support centers (reaching 100 locations by 2027), promoting and designating carbon-neutral green cities as representative models in each region, and encouraging eco-friendly lifestyles through incentives such as carbon neutrality points (in effect since 2022).

The government also suggests other initiatives, including the designation of carbon-neutral cities to promote decarbonization in spatial planning and mobility, the development of carbon-neutral spaces through the expansion of zero-energy buildings and green remodeling, support for transitioning commercial vehicles to eco-friendly alternatives, and the adoption of low-carbon transportation systems in rail, aviation, and other related sectors.

(2) Germany's approach

As in South Korea, carbon neutrality policies are being promoted at various levels of government in Germany, but progress toward an energy transition and levels of public awareness are vastly different.

Recent estimates by German Federal Association of Energy and Water Industries (BDEW) and the Baden-Württemberg Solar Energy and Hydrogen Research Center suggest that renewable energy accounted for 51.6% of Germany's total electricity consumption this year.[6)]

It is especially remarkable that this was achieved while Germany continued to phase out nuclear power amid a European energy crisis caused by various external factors and during an ongoing economic downturn. The success of renewable energy in Germany owes both to willful government efforts to pursue climate neutrality and broad public support for carbon neutrality and the phase-out of nuclear power.

1.1.3 Social and policy acceptance of CF reduction strategies

(1) Social issues and challenges in the process of decarbonization

In February 2024, farmers protested across Europe against the European Union's GHG emission reduction policy. In Germany, farmers opposed the plan to reduce tax breaks on agricultural diesel fuel.

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6) Hankyoreh (December 21, 2023), "Germany Surpasses 50% Renewables… a Miracle Made Possible by Citizen Support", accessed on March 26, 2024.

The EU implemented the Carbon Border Adjustment Mechanism (CBAM) as a type of trade tariff to solve the problem of carbon leakage, where carbon emissions are transferred from countries with strong carbon emissions reduction regulations to countries with weaker regulation.

In South Korea, a failure to transition to clean energy could have a negative impact on the entire economy. However, the government has encountered much difficulty in securing and distributing clean energy economically due to household and industrial electricity rates that are lower than both the OECD and IEA averages.

As of 2020, the average household electricity rate in Korea was $103.9/MWh, which is lower than the OECD average of $170.1 and less than a third of the rate in Germany, which had the most expensive electricity in the world ($344.7/MWh). The rate for industrial electricity in Korea was $94.3/MWh, which is also lower than the OECD average of $107.3.[7)]

Korea needs to reduce domestic carbon dioxide emissions by 91.5% compared to 2017 through a dramatic improvement in energy efficiency, an increase in the share of electricity with high decarbonization potential, and a significant expansion of renewable energy use, along with an increase in electricity rates, and it must do all this while supporting GHG reductions in developing countries in the service of the global net-zero objective.[8)]

However, we also need to consider ways to minimize the costs of higher electricity rates on vulnerable households, especially as prices for seemingly everything have risen.

(2) The acceptability of CF reduction policies

Policy acceptability often depends on the perceived fairness and effectiveness of policies. In the context of decarbonization, the concept of a "just transition" is important. A just transition refers to a shift toward a carbon-neutral society does not disproportionately harm certain groups, such as low-income households or workers in carbon-intensive industries.

From this perspective, it is necessary to consider public acceptability of decarbonization policies.

The Framework Act on Carbon Neutrality and Green Growth for Coping with Climate Crisis (hereinafter, the Carbon Neutrality Act) defines a just transition as "a policy direction to protect workers, farmers, and small business owners in regions or industries who may suffer direct or indirect damage during the transition to a carbon-neutral society, thereby socially sharing the burden arising

7) Greenpost Korea (March 8, 2022), "[Carbon Price Q&A ⑧] Domestic electricity prices...how do they compare to other countries?", accessed on March 26, 2024.
8) Lee, Kim, and Kim (2019).

during the transition and minimizing damage to vulnerable groups."

For a just transition, public acceptability of decarbonization response policies is important, and policy acceptability increases when policies are consistent with the interests of constituent groups in the larger public. Therefore, when establishing policies for a just transition, the interests and benefits of various groups must be considered.

This makes understanding the group and individuals that may be affected by carbon neutrality policies a prerequisite to successful policy implementation. Therefore, we should begin by identifying the factors that influence policy acceptability.

1.1.4 Research objectives

The purpose of this study is to compare how accepting Koreans and Germans are of urban planning policies designed to reduce the carbon footprint of the average household, and based on the results of this comparision, identify implications for policies that can contribute to the pursuit of global carbon neutrality.

The specific objectives of this study are as follows:

- Review existing research on policies on carbon footprint (CF) reduction in South Korea and Germany
- Identify specific CF reduction strategies for each major consumption sector: food, housing, transportation, waste, and water
- Survey and analyze acceptance and awareness types (in this study, we categorize different levels of acceptance and awareness into different "perception types") for CF reduction plan strategies and policies
- Propose policy utilization plans through a comparative analysis of survey data on acceptance and awareness

1.2 Research scope and methods

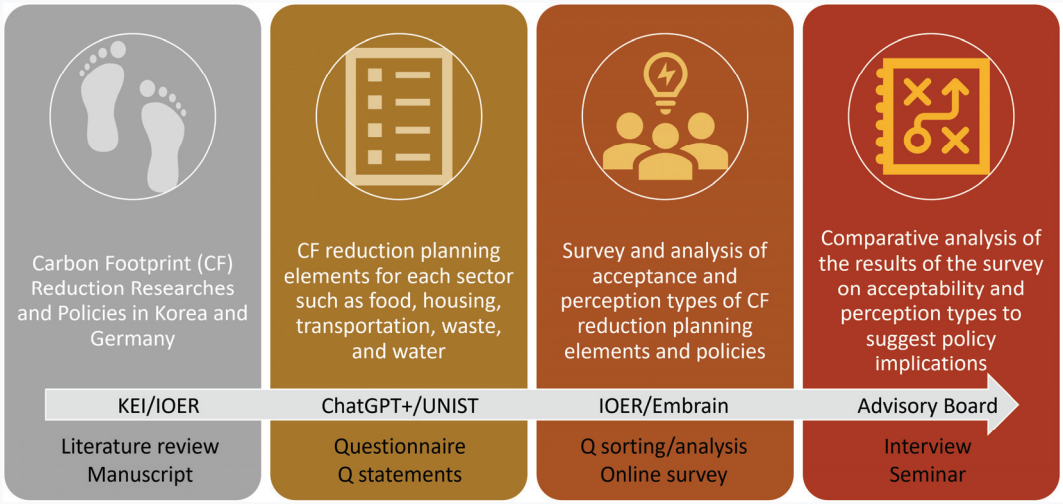
While previous studies have provided valuable insights into the factors influencing carbon footprints (CFs) at the local and national levels, this study goes employing a novel approach in conducting a cross-national analysis. We not only compare planning factors and policy acceptability, but also address the linguistic and cultural challenges of such a comparative study using advanced technological tools such as LangChain.

The basic methodologies and tools employed by the study are described as follows.

- LangChain: An open source framework for building building applications that integrate Large Language Models (LLMs). LangChain provides tools to improve the accuracy, customization, and relevance of information generated by LLMs. We describe how we used LangChain for this study in Chapter 3.
- Online survey: In addition to in-person surveys, for this study we utilized online surveys of Korean and international panels.
- Q methodology: A qualitative-quantitative mixed methodology differentiated from the traditional analytic hierarchy process (AHP), which is a survey targeting experts. The Q methodology adapt the AHP to classify awareness in the general population.
- International joint research (comparative analysis between countries): This study investigates urban planning elements and policies for reducing residents' CFs in Korea and Germany, and conducts a comparative analysis of public awareness and policy acceptability in both countries. The goal is to strengthen the effectiveness of introducing and adapting foreign policies in domestic contexts, while laying the groundwork for joint research and international cooperation in policy development.

Figure 1 below visually illustrates the main content of the study and the methodologies employed therein.

Figure 1 **Research content and methodology**



Source The authors.

Chapter 2

Urban Planning Elements and Policies for CF Reduction

2.1 Theoretical background

Urban dwellers consume food and energy that is almost always supplied from outside the cities in which they live.[9] Research on urban planning strategies and policies to reduce the carbon footprint (CF) of urban residents begins with discussions of urban planning strategies to reduce energy demand and increase efficiency after the oil shocks of the 1970s.[10]

Previous studies have proposed bunching activity spaces more closely together (Owens, 1990), designing more densely populated neighborhoods (Holden and Norland, 2005, pp. 2145-2166), and promoting mixed land use (Duvarci and Kutluca, 2008, p. 1155) as urban planning strategies to mitigate the environmental impacts of the spatial separation of energy demand and supply.

In terms of policy, the United Nations Framework Convention on Climate Change (UNFCCC) was established in 1992 at the first Earth Summit in Rio de Janeiro. The Environmentally Sound and Sustainable Development (ESSD) was held at Kuala Lumpur in 1993 and the Kyoto Protocol was signed in 1997. Sustainable city principles were described at the 2002 iteration of the Earth Summit in Johannesburg.[11]

9) Kim (2015), pp. 163-182.
10) Mohammad et al. (2014), pp. 67-71.
11) UNEP (2002).

These principles referred to the carbon footprint concept, and the importance of shrinking CFs to minimize the ecological impact of human activities.

In a later study on the relationship between CFs and urban planning factors (development density, land use), Ryu (2005) found that low density areas had higher product and service footprints and highly developed areas had higher housing footprints. Moos et al. (2006, pp. 195-224) found that high density residential designs, featuring small dwellings, small private lawns, and small parking spaces, were associated with lower residential CFs.

On the other hand, Kim et al. (2011, pp. 117-127) found that mixed land use and high-density development, which are known to reduce energy demand in the housing and transportation sectors, affect food consumption patterns and increase food footprints. Other studies have analyzed the effects of urban spatial features on residential CFs at the household (Kim, Kim, and Han, 2010, pp. 51-56) and individual (Kim and Kim, 2013, pp. 192-198) levels.

While the 1970s oil shocks initiated discussions on energy-saving measures, the current challenge is to implement comprehensive policies that incorporate sustainable practices and green infrastructure in urban environments.[12] The government of the US state of California quantifies carbon emission reduction inventories by mapping average household CF in a scenario-based census unit. It uses carbon inventories to prioritize GHG reduction in spatial planning and quantifies potential policies and programs to achieve GHG reduction targets using consumption-based, high-resolution planning models.[13]

Recently, in addition to planning factors such as density and land use, studies are being conducted on the differences in CF determinants comparing single-person households and multi-person households in the housing sector (Kim and Kim, 2023, pp. 115-137). Kim (2022) found that residents of high-rise apartments had higher ecological footprints (EFs) than residents of low- and mid-rise flats. Another study examined the impact of suburbanization on CFs in the residential sector (Kim and Noh, 2024, pp. 157-173).

In the following sections, we review research on CF reduction strategies in both Korea and Germany, with a view to identifying key CF reduction strategies grounded grounded in scientific observation.

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12) Francesco (2017).
13) Christopher, Stephen, and Daniel (2018).

2.2 Urban planning elements and policies for CF reduction in Korea

In relation to CF reduction, Korea's urban planning policy focuses on improving energy efficiency through zero-energy building certifications and the application of smart city technologies, expanding green infrastructure, and establishing sustainable transportation systems to reduce greenhouse gas (GHG) emissions and contribute to carbon neutrality efforts.

In this context, recent studies by Park et al. (2022) and Kim et al. (2024) have proposed regional implementation strategies for achieving carbon neutrality, along with principles for the integrated management of land and environmental plans at the local government level. These studies also present a range of specific implementation tools, summarized as follows.

2.2.1 Urban planning principles for CF reduction

(3) Regional carbon neutrality implementation inventory

Park et al. (2022) attempted to classify regions based on carbon emissions variables to inform regional carbon neutrality implementation strategies, and proposed an inventory of carbon neutrality implementation tools and strategies for different kinds of regions.

Park et al. (2022) proposed five regional carbon neutrality implementation strategies:

- Developing transition scenarios tailored to the characteristics of each region
- Strengthening local government capacity to effectively pursue carbon neutrality
- Establishing governance structures based on carbon neutrality principles
- Implementing monitoring and feedback systems to evaluate progress and adjust strategies as needed
- Formulating metropolitan-level strategies for coordinated carbon neutrality implementation

For this study, we compiled a list of carbon neutrality implementation tools and strategies in use around the globe, based on an exhaustive international survey of regional case studies and policies. The 140 total carbon neutrality implementation tools were grouped into the following categories: energy, buildings, transportation, resource circulation, industry, urban ecosystem and sinks, spatial planning, citizen participation, and policies. We then characterized individual implementation tools based on their essential attributes (technology development, program and budget support, regulation, facility expansion, etc).

(1) Carbon-neutral planning elements

Kim et al. (2024) collected and listed carbon-neutral city spatial planning strategies based on a survey of the literature and a review of relevant case studies (Condon et al., 2009; Lee, 2012; Choi et al., 2015; Kim, 2021; Lee, 2022; IPCC, 2022a, 2022b; Jain, 2023). The study classified urban planning strategies into 11 categories: land use/spatial structure, buildings, transportation, energy, resource circulation, water resources, sinks, ecosystems, industries, behavioral improvement, and policies/programs, considering the GHG reduction sector. Next, carbon neutrality planning items (carbon reduction, absorption, and avoidance) were considered and classified in detail.

Depending on the nature of the strategy, strategies that feature carbon reduction, absorption, and avoidance functions were classified as duplicates. For some strategies, additional planning elements were added and described in detail. The study then synthesized these strategies to derive a list of five foundational municipal spatial planning principles: 1. The establishment of a policy foundation for the pursuit of carbon neutrality through spatial and land use planning, 2. Carbon reduction through sector-specific planning and the application of key technologies, 3. Carbon absorption through ecological conservation and restoration, 4. Carbon neutrality that considers regional sustainability, and 5. The creation of synergies through sectoral and regional linkages. The strategies listed according to these principles are presented in Table 1 below.

Table 1 **Carbon neutrality planning elements**

Principle	Sector	Planning Technique
1. Establishing a carbon neutral foundation through spatial structure planning and land uses	Land use and spatial structure	1-1. Land use considering existing terrain (avoidance, absorption)
		1-2. Complex and three-dimensional land use (avoidance)
		1-3. High-density development, compact cities (avoidance)
		1-4. Distribution of infrastructure and social overhead capital services considering population density (avoidance)
		1-5. Securing wind paths (mitigation, absorption)
		1-6. Focused development of transportation nodes (avoidance)
		1-7. Introduction of carbon-neutral land use zoning (mitigation, avoidance, absorption)
		1-8. Urban regeneration and vacant lot development (mitigation, avoidance, absorption)
2. Mitigation through sector-specific planning and technology application	Energy	2-1. Energy independence, expansion of renewable energy (avoidance)

Table 1 **(continued)**

Principle	Sector	Planning Technique
2. Mitigation through sector-specific planning and technology application	Energy	2-2. Solar photovoltaic, solar thermal, geothermal, wind, bioenergy, cogeneration plants, etc. applied considering local conditions
		2-3. Smart grid system (avoidance, mitigation)
		2-4. Integrated energy infrastructure platform (avoidance, mitigation)
	Transportation	2-5. Improving accessibility to major facilities such as jobs, housing, and leisure (more walkable destinations) (avoidance)
		2-6. Transit-oriented development and transit malls (avoidance)
		2-7. Intermodal transit centers, etc.
		2-8. Improving pedestrian and bicycle networks (avoiding straight paths, diverse destinations) (avoidance)
		2-9. Pedestrian-only roads (avoidance)
		2-10. Building infrastructure for expanding eco-friendly vehicles (electric, hydrogen, etc.) to reduce transportation energy (avoidance)
		2-11. Vehicle and bicycle sharing systems (avoidance)
		2-12. Speed limit zones, vehicle restriction zones (avoidance)
		2-13. Intelligent Transportation Systems (ITS) (mitigation)
		2-14. Improving eco-friendly freight transportation systems (avoidance, mitigation)
	Buildings	2-15. Building layout considering natural lighting, sunlight, and wind direction (avoidance)
		2-16. Passive architecture, energy-efficient building systems (high-efficiency insulation, airtightness, ventilation, LED, heat sources, etc.) (mitigation)
		2-17. Building energy management systems (mitigation)
		2-18. Remodeling/reusing existing/old/low-income housing (mitigation)
		2-19. Smartifying and improving energy efficiency of new building types such as shared housing, shared offices, non-face-to-face/remote work (mitigation)
	Waste	2-20. Introducing resource circulation systems
		2-21. Automated collection systems (pneumatic pipes)
		2-22. Reducing and utilizing construction waste and industrial/household waste
		2-23. Water-saving equipment and systems (mitigation)
		2-24. Reusing rainwater, graywater, groundwater, wastewater (mitigation)
		2-25. Decentralized rainwater management (mitigation)
		2-26. Applying Low Impact Development (LID) (mitigation, absorption)

Table 1 **(continued)**

Principle	Sector	Planning Technique
3. Carbon absorption through ecological conservation and restoration	Ecosystem	3-1. Forming green-blue networks through ecosystem conservation and restoration (absorption)
		3-2. Conserving ecologically important areas such as wildlife habitats (absorption)
		3-3. Creating ecological spaces and open spaces in cities (absorption)
		3-4. Creating green spaces and biotopes considering biodiversity (absorption)
		3-5. Ecological restoration of damaged areas (absorption)
	Sinks	3-6. Expanding green spaces on natural/artificial grounds (carbon sinks) (absorption)
		3-7. Carbon absorption forests, carbon-fixing wetlands (absorption)
		3-8. Planting tree species with high carbon absorption rates (absorption)
		3-9. Increasing vegetation density (absorption)
		3-10. Soil carbon sequestration (absorption)
4. Carbon neutrality considering regional sustainability	Industrial structure	4-1. Eco-friendly agriculture (primary industry), local food self-sufficiency (sustainable agriculture, urban agriculture, smart agriculture)
		4-2. Eco-friendly tourism industry (low-carbon green tourism programs, eco-cultural content experiences)
		4-3. Attracting carbon-neutral industries, developing carbon-neutral industrial complexes (climate-friendly product manufacturing, low-emission industries, non-polluting industries, etc.)
		4-4. Regenerating existing industrial complexes into carbon -neutral ones (applying smart factory platforms, etc.)
		4-5. Introducing carbon capture & utilization (CCU), carbon capture & storage (CCS) and technologies in industrial sectors
		4-6. Improving eco-friendly freight transportation systems (avoidance, mitigation)
	Resident participation and behavioral improvement	4-7. Encouraging community climate action
		4-8. Promoting community participation in the planning process and expanding community organizations
		4-9. Education and promotion programs
		4-10. Nudging carbon-neutral behavior through design
		4-11. Revitalizing community facilities and improving accessibility for carbon-neutral community activities
	Policy	4-12. Policies to improve job-housing proximity and achieve balance (housing prices, jobs, etc.)
		4-13. Relevant regulations (mandatory planning, low-energy building systems, etc.) and incentive programs
		4-14. Local carbon reduction pilot projects
		4-15. Identifying and supporting climate-vulnerable groups

Source Kim et al. (2024), pp. 136-139.

2.2.2 Policy recommendations for CF reduction

In a 2023 policy document, the Korean Ministry of Environment proposed a vision and strategy for a basic carbon neutrality plan for local governments. The plan considers the environmental, socioeconomic, and industrial characteristics of individual regions. See Table 2 below.

Table 2 **Urban typologies and GHG reduction strategies**

Urban typology	Characteristics	Reduction strategies
Metropolitan Cities	• High emissions from buildings and transportation • Large building areas and population • Many registered vehicles	• Expand zero-energy buildings • Implement green remodeling • Manage transportation demand • Reduce waste generation
Industrial Regions	• High emissions from energy, industry, and manufacturing • High concentration of industrial complexes	• Manage small subcontractors and other small businesses excluded from national programs • Avoid duplicating national industrial targets
Agricultural and Livestock Regions	• High emissions from agriculture and livestock • High proportion of workers in these sectors	• Expand carbon sinks • Promote low-methane fertilizers • Disseminate eco-friendly agricultural technologies • Provide carbon neutrality education
Absorption-dominant Regions	• Carbon absorption exceeds emissions • Relatively small population and building areas	• Prevent reduction in absorption capacity through forest management • Connect with social-contribution forest carbon offset projects • Promote afforestation and sustainable forest management

Source Korean Ministry of Environment (2023), p. 82.

The aforementioned Park et al. (2022) classified regions based on sectoral carbon emissions and absorption levels, population density, and industrial characteristics. The paper identified four regional types: urban consumption-type emission zones, multi-sector high-emission zones, absorption-type zones, and industrial-type emission zones. For each type, it proposed a tailored inventory of transition tools. These implementation tools span a range of sectors, including buildings, transportation, energy, industry, resource circulation, spatial planning, and behavioral improvement.

Other research reports (Shin et al., 2022; Ahn and Yoon, 2021; Kang, 2022; Park, 2022) emphasize polices related to GHG reduction and carbon neutrality. The papers observe that carbon neutrality is not often incorporated into national land planning. The studies argue that the following factors contribute to the limited integration of carbon neutrality into national land planning. First, the effects of carbon neutrality within spatial units—such as land and cities—remain abstract, making it difficult

to translate the concept into concrete planning measures. Second, the system for collecting, managing, and utilizing spatial information related to carbon neutrality is wholly inadequate. Third, the absence of a dedicated governance structure hinders the institutionalization of carbon neutrality principles and the effective execution of related plans.

These findings suggest that planners need to consider carbon neutrality at the very outset of the planning process. To do so would require a foundation of data upon which to implement such a system. In addition, Kim et al. (2024) examined cities designated by the Korean government as "carbon-neutral green cities." Works in the extant literature have also reviewed several examples of carbon-neutral spatial environment plans, including the carbon-neutral plan for the Saemangeum Smart Waterfront City (see Table 3), the land use plan and nature-based solutions for carbon neutrality in Dresden, Germany, and the Green City Zurich initiative in Switzerland. From these cases, they identified key elements of carbon emission reduction plans as well as institutional improvement tasks (Kim and Choi, 2023).

Table 3 **Key strategies for carbon-neutral green cities: Suwon and Chungju**

Category	Suwon	Chungju
Energy transition	• Public building BEMS construction • Green remodeling • Solar power systems for senior centers, parking lots, and green hydrogen production modules	• Creation of hydrogen mobility stations • Solar and wind energy for self-reliant villages
Carbon sink expansion	• Utilization of reserved land and unused spaces for carbon sinks • Establishment of educational spaces in schools	• Formation of carbon absorption forests and green spaces • Creation of carbon-neutral trails
Resource circulation	• Smart garbage systems using AI and IoT • Installation of smart streetlights and reflective pavement	• Waste-free systems, including recycling stations and water reuse systems
Climate change adaptation	• Expansion of green spaces in public offices • Climate shelter establishment • Promotion of permeable pavement	• Creation of smart drainage infrastructure • Low-impact development
Social transformation programs	• Launch of a carbon-neutral lifestyle project • Development of citizen engagement models	• Implementation of education programs for sustainable mobility and carbon-neutral technologies

Source Compiled by the authors based on Korean Ministry of Environment (April 27, 2022), pp.1-4, accessed on January 8, 2025, and Kim et al. (2024).

Table 4 **Saemangeum smart waterfront city carbon neutral master plan**

3 Main goals	7 Planning tasks	11 Execution strategies
I. Realization of building energy transition	I-1. Promotion of zero-energy buildings	I-1① Application of advanced standards for zero-energy building supply I-1② Establishment of new zero-energy building value chain
	I-2. Transition to clean energy production and supply	I-2③ Implementation of energy transition systems I-2④ Phased supply of community energy based on renewable energy
	I-3. Expansion of smart energy systems	I-3⑤ Expansion of renewable energy installations in urban-based facilities I-3⑥ Establishment of energy platform using cloud systems
II. Promotion of carbon-free smart transportation	II-1. Establishment of carbon-free transportation systems	II-1⑦ Transition of transportation fuels to carbon-free alternatives
	II-2. Expansion of smart mobility supply	II-2⑧ Implementation of eco-friendly transportation systems
III. Realization of ecological carbon sequestration	III-1. Activation of Suwon's green & blue carbon	III-1⑨ Strengthening ecological carbon sequestration through urban forest management
		III-1⑩ Strengthening blue carbon utilization in Suwon
	III-2. Promotion of carbon sequestration technologies	III-2⑪ Development and promotion of innovative carbon sequestration technologies

Source Compiled by the authors based on Saemangeum Development Corporation (2022) and Kim et al. (2024).

2.3 Urban planning elements and policies for CF reduction in Germany

2.3.1 Background and legislative framework

A number of decisions taken by the German government have a large impact on reducing the country's carbon footprint (CF). In parallel, there are several external driving factors fueling demand for

emissions reductions. These developments have been greatly influenced by the debates and discussions of the United Nations Framework Convention on Climate Change (UNFCC). The members of the UNFCC constitute the signatory parties to the Paris Agreement of 2015.

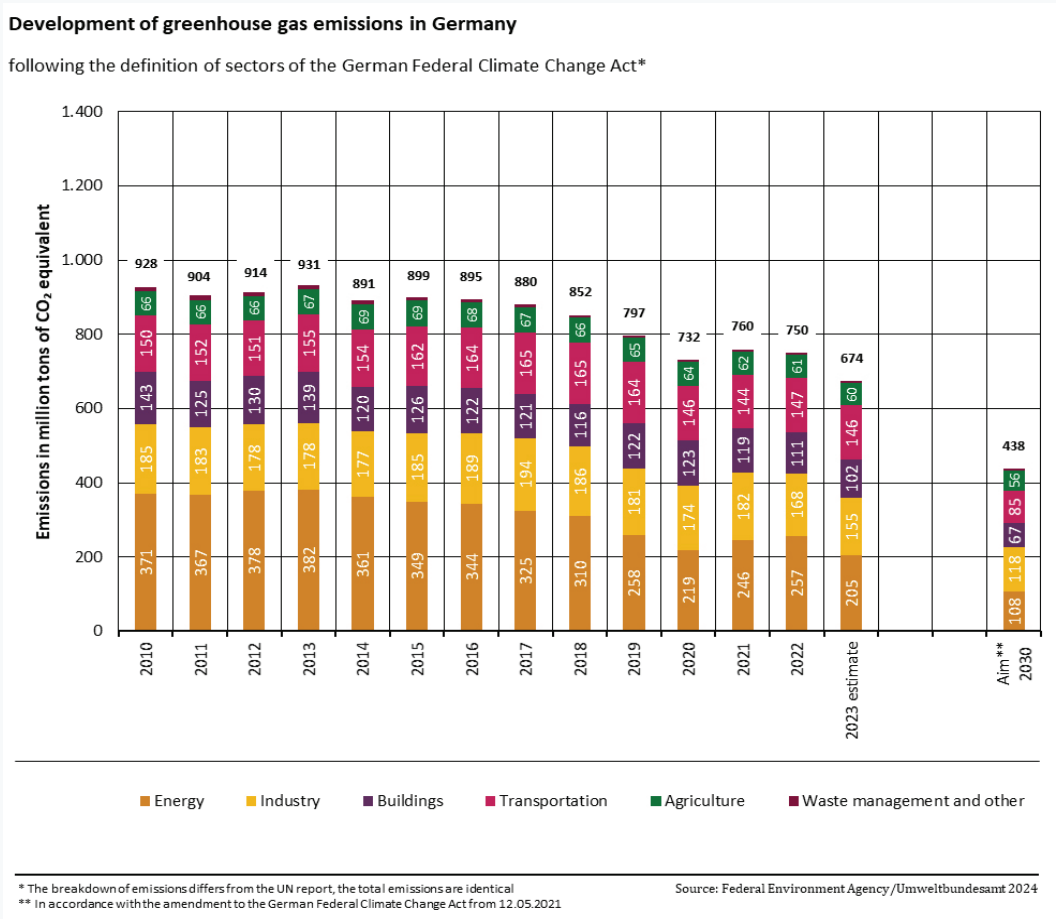
Currently, Germany's goal is to achieve carbon neutrality by 2025. The legal basis upon which climate efforts rest in the country is the Federal Climate Change Act, which was passed in 2019, and subsequently amended in 2021[14] and 2024[15]. The reduction target for 2030 is at least 65 percent of GHG emissions compared to 1990, with a reduction target of at least 88 percent for 2040. The law also functions as a framework for additional climate-related legislation, funding schemes, incentives, and reduction measures.

The German efforts are an integral part of the European strategy. The European Climate Law[16] of 2021 binds all European Union (EU) member states to pursue climate neutrality by 2050. Germany hopes to achieve this goal five years early. After 2050, the EU should achieve negative emissions. The target for 2030 is to reach 55 % net GHG emissions. For 2040, the European Scientific Advisory Council on Climate Change will set the EU's GHG budget. Supporting strategies to reach the aim of carbon neutrality include the European Green Deal[17] and the Fit for 55 package of supportive legislation, policy directions, and regulations.[18]

However, the term "carbon footprint" is rarely found in European or German and CF reduction strategies are mostly absent in the policy literature. Most policies couch climate efforts in terms of climate neutrality or GHG emissions cuts. The current state of sectoral emissions in Germany is shown in Figure 2 below.

14) German Federal Ministry of Justice, Federal Climate Action Act.
15) German Federal Law Gazette, Second Act Amending the Federal Climate Action Act.
16) European Union's Official Legal Database: EUR-Lex, Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021.
17) European Commission Press Corner (July 14, 2021).
18) European Council (January 31, 2025), "Fit for 55: The EU Plan for a Green Transition", accessed on October 15, 2024.

Figure 2 **Greenhouse gas emission overview for the sectors of the German Federal Climate Change Act, 1990-2023**



Source German Environment Agency (2024), accessed on October 15, 2024.

Figure 2 shows us that German GHG emissions in plunged by 10.1 percent compared to the previous year. This sharp decline—the largest since 1990—was driven by a higher share of renewable energy in the power mix, reduced fossil fuel production, and decreased energy demand from both industry and consumers.

2.3.2 Urban planning elements aiming to reduce the carbon footprint of city dwellers in Germany

Next, we will explore some of the sectoral measures in place in Germany to reduce GHG emissions, and offer a brief summary of the German approach to urban planning. For a more detailed, comprehensive analysis of German urban planning strategies, see Kim et al. (2024). The role of public participation in the planning process is also discussed in section 2.3.5.

The guiding principle of the German spatial planning system is sustainable spatial development that harmonizes social and economic needs for space with ecological functions, and fosters to a large-scale, balanced, permanent order with equitable living conditions. A 2016 strategy brief released by the German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety proposes a set of guiding principles for spatial development. Principle 4, "Shaping climate change and the energy transition," covers several climate neutrality issues. The plan includes goals such as preserving and enhancing natural carbon sequestration potential, structuring settlements to conserve energy and reduce traffic, and expanding renewable energy and power grids. These national goals or strategies are transferred through the planning system to federal state plans, regional plans and ultimately to municipal plans.

In addition, the federal government in 2018 promulgated the German Adaptation Strategy, which currently promotes a strong, precautionary climate adaptation strategy (as of December 2024).[19] The aim is to achieve the objectives of the strategy to safeguard people and infrastructure to the greatest possible extent. The country's fourth Adaptation Action PLan (API IV) is part of this strategy, and features over 180 measures. Progress toward the objectives is measured through a monitoring system that uses defined indicators. Based on these results, the strategy will be reviewed and updated every four years, with objectives and measures refined as needed. This marks the first step toward a strategic and adaptive federal climate management system grounded in clear targets and measurable progress.

Germany also attaches much importance to green and blue infrastructure, seeing it as important not only for preserving biodiversity but also for supporting climate protection and adaptation in a variety of ways. It deploys an array of strategies to achieve these ends. For example, open-air corridors, shaded areas, and water features can mitigate urban heat islands and create cooling zones. Multifunctional open spaces that provide a high quality of use also help protect the population from heat stress. Sustainable rainwater management—through retention areas and tree infiltration channels—can reduce the risks of both flooding and drought. Enhancing biodiversity contributes to species protection and improves the ecological quality of public spaces. Numerous federal states and institutions have published resources and guidelines to support these efforts in urban planning (German Ministry for Climate Protection, Environment, Agriculture, Nature Conservation, and Consumer Protection of North Rhine-Westphalia, 2011; Ministry of Transport and Infrastructure of Baden-Wurttemberg, 2015; Bavarian State Office for the Environment, 2023).

The Urban Climate Handbook (German Ministry for Climate Protection, Environment, Agriculture,

19) German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection, "German Strategy for Adaptation to Climate Change", accessed on October 15, 2024.

Nature Conservation, and Consumer Protection of the State of North Rhine-Westphalia, 2011) recommends numerous specific measures that should be implemented in urban land use plans (city-wide) or development plans (project-specific) to adapt to climate change of these, many focus on direct and indirect contributions to carbon reduction. These measures include:

- Defining development boundaries (spatial distribution of development, building density)
- Preserving open spaces and creating new open spaces
- Creating, maintaining, and redesigning parks
- Greening streets, roofs, and facades
- Preserving and creating Clean Air Zones (CAZs)
- Creating open water areas
- Optimizing building orientation
- Shading house walls and providing thermal insulation
- Preserving and creating urban air flow paths
- Keeping slopes free of parallel block development
- Adding structural shading elements to public spaces
- Greening urban spaces with heat and drought-resistant plant species
- Encouraging more plantings of groundcover vegetation, and avoiding artificial ground coverings
- Improving the permeability of topsoil in urban environments through appropriate plantings with sufficient root penetration
- Removing sealed surfaces
- Carefully managing land use on slopes, and promoting good drainage and erosion-mitigation measures
- Improving and facilitating soil infiltration
- Creating intermediate rainwater reservoirs and emergency waterways
- Ensuring that underpasses have drainage/infiltration ditches on both sides

The handbook also contains implementation case studies an some evaluations of policy effectiveness.

In most cases, planners consider a large number of other variables as well, but overall, the protection and development of ecosystem services is a high in German spatial and urban planning. As an example, the city of Dresden pursues the strategic model "The compact city in the ecological network" with their landscape plan (German State Capital Dresden, 2018).

Targeted funding programs exist to facilitate the implementation of such measures. For example, as part of the so-called climate contingent in the federal state of Hesse, EUR 15 million from urban development funding has been used annually since 2022 specifically for the implementation of

individual measures that have been found to have an exemplary effect on climate protection and climate impact adaptation in the area of green and blue infrastructure.[20] At the federal level, there is the Climate and Transformation Fund, which has been funding projects with a total budget of EUR 576 million since 2020.[21]

2.3.3 Energy transition processes

In Germany, the centerpiece of action for reducing GHG emissions is the transformation of the energy sector. This transformation includes transitioning from the unsustainable use of fossil fuels and nuclear energy to a sustainable energy supply using renewable energies to generate electricity, heat homes and businesses, and move people and things around the country. The aim of the energy transition is to ultimately see that all of Germany's energy requirements can be met by renewable sources. The core elements of the transition are expanding renewable energy, increasing energy efficiency, and implementing energy-saving measures. Given that global warming is largely driven by human activity, decarbonizing the energy sector—by phasing out fossil fuels such as oil, coal, and natural gas—has become an urgent priority. The energy transition is also motivated by the finite nature of fossil fuel resources and the risks associated with nuclear power. Addressing the global energy challenge is widely considered one of the defining tasks of the 21st century, and Germany is among the most countries in this regard.

The origins of the German energy transition date back to the 1970s. At that time, considerable protests against the use of nuclear energy began. Accordingly, the massive expansion of renewable energies since around 2000 has also been used as an argument for shutting down nuclear power plants in addition to fossil fuel-based power generation facilities. The most significant events that ultimately led to Germany's withdrawal from nuclear power were the serious nuclear power incidents in Chernobyl in 1986 (some of the effects of which directly affected Germany) and Fukushima in 2011, in connection with the unresolved issue of nuclear waste disposal. A complete nuclear phase-out was legally agreed-upon in 2001, but later undermined. Just three days after the Fukushima disaster, the German government announced a three-month nuclear moratorium and then, on June 6, 2011, a complete phase out by 2022.

Successive German governments have continually stressed the importance of climate protection. The red-green government (1998-2002, 2002-2005) achieved far-reaching changes. Key measures

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20) Hessian Ministry of Economic Affairs, Energy, Transport, Housing, and Rural Development, "Securing the Future! The Hessian Climate Contingent 2024", accessed on October 15, 2024.

21) German Federal Institute for Research on Building, Urban Affairs and Spatial Development, "Adaptation of Urban and Rural Areas to Climate Change", accessed on October 15, 2024.

included the introduction of the so-called eco-tax on energy consumption, more intensive promotion of renewable energies, and the 100,000 roofs program to promote photovoltaics. These were regarded as core elements of the energy transition. These policies and decisions triggered a major change in the country's electricity mix. The Renewable Energy Sources Act (EEG) was passed in 2000. This was the first time that the purpose of the energy transition was laid down in law. In the years that followed, the law was amended several times. Some aspects of these amendments can be found in earlier pieces of legislation, such as the Electricity Feed-in Act (StromEinspG) of 1990. The German federal government has also tighter restrictions on heating in the building sector. New regulations included the Energy Saving Ordinance (EnEV) of 2001, the Energy Saving Act (EnEG), which was originally passed in response to the first oil crisis in 1976 and last amended in 2005, and the Renewable Energies Heat Act of 2008. Since 2024, these regulations have been consolidated under the Building Energy Act (GEG).

In addition, enhanced international commitments to climate protection—particularly the Paris Climate Agreement—led to the decision to phase out the use of coal in Germany. In 2020, an agreement between the federal government and the constituent states laid the foundations for a coal phase-out law, which was passed in the same year. This was preceded by several draft laws for reductions in the hard coal sector and months of negotiations with lignite companies. Among other things, an orderly decommissioning path to 2038 was agreed-upon with the aim of a possible earlier phase-out in 2035 or 2030.

However, the Russian invasion of Ukraine in February 2022 led to an energy crisis in Germany. Due to reduced gas supplies from Russia in connection with the destruction of the Nordstream pipelines by an attack, the debate about the use of coal and nuclear power was reopened at short notice. Initially, backup coal power plants were able to stabilize electricity generation in the short term. The aim was to reduce the demand for natural gas for power generation and to lower the price of electricity by increasing supply. Nevertheless, prices for electricity and fuels rose considerably after the Russian attack on Ukraine, prompting the government to respond with several relief packages totaling EUR 300 billion. The effectiveness of these measures has been proven in several studies.[22) 23)]

Among other things, price brakes were set for electricity and gas, which subsidized the market in order to mitigate the consequences of rising prices.[24)] The country's value-added tax (VAT) on gas and heat was reduced from 19% to 7% from October 2022 to March 2024. At the same time, the population was asked to use energy sparingly. The government sought to lead by example, and so limited heating in

22) German Federal Ministry of Finance (May 25, 2023).
23) German Economic Institute (July 3, 2023).
24) German Federal Ministry of Finance, "Our Relief Measures are Working", accessed on October 15, 2024.

public buildings and kept some kinds of nighttime lighting off.

The statistics on electricity generation for the first half of 2024 show that these ambitious efforts are bearing fruit. In this period, 61.5% of the electricity generated in Germany came from wind, solar, hydropower and biomass sources. That is over nine percent more climate-friendly electricity than in the first half of 2023 and the most ever generated in the first six months of a year. Progress was also made in electricity consumption in the first half of 2024: 57% of the electricity consumed was covered by renewable energy sources (the aim for 2030 is 80%).[25] This momentum continues to grow, as renewable energy generation facilities are being approved at an accelerated pace. The German government expects the supply of renewable energy to greatly expand going forward. The rising cost of CO_2 certificates under the Fuel Emissions Trading Act (BEHG) enacted in 2019, combined with falling electricity prices driven by the growing share of renewable energy, has made coal-fired power increasingly uneconomical.

Nevertheless, several challenges remain. These include the need for greater flexibility in the energy system, which requires not only controllable large-scale generation plants but also, where possible, responsive consumer-side installations. Expanding and better controlling energy storage networks is another key priority. In parallel, the development and scaling of a hydrogen grid through the transformation of the existing gas infrastructure is essential. Further expansion of the electricity grid is also required, with an emphasis on standardization, coordination, and digitalization. Finally, significantly increased investment, particularly from the private sector, will be critical to advancing these goals.

As part of its "Long-term Scenarios for the Transformation of the Energy System in Germany" projec t,[26] the German Federal Ministry for Economic Affairs and Climate Action models several scenarios projecting the future trajectory of the energy system in Germany.

The modeling covers the entire energy system, including the production of heat, electricity, and hydrogen, as well as demand for energy in the industrial, transportation, building, and residential sectors. The future trajectory of electricity and gas infrastructure is also modeled. The focus of the analysis is not on the development of a single lead scenario, but rather the exploration of various potential scenarios in order to gain insights into the advantages and disadvantages of alternative paths for the transformation of the energy system through the comparative analyses.

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25) Clean Energy Wire (July 18, 2024), "Renewables Cover 57% of Germany's Electricity Consumption in First Half 2024", accessed on October 15, 2024.

26) German Federal Ministry for Economic Affairs and Climate Action, "Long-term Scenarios for the Transformation of the Energy System in Germany", accessed on October 15, 2024.

For example, the EU's 42.5% renewable energy expansion target by 2030 was made legally binding,[27] an agreement was reached on establishing a unified European electricity grid, and a phase-out of fossil fuel vehicle sales by 2035 was also adopted.[28]

2.3.4 Sectoral carbon footprint reduction measures in Germany

Figure 3 is a visualization of Germany's Sustainable Development Strategy. We can note a focus on achieving the UN's Sustainable Development Goals (SDGs).

Figure 3 Areas of transformation, off-track indicators, and measures

Note Marianne Beisheim, SGP, statement as part of the dialogue process, October 2020 (updated with regard to off-track indicators and with the addition of German Government input on core measures in the specific areas of transformation).

Source German Federal Government (March 10, 2021).

27) Council of the European Union (January 31, 2025), "Fit for 55: How the EU Plans to Boost Renewable Energy", accessed on October 15, 2024.

28) European Parliament (October 19, 2022), "EU Ban on Sale of New Petrol and Diesel Cars from 2035 Explained", accessed on October 15, 2024.

It depicts the main areas of transformation, off-track indicators as well as measures and provides a good overview.

Table 5 **Selected sector-specific measures for carbon footprint reduction in Germany**

Sector	Measure
Energy	• National transformation of energy production to renewable systems • Nuclear phase-out by 2022 • Coal phase-out by 2038 (preferably 2030) • Expansion of renewable energies • Increase in energy efficiency • Municipal heat planning • Promotion of energy-efficient renovation of buildings • Supporting decentralized photovoltaic systems ("balcony power stations") • Expansion of energy storage systems • Expansion of the electricity grid • Converting the gas network into a hydrogen network
Industry	• European Union Emissions Trading System • Emission certificates trading • EU Energy label for products
Transportation	• Promotion of e-cars (ended 2023) • Promotion of e-buses in public transport (ended 2023) • Germany Ticket ("49 Euro-Ticket") introduced 2023 for Germany-wide use of public transport and regional trains • Vehicle taxes • Mineral oil tax rates
Buildings	• Supporting conversion of heating systems from fossil fuels to renewables • Supporting decentralized photovoltaic systems ("balcony power stations") • Promotion of energy-efficient renovation of buildings • Energy label for houses/apartments • Carbon Dioxide Cost Sharing Act
Agriculture	• Propagation and financial support of organic agriculture • Food • Initiatives to eat less meat and adopt a plant-based diet • Reduction of food waste • Promotion of seasonal and regional food
Waste management and others	• Waste avoidance, waste separation, recycling and reusable packaging • Ban of certain single-use plastic products since 2021 • Labels for environment-friendly products • Initiative to repair products

Source The authors.

Many of the areas of transformation overlap with the sectors addressed in the German Federal Climate Change Act. Table 5 presents an overview about selected sector-specific carbon footprint (CF) reduction measures in Germany. The sectors are listed according to their share of GHG emissions (see Figure 2). The following sections will explain the measures in more detail.

(1) Measures in the energy sector

Germany's ambitious climate policy goals require, reorganization of the energy system (see section 2.3.2). For a greenhouse gas-neutral energy system, electricity from renewable energy sources will be the most important form of energy in the future;[29] in Germany, this will be wind energy and solar photovoltaic in particular. Energy storage is also of particular interest to the German government, which notes the ability of hydrogen (and particularly green hydrogen, or hydrogen produced using renewable sources of energy) to store energy. There are also synthetic sources of energy storage (power-to-gas, power-to-liquid). Germany needs to expand its grid infrastructure to efficiently (German Federal Ministry for Economic Affairs and Climate Action, 2021, pp. 22-29).

At the same time, the grid infrastructure needs to be expanded in order to transfer the wind power generated in the north of Germany to the industrialized south. The expansion of these power lines is often associated with resistance from local communities which frequently leads the government and developers to instead lay cables underground, which is an expensive undertaking. Wind turbines are also often associated local resistance, so it makes sense to involve local residents at an early stage and give them a share any profits generated.

In order to promote the expansion of renewable energies, the federal government is also promoting the installation of decentralized photovoltaic systems. These are the so-called "balcony power plants."[30] Owners of photovoltaic systems can consume the electricity produced by these panels to directly reduce their energy expenditures.

Alongside the expansion of renewable energies, energy efficiency[31] is the second pillar of Germany's energy transition. In this context, it refers primarily to cutting the use of fossil fuels and by extension, GHG emissions. At the same time, it reduces the need for generation capacity and distribution infrastructure. Energy-efficient building refurbishment and greater energy and material efficiency in industry can also contribute to increased energy efficiency. In addition, energy consumption in Germany has been decreasing thanks to several specific technologies, such as LED streetlamps and lighting, especially in the direct use of electricity as part of sector coupling (German Federal Ministry for Economic Affairs and Climate Action, 2021, pp. 22-29).

The energy used to heat homes and businesses in Germany constitutes a significant proportion of

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29) German Federal Ministry for Economic Affairs and Climate Action (February 25, 2021), "What Could the Energy System of the Future Look Like?", accessed on October 15, 2024.

30) Saxon Development Bank (February 4, 2025), "Balcony Power Plants (Plug-and-Play PV Systems)", accessed on October 15, 2024.

31) German Federal Office for Economic Affairs and Export Control, "Energy Efficiency", accessed on October 15, 2024.

total energy consumption in the country. German Building Energy Act (GEG) 2024[32] requires the creation of a municipal heat planning authority for municipalities with more than 100,000 inhabitants by 2026, and for smaller municipalities by 2028.[33] These commissions would design and implement heating infrastructure both neighborhoods and even entire municipal areas. The aim is to convert the supply of heating energy to renewable sources or use waste heat from existing power plants as district heating, for example. In addition, the government is also promoting heating conversions for individual homeowners. Heating systems are to be converted from fossil fuels to renewable energies such as heat pumps, district heating, solar systems, geothermal energy, and others. The GEG stipulates that new heating systems must use at least 65% renewable energy from 2026/2028.[34]

Another measure for reducing heating energy requirements is to promote the energy-efficient refurbishment of existing buildings. Funding programs have been set up for this purpose.[35]

In the energy sector, GHG emissions in 2023 fell by around 51.8 million tons of CO_2 equivalents (CO_2e) or 20.1% compared to the previous year, which is due to the reduced use of fossil fuels in the generation of electricity and heat. Declining use of both lignite and hard coal was notable, and a large decrease was also observed in use of natural gas. The reasons for this include the significant drop in coal-fired power generation, the consistent expansion of renewable energies and an electricity import surplus coupled with a simultaneous drop in energy demand. Other drivers were energy savings as a result of higher consumer prices and mild weather conditions in the winter months.[36]

(2) Measures in the industry sector

Emissions trading is an important instrument for reducing GHG emissions in the industrial sector. The European Union Emissions Trading System[37] is a market-based emissions trading system, or ETS, with the aim of reducing GHG emissions within the EU. In line with the reduction in emissions set out in the climate protection targets, an upper limit is set for the total quantity of GHGs that polluters such as energy producers or industrial companies may release. This cap will be gradually lowered in order to reduce the total permitted emissions to zero by 2050. the ETS currently covers around 45% of GHG

32) German Federal Ministry of Justice and Consumer Protection, “Building Energy Act”.
33) German Federal Ministry for Housing, Urban Development and Building, “Municipal Heat Planning”, accessed on October 15, 2024.
34) German Federal Government (August 27, 2024), “For more Climate-Friendly Heating”, accessed on October 15, 2024.
35) KFW Development Bank, “Renew Energy Efficiently and Save Permanently”, accessed on October 15, 2024.
36) Umwelt Federal Agency (March 15, 2024), “Climate Emissions Decrease by 10.1% in 2023 – Largest Drop Since 1990”, accessed on October 15, 2024.
37) European Union, Directive 2003/87/EC Establishing a Scheme for Greenhouse Gas Emission Allowance Trading.

emissions in the EU, but is to be gradually extended to all emissions. It was incorporated into German law through the Greenhouse Gas Emissions Trading Act (TEHG)[38] of 2004.

A limited number of certificates is distributed to the member states of the EU, which either allocate them or auction auction them. This is the primary market of the ETS. Each certificate entitles the holder to emit one ton of CO_2e. At the end of the year, GHG emitters must present certificates equal to their emissions. If necessary, they can buy additional certificates on an exchange. This is the secondary market of the ETS. They can sell surplus certificates to other polluters. Trading creates economic incentives to reduce emissions where possible at the lowest possible cost. EU emissions trading covers 30 European countries (27 EU states plus Liechtenstein, Iceland and Norway). There is also a so-called linking agreement with Switzerland. The EU Emissions Trading System (ETS) is the first cross-border and largest emissions trading system in the world and acts as a pioneer for a possible global system of CO_2 pricing.

The EU ETS has gone through a number of trading periods. Each trading period has seen various reforms to improve the system. The effectiveness of the EU ETS has long been controversial due to initially low prices. As a result of political reforms, the price of certificates has reached new highs since 2018. The EU ETS is an effective and efficient instrument for combating climate change. In addition, the EU ETS has likely contributed to better public health outcomes by incentivizing fewer emissions of air pollutants, reducing regional concentrations of harmful gases and substances.

At German level, there is also the National Fuel Emissions Trading Act (BEHG).[39] It supports the achievement of defined GHG reduction targets (Climate Action Plan 2050[40]). To this end, a complementary national ETS was introduced in the heating and transport sectors from 2021, which are not covered by the EU ETS.

Emissions trading transforms GHG emissions from the use of fossil fuels into a tradable commodity. The aim is to limit and continuously reduce annual emissions. Fossil heating and motor fuels are affected, in particular heating oil, liquid gas, natural gas, coal, petrol and diesel, but also waste.

Based on a specific emissions cap set by the European Commission in accordance with Article 4 of the EU Climate Protection Regulation (Section 4(1) of the BEHG), companies that place fuels on the market in accordance with the system of energy tax law must purchase (trade) certificates from the Federal Republic of Germany, which entitle them to emit one tonne of ton of CO_2e over a defined period

38) German Federal Ministry of Justice, "Greenhouse Gas Emissions Trading Act".
39) German Federal Ministry for Economic Affairs and Climate Action, "Fuel Emissions Trading Act".
40) German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (November 2016).

(Section 3(2) of the BEHG). The certificates are issued by the German Emissions Trading Authority. The proceeds are due to the Federal Government (Section 10(4) of the BEHG). Further details can be found in the Ordinance on the Implementation of the Fuel Emissions Trading Act.[41)]

In principle, prices should be set on the market. As the number of certificates is limited by the constantly decreasing emissions cap, the certificates become more expensive over time and therefore represent an economic incentive to reduce or avoid emissions by investing in mitigation technologies and equipment to save money.

In this context, we can see that emissions represent a kind of special advantage, which is skimmed off when fossil fuels are placed on the market by surrendering a corresponding number of chargeable certificates. This functionally creates system for managing the use of the atmosphere governed by public law.

The German government is also supporting large-scale industrial research projects to reduce GHG emissions. These include programs to facilitate the use of green hydrogen, green hydrogen, which is produced using renewable energy, as well as blue hydrogen, which is produced using natural gas coupled with carbon capture and storage technologies. The government is promoting hydrogen use in energy-intensive industries such as steel.

For the manufacture of consumer goods, there are also labeling options for energy requirements (EU Energy label for products[42)]) to promote energy efficient products. In addition, further development towards an EU Ecodesign label[43)] for sustainable products is planned, for example for long-lasting or repair-friendly products.

In the industrial sector, emissions fell for the second year in a row to around 155 million tons of CO_2e in 2023. This corresponds to a decrease of almost 13 million tons or 7.7% compared to the previous year. The industrial sector is thus around 18 million tons of CO_2e below its annual emissions volume for 2023. Here, too, the decline in emissions is determined by the reduced use of fossil fuels, in particular natural gas and hard coal. Key drivers of this trend are ongoing recession in Germany and increased production costs, which have led to declines in production.[44)]

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41) German Federal Law Gazette, "Regulation for the Implementation of the Fuel Emissions Trading Act".
42) European Commission (January 10, 2024), "Understanding the Energy Label", accessed on October 15, 2024.
43) European Commission, "The Legislative Framework", accessed on October 15, 2024.
44) Umwelt Federal Agency (March 15, 2024), "Climate Emissions Decrease by 10.1% in 2023 – Largest Drop Since 1990", accessed on October 15, 2024.

(3) Measures in the transportation sector

The government has also implemented several CO_2 reduction measures in Germany's transportation sector. These include:

- The promotion of electric cars, which was supported by government subsidies until the end of 2023 (German Federal Office for Economic Affairs and Export Control, Electromobility, accessed October 15, 2024).[45)]
- Support for the introduction of electric buses in public transportation, with funding programs also ending in 2023 (German Federal Ministry for Economic Affairs and Climate Action, Funding Program for the Acquisition of Electric Buses in Public Transport, accessed October 15, 2024).[46)]
- The launch of the Deutschlandticket (also known as the "49-Euro Ticket") in 2023, which allows for nationwide use of public transport and regional trains (Deutschlandticket, Deutschlandticket, accessed October 14, 2024).
- A vehicle tax system that varies based on engine capacity and pollutant class for vehicles registered before 2009, and on CO_2 emissions for diesel and petrol vehicles registered after 2009. Electric vehicles are currently exempt from this tax until 2030 (German General Customs Directorate, Tax Amount for Motor Vehicle Tax).[47)]
- Energy taxes on fuel, with current rates set at €0.47 per liter for diesel and €0.65 per liter for petrol. A reduced rate of €0.26 per liter applies to agricultural use ("farm diesel") (German General Customs Directorate, Tax Amount for Energy Taxation).[48)]

However, the transportation sector still has much work to do in terms of climate action. It is once again falling well short of its climate targets and now sits 13 million tons above its permitted sector budget. Urgent action is needed in this area, including the expansion of electromobility, the introduction of a speed limit on motorways, and the reduction of climate-damaging subsidies. These subsidies include the company car privilege (tax breaks that often encourage the purchase of CO_2 -intensive vehicles), the diesel privilege (lower fuel taxation on diesel compared to gas), and the distance allowance—also known informally as the commuter allowance—which provides tax refunds for travel between home and work (currently €0.30 per kilometer for the first 20 km, and €0.38 per kilometer for distances over 21 km).

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45) German Federal Office for Economic Affairs and Export Control (December 18, 2023), "Electromobility", accessed on October 15, 2024.
46) German Federal Ministry for Economic Affairs and Climate Action, "Funding Program for the Acquisition of Electric Buses in Public Transport", accessed on October 15, 2024.
47) German General Customs Directorate, "Tax Amount for Motor Vehicle Tax".
48) German General Customs Directorate, "Tax Amount for Energy Taxation".

The transportation sector emitted around 146 million tons of CO_2e in 2023. This means that GHG emissions in the transportation sector are around 1.8 million tons (1.2%) below the 2022 figure and around 13 million tons above the annual emission volume of 133 million tons CO_2 permitted under the Klimaschutzgesetz (KSG, or German Climate Protection Act) for 2023. Emissions had risen slightly in the previous year. In view of the fact that the building sector only slightly exceeded its target, the transportation sector is the only sector to fall well short of its target and move further away from the statutory target path. Moreover, the main driver of the modest decrease in transportation emissions was not the combined effect of climate policy, but rather lower road freight mileage. Compared to 2022, passenger car traffic actually slightly in 2023. The new electric vehicles (EVs) registered in the passenger car fleet in 2023 a slight emissions-reducing effect here.[49)]

(4) Measures in the buildings sector

A 2020 study by the German Federal Institute for Research on Building, Urban Affairs and Spatial Development describes the current environmental footprint of buildings in Germany. In the buildings sector, it measures support for the conversion of heating systems from fossil fuels to renewables (heat pumps, district heating, solar photovoltaics, etc.)[50)] since new heating systems must use at least 65 percent renewable energy from 2026/2028 according to the German Building Energy Act (GEG) 2024.[51)] The same law also stipulates energy performance certificates for houses and apartments.[52)] Further measures include incentives to support installing decentralized photovoltaic systems,[53)] for the energy-efficient construction of new residential buildings[54)] or the renovation of existing buildings[55)] that have been described already in the energy sector (See section 2.3.4(1)).

There is an additional regulation for tenants and landlords of rental units. The Carbon Dioxide Cost Sharing Act is based on the regulation of the incentive system created by the Fuel Emissions Trading Act (BEHG) (see section 2.3.4(2)) to reduce GHG emissions for heating and applies it to rented residential space. Since 2023, national CO_2 costs under the BEHG have been divided between landlords and tenants according to their areas of responsibility and ability to influence a building's CO_2

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49) Umwelt Federal Agency (March 15, 2024), "Climate Emissions Decrease by 10.1% in 2023 – Largest Drop Since 1990," accessed on October 15, 2024.
50) German Federal Government (August 27, 2024), "For More Climate-Friendly Heating", accessed on October 15, 2024.
51) German Federal Ministry of Justice, "Building Energy Act".
52) German Energy Agency (April 1, 2023).
53) Saxon Development Bank (February 4, 2025), "Balcony Power Plants (Plug-and-Play PV Systems)", accessed on October 15, 2024.
54) KFW Development Bank, "Energy-Efficient Construction or Purchase – Funded by KFW", accessed on October 15, 2024.
55) KFW Development Bank, "Renew Energy Efficiently and Save Permanently", accessed on October 15, 2024.

emissions. Both parties are to have an equal influence on reducing consumption. Previously, only tenants paid the CO_2 levy for heating with natural gas and oil alone.

In the building sector, a reduction in emissions of 8.3 million tons of CO_2e to around 102 million tons of CO_2e (a drop of 7.5%) was achieved. Despite this reduction, the building sector once again exceeded its annual emissions allotment under the Federal Climate Protection Act (KSG), this time by around 1.2 million tons of CO_2e . The main drivers for the decrease in emissions are once again energy savings due to the mild weather conditions in the winter months of 2023 and higher consumer prices. The expansion of heat pumps also had a positive effect on the development of emissions in the building sector, as less natural gas and heating oil were used, for example.[56)]

(5) Measures in the agriculture sector

Promotional and financial support measures in the agriculture sector include both support for organic farming and initiatives related to food consumption.[57)][58)] These efforts encompass encouraging reduced meat intake, promoting plant-based diets,[59)] the reduction of food waste,[60)][61)] and advocating for the consumption of seasonal and locally sourced foods.[62)]

(6) Measures in the waste management sector and others

Waste avoidance, waste separation and recycling have been promoted in Germany for many years.[63)] An important aspect of waste prevention is the use of reusable packaging (especially for drinks or dairy products). Waste separation and recycling are important components of the circular economy. Packaging waste (plastics, composites, metals), paper and cardboard waste, glass waste, organic waste, and waste electrical appliances and waste batteries are collected separately as it is easier to recycle these types of waste once they are separated.[64)] Construction waste is also collected

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56) Umwelt Federal Agency (March 15, 2024), "Climate Emissions Decrease by 10.1% in 2023 – Largest Drop Since 1990", accessed on October 15, 2024.
57) German Federal Ministry of Food and Agriculture (November 16, 2023), "2030 Organic Strategy: National Strategy for 30% Organic Production in the Farming and Food Sector by 2030", accessed on October 15, 2024.
58) German Federal Ministry of Food and Agriculture, "Federal Organic Farming Program", accessed on October 15, 2024.
59) German Federal Ministry of Food and Agriculture (January 17, 2024).
60) German Federal Ministry of Food and Agriculture (January 2, 2025), "National Strategy to Reduce Food Waste", accessed on February 24, 2025.
61) German Federal Ministry of Food and Agriculture (November 20, 2024), "BMEL Activities to Combat Food Waste", accessed on February 24, 2025.
62) German Federal Ministry of Food and Agriculture (September 19, 2023), "Regional Food – Transparently Labeled a Good Choice", accessed on October 15, 2024.
63) Waste Separation Works Initiative, "Waste Separation Works", accessed on October 15, 2024.
64) Umwelt Federal Agency (December 2020).

separately and recycled to the greatest possible extent. Plastic waste, for example, is almost completely recycled. In 2021, just under 35% of all plastic waste collected was materially recycled and 0.4% was used as raw material or chemically recycled. However, 64% of plastic waste was recycled for energy.[65)]

In 2021, a number of single-use plastic products were banned in the EU. These include drinking straws, stirrers, balloon sticks and disposable tableware made from conventional plastic and "bioplastics." To-go cups and disposable polystyrene containers may also no longer be produced and sold in the EU.[66)]

Various labels have been developed to positively influence purchasing behavior and draw attention to environmentally friendly products. Products are labeled if they are durable, avoid waste and conserve resources or have been manufactured in an environmentally friendly way. Examples include The German Ecolabel "Blue Angel"[67)] and the EU Ecolabel.[68)]

Recently, there have also been initiatives to have products (especially electronic devices) repaired in order to avoid waste. There are financial incentives for private individuals to do this.[69)]

2.3.5 Public participation in urban planning processes in Germany

In addition to the aforementioned measures, urban planning can also contribute to GHG reductions. Public participation is a critical component of the urban planning process.

In general, there are two types of public participation in urban planning processes: formal and informal. In the case of formal participation, the German building and planning law stipulates exactly who participates, when they do so, and what form this participation assumes. Formal participation is often referred to as public participation or disclosure. Under German law, formal public participation is required in various planning and approval processes, including land-use planning (such as urban development and land-use plans), regional and state development planning, environmental impact assessments, and legal approval procedures for emission-producing technical facilities. With the amendment of the Environmental Impact Assessment Act (UVPG)[70)] in 2017, environmental impacts caused by climate change must also be examined.

Informal participation, on the other hand, refers to all procedures that are not regulated by law. It can

65) Umwelt Federal Agency (June 30, 2023), "Plastic Waste", accessed on October 15, 2024.
66) German Federal Government (July 4, 2021).
67) Blue Angel, "The German Ecolabel", accessed on October 15, 2024.
68) EU Ecolabel, "The Environmental Label You Can Trust", accessed on October 15, 2024.
69) Saxon Development Bank, "Repair Bonus", accessed on October 15, 2024.
70) German Federal Ministry of Justice, "Environmental Impact Assessment Act".

therefore be freely decided who is involved, when and how. This kind of voluntary participation often occurs at the very earliest stages of planning, when much has yet to be decided. The main purpose of informal participation is to allow to discuss a topic or task with each other and exchange opinions. Informal types of public participation include, for example, information events, dialogues, discussions, surveys, workshops, planning workshops, unofficial votes, and various kinds of digital participation. For example, the city of Dresden offers a portal which lists all informal participation procedures in the field of urban planning and mobility.[71] Information on formal participation procedures (development plans and other plans and concepts) is also available online.[72]

2.3.6 Conclusion

Germany has set ambitious climate protection targets in close alignment with the European Framework. To achieve these goals, numerous laws have been passed, strategies developed, funding programs launched and measures defined. In addition, developments are being monitored intensively in order to counteract possible undesirable developments.

Both the German planning system, which is organized on several levels, and the existing strategies of the federal government support efforts to achieve climate neutrality. Numerous fundamental principles and specific objectives of spatial planning are suitable for supporting the reduction of GHG emissions. Citizens can also influence planning processes, particularly at local and municipal levels, through participation processes.

A look at emissions statistics shows that, after an initially modest decline, we can now speak of a significant reduction. Nevertheless, Germany faces a long road ahead on its journey to become a carbon-neutral country.

2.4 Key measures to reduce CF

In addition to the review of the scholarly literature on the elements of CF reduction and case studies on CF reduction policies in Korea and Germany, we analyzed UN's 170 Actions to Combat Climate Change and Jain (2023) to identify additional relevant measures. Both the UN and Jain (2023) emphasize the need for integrated urban planning that crosses traditional sectoral boundaries. The framework of the UN's 170 actions to combat climate change provides a practical guide to 170 climate action plans that individuals, communities, and organizations can take in response to climate change, aligned with the UN Sustainable Development Goals (SDGs).

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71) City of Dresden, "Current Citizen Participation", accessed on October 15, 2024.
72) City of Dresden, "Public Participation – Current Open Positions", accessed on October 15, 2024.

These actions are organized around 17 SDGs, each addressing aspects such as sustainability, social equity, and environmental conservation. Among these goals, SDG 11 presents climate change response actions for sustainable cities and communities, as shown in Table 6.

Table 6 **Actions for sustainable cities and communities to combat climate change**

Number	Action
101	Advocate for more and safer bike lanes.
102	Lobby for more green spaces in your area, such as parks and forests.
103	Include underprivileged households in the decision-making process of the city's green policies.
104	Turn off all your lights when you are no longer using them.
105	Support the elimination of single-use plastics in your community.
106	Generate awareness about your city's environmental footprint.
107	Take public transport and leave your car at home as much as you can.
108	Sponsor and participate in the building of an urban community garden.
109	Organize or participate in a flea market and give old things a new life.

Source United Nations Geneva (2020), p. 14.

Actions suggested to combat climate change, such as expanding bike lanes, securing green space, turning off unnecessary lights, raising awareness of the environmental footprint of urban areas, using public transportation and refraining from using private cars, creating urban community gardens, and hosting flea markets, are also closely related to reducing CFs. In Jain (2023), the importance of integrated urban systems and cross-sectoral collaboration is emphasized through an advocacy for systems thinking, where urban infrastructure, transportation, energy, water, and housing systems must function in harmony to reduce emissions and enhance climate resilience. The study presents detailed, consolidated strategies for sustainable urban development across several categories, including water resources, green spaces, public services, housing, infrastructure, and energy. These strategies are outlined in Table 7.

Table 7 **Consolidated sustainable urban development strategies**

Category	Details
Water resources	Resource protection, efficiency improvement, and recycling Water quality improvement Water supply standardization Water resource conservation and optimal utilization Flood management strategies Rain garden and eco-friendly water retention Wastewater reuse Sustainable water management

Table 7 **(continued)**

Category	Details
Green spaces	Eco-friendly landscape design Strengthening plant resilience Pollution and heat control through greenery Green-blue connectivity with greenery Urban agriculture and garden spaces Cultural space preservation
Services	Sustainable Urban Drainage Systems (SUDS) Biological drainage for zero discharge 5Rs waste management (Refuse, Reuse, Reduce, Recycle, Recover) Food waste treatment options Construction and demolition waste resource recovery Smart solutions
Housing	Improvement of slum and informal housing areas Promotion of rental housing Self-help and community-led housing Land use for self-reliant communities Affordable and cost-effective housing Compact and dense housing Eco-friendly buildings and natural housing Cost-optimized housing Sustainable residential diversification
Infrastructure	Optimization of density and mixed land use Connectivity, walkability, and mobility Accessibility for all Traffic calming Pollution-free industry and regenerative power Biomass fuel phase-out Dust control Green buildings
Circulation systems	Urban ecological buffer zones Restoration, redevelopment, and regeneration Land use recycling, rezoning, and adaptive reuse Remote sensing and digital planning Land pooling and management LADM framework and participatory planning
Transportation	Public transport options Transit-Oriented Development (TOD) Diversification of urban road types Urban road design guidelines Improved pedestrian and cyclist services Bicycle roads Traffic calming and noise control Barrier-free and safe access Firefighting system improvement Intelligent Transportation Systems (ITS)

Table 7 (continued)

Category	Details
Energy	Electric vehicles Energy storage Solar cities Renewable energy Energy efficiency enhancement Energy-efficient urban structures Sustainable energy and buildings Passive building design Building facade and envelope optimization for energy savings Smart buildings Heating, ventilation, and air conditioning (HVAC) system improvements Smart microgrid and ecosystem

Source Compiled by the authors based on Jain (2023).

Both documents propose a mix of grassroots actions and high-level policy interventions. On the grassroots side, community involvement in sustainability projects—from waste management to tree planting—is emphasized as a vital strategy for building more resilient and eco-friendly cities. This is reflected in the UN's call for action at the individual and community levels, as well as in Jain (2023), which emphasizes citizen participation in urban planning and environmental management (United Nations Geneva, 2020; Jain, 2023). In terms of policy interventions, Jain (2023) also advocates for stronger national and municipal policies, including building regulations that mandate energy efficiency standards, subsidies for green technologies, and incentives for businesses to adopt sustainable practices. The planning elements and policies discussed in the references above—including Park, C. et al. (2022) and Kim et al. (2024)—are synthesized into Table 8, where we categorize the relevant planning and policy elements from those two papers into the five key CF reduction sectors: food, housing, transportation, waste, and water.

Table 8 Carbon footprint reduction planning and policies by sectors

CF reduction sector/ CO_2 absorption (Increasing biocapacity)	Category	Planning elements and/or policies
Overall	Action/Initiative	Actions to reduce carbon footprints
	Planning/Design	Land-use planning to reduce carbon footprints
	Policy/Program/Project	Policies, programs, and projects to reduce carbon footprints
	Policy/Program/Project	Community-led environmental monitoring programs
	Policy/Program/Project	Smart city technologies: smart grids, using real-time, data-driven urban management

Table 8 (continued)

CF reduction sector/ CO_2 absorption (Increasing biocapacity)	Category	Planning element and policy
Food	Policy/Program/Project	Local food production, support for local farmer's markets and local food cooperatives
	Action/Initiative	Support for urban agriculture initiatives
	Policy/Program/Project	Reducing meat consumption in favor of plant-based diets
Housing	Policy/Program/Project	Energy-efficient retrofits of existing buildings
	Policy/Program/Project	Promoting the use of renewable energy sources in residential areas
	Policy/Program/Project	Energy-efficient appliances and home systems
	Policy/Program/Project	Green roofs and green walls
Transportation	Planning/Design	Expansion of public transportation networks
	Planning/Design	Pedestrian-friendly urban planning rather than giving priority to cars
	Policy/Program/Project	Incentivizing electric vehicles
	Planning/Design	High-density planning
	Planning/Design	Planning to place amenities near residential areas
	Planning/Design	Residential areas with nearby job opportunities to decrease commuting distances and reduce carbon emissions
Waste (goods and services)	Policy/Program/Project	Waste reduction and recycling programs
	Action/Initiative	Reducing single-use plastics
	Policy/Program/Project	Composting programs for organic waste
	Action/Initiative	Support for zero-waste stores and packaging-free shops
Absorption	Planning/Design	More green spaces and parks in urban areas
	Policy/Program/Project	Support for urban reforestation and tree planting programs

Source Compiled by the authors based on United Nations (2020); Park et al. (2022); Jain (2023); and Kim et al. (2024).

We now turn to the development of the questionnaire used in the surveys. To construct the questionnaire, we first utilized our understanding of the material surveyed in this chapter, which includes policy literature, scholarly papers, and the promotional initiatives of international organizations.

Recognizing the limitations of this base of knowledge, as a supplemental effort we employed the ChatGPT Large Language Model (LLM)[73] to generate a set of 10 items. The LLM was instructed to

73) ChatGPT(4o)[large language model] (2024), OpenAI.

frame the questions in a way that allows us to assess public acceptance of decarbonization and energy transition strategies, elements, and measures in urban planning, and specifically in the food, housing, transportation, and waste sectors, all within the broader context of reducing the carbon footprint (CF) of the larger residential sector.

Based on the literature review and the output from the LLM, we drafted 25 statements designed to gauge the degree of acceptance (that is, agreement) on CF reduction urban planning elements and policies. Considering the nature and methodology of the research (i.e., the number of statements, the structure of the P-sample, and the online survey format) we sought input from 20 experts to assess the validity of the draft statements and review their linguistic appropriateness in each of the three languages used (Korean, English, and German).

A second round of review was conducted with additional experts and native German speakers (specialists and members of the general public) to arrive at a final set of 35 statements. We grouped the 35 key CF reduction urban planning elements, each individually reflected in the 35 statements, into three thematic categories: Actions/Initiatives, Planning/Design, and Policies/Programs/Projects.

- The Actions/Initiatives category (A) includes practical steps and actions that individuals, communities, and organizations can take to directly reduce their carbon emissions, such as encouraging public transportation use, promoting energy conservation through public awareness campaigns, and supporting urban environments that are friendly to cycling and walking. Recycling programs, waste reduction initiatives, and the adoption of renewable energy at the household level also fall into this category.
- The Planning/Design category (B) focuses on long-term urban and infrastructure planning and design that contributes to reducing carbon emissions. Creating sustainable cities through energy-efficient buildings, green infrastructure, compact urban layout design, integrated land-use planning, and smart urban design, optimizing energy and resource use, and integrating renewable energy systems into urban landscapes are key elements in this category.
- The Policy/Program/Project category (C) includes regulatory policies for reducing the carbon footprint of governments and institutions, such as carbon emission reduction targets or energy efficiency regulations. It also includes financial and structural support programs or initiatives, such as subsidies for renewable energy facilities, green building certification, and incentives for public transportation.

The statements representing CF reduction plan elements and policies were evenly distributed across the seven sectors.

Each sector was designed to include at least one item from each of the three categories described above. The seven sectors include: (1) overall CF, reflecting the roles of relevant stakeholders; (2-5) the major consumption areas that contribute to the CF of urban residents (food, housing, transportation, waste, and water); (6) absorption, which addresses carbon sinks; and (7) issues, which include cross-cutting challenges related to CF reduction.

The seven sectors consist of the roles of related entities across the carbon footprint (overall CF), major consumption sectors that make up the carbon footprint of urban residents (food, housing, travel, and waste), sinks for absorbing carbon in the atmosphere (absorption), and issues related to reducing the carbon footprint (issue).

Table 9 **Statements with 35 key measures**

Category		Statements
Overall CF	A	1. Individuals should make an effort to reduce their consumption of food, housing, transportation, and goods and services.
	B	2. Urban planning and design are needed to reduce the carbon footprint of city dwellers.
	C	3. The government and local authorities should roll out policies, programs, and initiatives to reduce their carbon footprint.
	C	4. Companies need to take steps to reduce their carbon footprint in their manufacturing processes.
	C	5. I support increased investment and support for research and development of technologies that reduce our carbon footprint.
Food	C	6. I support expanding and revitalizing local farmers markets.
	C	7. The government and local authorities should promote the certification and consumption of low-carbon, eco-friendly, and organic agricultural products.
	A	8. Individuals should make an effort to reduce their consumption of meat and imported/packaged/processed foods.
	C	9. Companies should ramp up efforts to expand plant-based options in restaurants and stores, along with developing meat alternatives.
	B	10. I support plans that reduce transportation distances by producing and consuming food within cities, like urban farming.
Housing	C	11. I support green remodeling efforts that improve the energy efficiency of existing buildings.
	C	12. I support installing renewable energy sources like solar panels and solar thermal systems on buildings and homes.
	A	13. Individuals should make an effort to conserve electricity, gas, and water at home.
	C	14. Require buildings or factories to install green roofs or solar panels.
	B	15. Require new buildings to be designed to be zero energy, meaning they don't rely on outside energy sources.

Table 9 (continued)

Category		Statements
Travel	A	16. Individuals should make an effort to use public transportation, such as buses, trains, or bikes, instead of driving their own cars.
	B	17. I support expanding bike lanes and pedestrian walkways.
	C	18. I support limiting the use of high carbon-emission vehicles.
	B	19. I support plans and designs that increase the proportion of residential areas and population density within cities to reduce urban sprawl through mixed-use development.
	C	20. I support expanding the infrastructure for electric vehicle charging and dedicated parking spaces.
Waste	A	21. We all need to do our part to reduce food and general waste and increase recycling and reuse.
	C	22. The government and local authorities should implement policies to reduce single-use items in places like stores and hotels.
	C	23. I support policies that discourage single-use products and mandate reusable containers.
	A	24. Companies need to cut back on product packaging and create reusable containers.
	B	25. I support the plan to build a biogas facility with organic waste such as food waste, livestock manure, and sewage sludge.
Absorption	B	26. I support increasing the amount of green space and parks in urban areas.
	A	27. Companies should get involved in programs and initiatives that expand carbon sinks, such as creating parks and planting trees.
	C	28. I support expanding the greenbelt designation, which limits development on existing green spaces.
	C	29. The government should invest more in research and development to boost the carbon-absorbing capacity of our forests and green spaces.
	B	30. We need an ecological restoration plan that includes green spaces and biotopes that take biodiversity into account.
Issues	B	31. Citizen engagement should be fully integrated into city planning, policies, programs, and procedures that aim to reduce carbon footprint.
	C	32. I support putting small modular reactors (SMRs) in cities that need a lot of electricity.
	C	33. I support phasing out coal-fired power plants, even if it means paying more for electricity.
	A	34. The government and local authorities should expand their social media campaigns to reduce their carbon footprint.
	C	35. I support raising electric rates to encourage the energy transition and to reduce our carbon footprint.

Note A - Action/Initiative, B - Plan/Design, C – Policy/Program/Project.
Source The authors.

Chapter 3

Measuring Perception Types and Acceptability on Key Measures to Reduce CF

3.1 Multilingual translation using LangChain

LangChain, an open source framework for building applications based on large language models (LLM), was used to conduct cross-language validation of policy-related survey questions, ensuring consistent understanding of carbon footprint (CF) reduction policies between among the South Korean and German participants.

This section explores the use of multilingual translation tools for cross-cultural research, focusing on the acceptability of carbon footprint (CF) reduction policies. This study's novel integration of LLMs into LangChain for the purpose of translation ensured linguistic consistency and cultural appropriateness of the 35 survey statements described in Chapter 2 across all three languages (English, Korean, and German).

Cross-cultural research often faces challenges due to linguistic differences. Traditional back-translation methods, such as Brislin's translation model, require skilled bilingual translators, making the process time-consuming and costly. This study addresses these challenges using LLMs, including ChatGPT3.5, ChatGPT4o, Google-Gemini, and Anthrophic-Claud3 integrated through LangChain. The Python-based program with a Streamlit[74] interface demonstrates that LLM-assisted back-translation can effectively support cross-cultural environmental policy research, particularly in

74) Streamlit(Windows)[Computer application] (2019), Snowflake.

CF reduction planning. Figures 4 and 5 show screenshots of the user interface.

Figure 4 English-German forward-backward translation interface

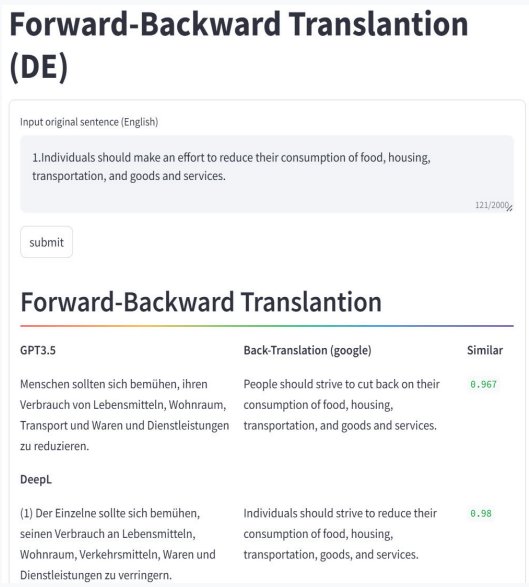
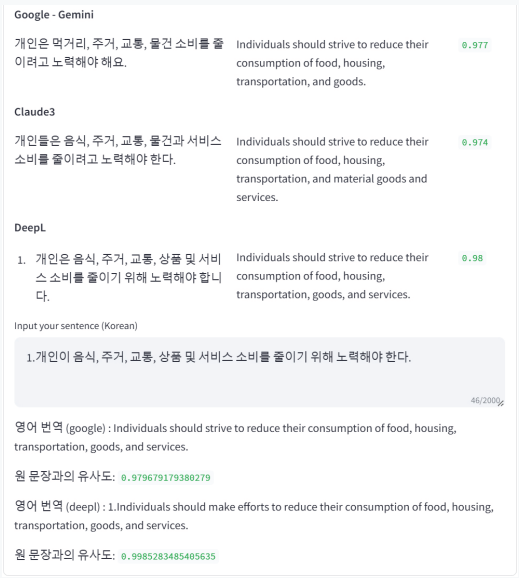


Figure 5 Korean-English forward-backward translation interface



Source The authors.

We also took steps to verify the reliability of the translated CF reduction policy statements in English, Korean, and German. Using the UN's 170 Climate Change Actions as a reference,[75] 40 participants from Korea and Germany, including both experts and laypeople, evaluated the translations.

We found that the LLM-based approach high levels of linguistic and conceptual accuracy, with cosine similarity scores between 0.93 and 1.00. Cosine similarity is the angle between vectors divided by their cosine. For example, two proportional vectors in this case, two sentences that have the same meaning should have a cosine similarity of 1, while two opposite vectors have a similarity of -1. We reviewed the translations, back-translations, and the cosine similarity results to select the most appropriate translated text. After a proofreading process, we obtained the final translated text.

In addition to the English-Korean translation program we built on the LangChain platform, we also developed an English-German translation program to conduct a comparative study of well-established research tools in Korea and Germany.

To verify the accuracy of the back-translation program, an expert review was conducted to ensure that the translation preserved the meaning of the statements with minimal discrepancies. The final

75) United Nations Geneva (2020).

translation results were then evaluated by native speakers of German and Korean, including both experts and laypeople, who assessed the linguistic and conceptual accuracy of the translated sentences.

The use of LangChain in this study enabled seamless integration of multiple LLM Application Programming Interfaces (APIs), streamlining the translation process and ensuring that this study on policy acceptability was not compromised by linguistic barriers. The high similarity scores highlight the effectiveness of LLMs in maintaining the integrity of complex environmental policy content.

3.2 Measuring perception types: Q methodology

For this study, we also analyzed the perceptions of local community members in Germany and Korea on CF reduction elements and policies in urban planning using Q methodology. Unlike expert-driven decision-making techniques such as Analytic Hierarchy Process (AHP), the Q methodology is a mixed qualitative-quantitative methodology that allows for the systematic exploration of subjective views and judgment criteria among the general population, and is useful for discovering the determinants of acceptability and differences in perceptions. By identifying the subjective judgment criteria of respondents who show differences in acceptability across mitigation factors and sectors, it is possible to pinpoint key public perceptions that should be considered in the policy formulation process. In this study, we used the PQmethod program to classify distinct perception types, which were then interpreted to draw policy implications for each group. The analysis provides a basis for the effective implementation of CF reduction policies.

3.2.1 Introducing the Q methodology

There are two main methods: quantitative research based on questionnaires utilizing Likert scales, and qualitative research. The Q methodology (or Q method) is a qualitative research method. Quantitative research is useful for identifying universal perceptions and perceptions of individual categories, but it has limitations when it comes to in-depth analysis and comprehensive understanding of a specific topic. The Q methodology, on the other hand, is not used to generalize, but rather to develop new typologies based on commonalities and differences in perceptions among research subjects, and to identify the implications of these relationships.

The Q methodology is a widely recognized scientific approach to exploring human subjectivity (Brown, 1980; Watts and Stenner, 2012; McKeown and Thomas, 2013). It is often classified as a mixed method, as it draws on the strengths of both qualitative and quantitative research. Originally developed in the 1930s, the Q methodology continues to be used across a range of academic

disciplines (Watts and Stenner, 2012; Ramlo, 2016, pp. 28-45).

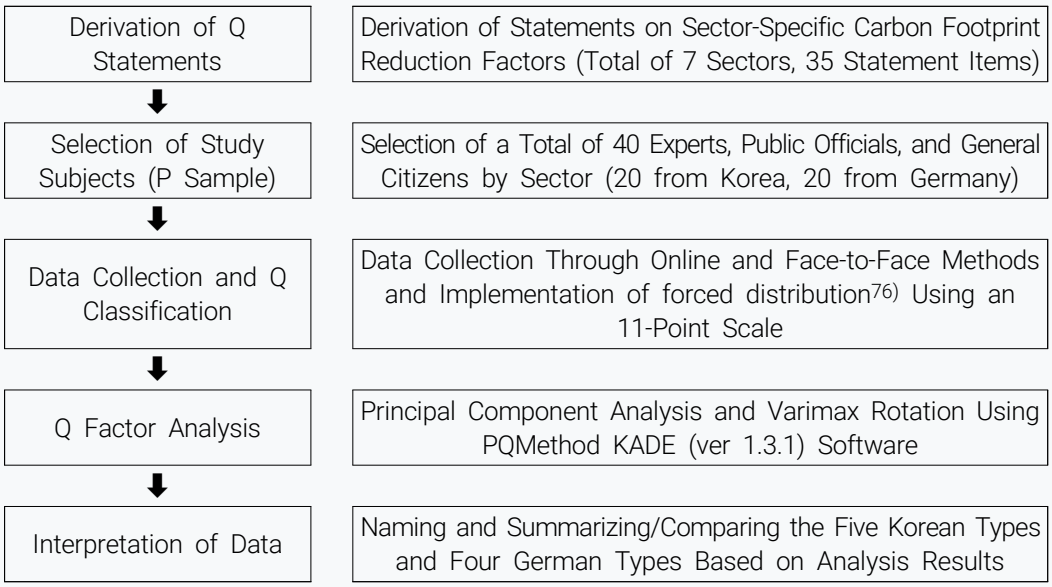
Unlike traditional quantitative research, which is typically hypothesis-driven and deductive, Qualitative research employing the Q methodology is hypothesis-generative. It seeks to uncover new insights by examining the subjective viewpoints of a relatively small number of participants, and uses this understanding as a basis for formulating new hypotheses (Brown, 1993, pp. 91-138). Watts and Stenner (2012) describe it as a powerful tool for revealing the underlying structure of individual subjectivity, offering insights that often remain hidden in conventional quantitative approaches (Durning, 1999, pp. 389-410).

A analysis using the Q method begins with the construction of Q-statements related to the research topic. These statements are often derived from participant interviews, but can also be drawn from the theoretical literature other sources relevant to the research topic (Brown, 1996, pp. 561-567). Participants are asked to sort and rank statements according to a predefined grid pattern. If they feel that they agree with a particular statement, they are asked to place it closer to the right side of the grid (positive), and if they disagree, they are asked to place it on the left side of the grid (negative). This process quantifies subjective views and allows us to derive viewpoint typologies (Kim et al, 2016, pp. 1-190).

The resulting grid of participants' statements can be analyzed through specialized software, such as the PQ Method software suite, designed specifically for Q analysis. It is popular because it is relatively easy to input data and can maximize the explanatory variables by enabling both main factor analysis and centroid analysis. The KADE frontend (for this study, version 1.3.1) can be used as a graphical interface for Q analysis (Banasick, 2019, p. 1360).

We used the Q methodology to identify and group types of perceptions of CF reduction policies in Korea and Germany, focusing on the acceptability of these policies. We adopted a five-stage approach to the analysis based on Watts and Stenner (2012): deriving the Q statements, selecting the sample, collecting data and conducting Q sorting, performing Q factor analysis, and interpreting the results. We also took steps to enhance the validity and reliability of the analysis. See Figure 6 below.

Figure 6 **Steps in the Q methodology process**



Source The authors.

3.2.2 Application of Q methodology

(1) Derivation of policy acceptability evaluation items (Q statements)

The Q statements serve as stimulus items designed to reveal the subjectivity of research participants. These statements were selected through a process involving a review of existing literature, the classification of statements into subcategories, and streamlining of redundant statements (Kim, 2016, pp. 225-243). Based on key categories, the evaluation criteria were divided into seven sectors: overall CF policy, food, housing, travel, waste, sink, and miscellaneous issues. Each sector included five statements, resulting in a total of 35 evaluation items.

First, the Overall category establishes the overarching framework and fundamental direction of CF reduction policies, including aspects related to individuals, governments, and urban planning, ensuring applicability across all sectors. Second, the Food category addresses the CF associated with the production, distribution, and consumption of food. Third, the Housing sector encompasses energy efficiency in buildings and the types of energy used in residential spaces. Fourth, the Travel category focuses on carbon emissions from various modes of transport, including automobiles, aviation, rail, and public transportation. Fifth, the Waste category considers methane and carbon dioxide (CO_2)

76) Forced distribution: It is a procedure that simply takes the cards entered in the form of statements, divides them into three groups into consent (+), neutral (0), and disagree (-), and classifies them into a nine-point scale by looking at the classified cards again (Kim Soon-Eun, 2007, p. 51).

emissions produced during waste management and disposal processes. Sixth, the Sinks sector refers to natural resources such as forests and wetlands that play a role in absorbing carbon emissions. Finally, the Issues category extends beyond individual sectors to address broader issues such as carbon tax implementation and industrial transitions, covering policy and social aspects of carbon reduction efforts.

Following consultations with experts and internal debate, we streamlined or removed redundant items, resulting in a final selection of 35 Q statements, presented below in Table 10. We used the application built using LangChain to translate the 35 statements shown in Table 10 into into German. See Table 11.

Table 10 Q statements (N=35)

Category	Statements
Overall	1. Individuals should make an effort to reduce their consumption of food, housing, transportation, and goods and services.
	2. Urban planning and design is needed to reduce the carbon footprint of city dwellers.
	3. The government and local authorities should roll out policies, programs, and initiatives to reduce their carbon footprint.
	4. Companies need to take steps to reduce their carbon footprint in their manufacturing processes.
	5. I support increased investment and support for research and development of technologies that reduce our carbon footprint.
Food	6. I support expanding and revitalizing local farmers markets.
	7. The government and local authorities should promote the certification and consumption of low-carbon, eco-friendly, and organic agricultural products.
	8. Individuals should make an effort to reduce their consumption of meat and imported/packaged/processed foods.
	9. Companies should ramp up efforts to expand plant-based options in restaurants and stores, along with developing meat alternatives.
	10. I support plans that reduce transportation distances by producing and consuming food within cities, like urban farming.
Housing	11. I support green remodeling efforts that improve the energy efficiency of existing buildings.
	12. I support installing renewable energy sources like solar panels and solar thermal systems on buildings and homes.
	13. Individuals should make an effort to conserve electricity, gas, and water at home.
	14. Require buildings or factories to install green roofs or solar panels.
	15. Require new buildings to be designed as zero-energy buildings, meaning they do not rely on external energy sources.

Table 10 (continued)

Category	Statements
Travel	16. Individuals should make an effort to use public transportation, such as buses, trains, or bikes, instead of driving their own cars.
	17. I support expanding bike lanes and pedestrian walkways.
	18. I support limiting the use of high carbon-emission vehicles.
	19. I support plans and designs that increase the proportion of residential areas and population density within cities to reduce urban sprawl through mixed-use development.
	20. I support expanding the infrastructure for electric vehicle charging and dedicated parking spaces.
Waste	21. We all need to do our part to reduce food and general waste and increase recycling and reuse.
	22. The government and local authorities should implement policies to reduce single-use items in places like stores and hotels.
	23. I support policies that discourage single-use products and mandate reusable containers.
	24. Companies need to cut back on product packaging and create reusable containers.
	25. I support the plan to build a biogas facility with organic waste such as food waste, livestock manure, and sewage sludge.
Sinks	26. I support increasing the amount of green space and parks in urban areas.
	27. Companies should get involved in programs and initiatives that expand carbon sinks, such as creating parks and planting trees.
	28. I support expanding the greenbelt designation, which limits development on existing green spaces.
	29. The government should invest more in research and development to boost the carbon-absorbing capacity of our forests and green spaces.
	30. We need an ecological restoration plan that includes green spaces and biotopes that take biodiversity into account.
Issues	31. Citizen engagement should be fully integrated into city planning, policies, programs, and procedures that aim to reduce carbon footprint.
	32. I support putting small modular reactors (SMRs) in cities that need a lot of electricity.
	33. I support phasing out coal-fired power plants, even if it means paying more for electricity.
	34. The government and local authorities should expand their social media campaigns to reduce their carbon footprint.
	35. I support raising electric rates to encourage the energy transition and to reduce our carbon footprint.

Source The authors.

Table 11 **Q statements German version (N=35)**

Category	Statements
Kohlenstoff-Fußabdruck	1. Jede/r Einzelne sollte darauf hinwirken, den Verbrauch an Lebensmitteln, Wohnraum, Verkehrsmitteln, Waren und Dienstleistungen zu verringern.
	2. Stadtplanung und -gestaltung sind notwendig, um den CO_2-Fußabdruck von Stadtbewohnern zu reduzieren.
	3. Die Regierung und lokale Behörden sollten Richtlinien, Programme und Initiativen auf den Weg bringen, um ihren CO_2-Fußabdruck zu reduzieren.
	4. Unternehmen sollten Maßnahmen ergreifen, um den CO_2-Fußabdruck ihrer Produktionsprozesse zu verringern.
	5. Ich befürworte verstärkte Investitionen und die Förderung von Forschung und technologischer Entwicklung, die unseren CO_2-Fußabdruck verringern.
Ernährung	6. Ich befürworte eine Einrichtung und verstärkte Nutzung lokaler Bauernmärkte.
	7. Die Regierung und lokale Behörden sollten die Zertifizierung und den Konsum von Produkten aus CO_2-emissionsarmer, umweltfreundlicher ökologischer Landwirtschaft fördern.
	8. Jede/r Einzelne sollte sich bemühen, den Konsum von Fleisch sowie von importierten, verpackten und verarbeiteten Lebensmitteln zu reduzieren.
	9. Unternehmen sollten ihre Bemühungen verstärken, das vegetarische Angebot in Restaurants und Geschäften auszubauen und Fleischalternativen zu entwickeln.
	10. Ich befürworte Initiativen, welchen die Transportwege durch die Erzeugung und den Verbrauch von Lebensmitteln innerhalb städtischer Zentren verkürzen, wie etwa die städtische Landwirtschaft.
Wohnen	11. Ich befürworten ökologische Sanierungsmaßnahmen, welche die Energieeffizienz bestehender Gebäude verbessern.
	12. Ich befürworte die Installation erneuerbarer Energiequellen wie Solaranlagen (Fotovoltaik) und solarthermische Anlagen auf Gebäuden und Wohnhäusern.
	13. Jede/r Einzelne sollte sich bemühen, zu Hause den Verbrauch von Strom, Gas und Wasser zu reduzieren.
	14. Es sollte eine Verpflichtung für Gebäude und Fabriken eingeführt werden, Dächer zu begrünen oder Solaranlagen zu installieren.
	15. Neue Gebäude sollten so entworfen werden, dass sie einen Energieverbrauch von null aufweisen (Nullenergiehaus) und somit nicht auf externe Energiequellen angewiesen sind.
Verkehr	16. Jede/r Einzelne sollte sich bemühen, öffentliche Verkehrsmittel wie Busse oder Züge und Fahrräder anstelle von privaten Kraftfahrzeugen zu nutzen.
	17. Ich befürworte den Ausbau von Fahrrad- und Fußwegen.
	18. Ich befürworte die Einschränkung der Nutzung von Fahrzeugen mit hohem Kohlenstoffausstoß.
	19. Ich befürworte Pläne und Entwürfe, die den Anteil von Wohngebieten und die Bevölkerungsdichte innerhalb von Städten erhöhen und die Zersiedelung durch gemischte Bebauung reduzieren.
	20. Ich befürworte den Ausbau der Ladeinfrastruktur für Elektrofahrzeuge und die Einrichtung entsprechender Parkplätze.

Table 11 **(continued)**

Category	Statements
Abfall	21. Wir sollten alle unseren Teil dazu beitragen, Lebensmittel- und allgemeine Abfälle zu reduzieren, mehr zu recyceln und Dinge so oft es geht wiederzuverwenden.
	22. Die Regierung und lokale Behörden sollten Maßnahmen ergreifen, um die Verwendung von Einwegprodukten in Geschäften und Hotels zu reduzieren.
	23. Ich befürworte Maßnahmen, welche den Einsatz von Einwegprodukten einschränken und die Nutzung wiederverwendbarer Verpackungen vorschreiben.
	24. Unternehmen sollten Maßnahmen ergreifen, um die Verpackung von Produkten zu reduzieren und wiederverwendbare Verpackungen bereitzustellen.
	25. Ich befürworte Pläne zum Bau von Biogasanlagen für organische Abfälle, wie Lebensmittelabfälle, Viehdung und Klärschlamm.
Kohlenstoff aufnahme	26. Ich befürworte eine Ausweitung von Grünflächen und Parks in städtischen Gebieten.
	27. Unternehmen sollten sich an Programmen und Initiativen zur Erweiterung von Kohlenstoffsenken beteiligen, beispielsweise durch das Anlegen von Parks oder das Pflanzen von Bäumen.
	28. Ich befürworte eine Ausweitung der Grünflächenausweisung, die eine Bebauung bestehender Grünflächen ausschließt.
	29. Die Regierung sollte mehr in Forschung und Entwicklung investieren, um die Kohlenstoffaufnahmefähigkeit unserer Wälder und Grünflächen zu erhöhen.
	30. Es sollten ökologische Wiederherstellungspläne entwickelt werden, die Grünflächen und Biotope unter Berücksichtigung der biologischen Vielfalt mit einbeziehen.
Themen	31. Die Beteiligung der Bürger sollte vollständig in städtische Planung, Politik, Programme und Verfahren integriert werden, wenn es darum geht, den CO_2 -Fußabdruck zu reduzieren.
	32. Ich befürworte die Installation kleiner modularer Atomreaktoren (SMRs) [MN1] in Städten mit hohem Strombedarf.
	33. Ich befürworte den Ausstieg aus der Kohlekraft, auch wenn dies eine Erhöhung der Stromkosten zur Folge hat.
	34. Die Regierung und die lokalen Behörden sollten ihre Kampagnen zur Verringerung des CO_2-Fußabdrucks in den sozialen Medien ausweiten.
	35. Ich befürworte eine Erhöhung der Strompreise, um den Übergang zu Energiewende zu fördern und unseren CO_2-Fußabdruck zu verringern.

Source The authors.

(2) Selection of study subjects (P-set)

In the Q methodology, the P-set refers to the research subjects. However, in actual analysis, it functions similarly to a variable, making the size of the P-set relatively less significant compared to quantitative research (Brown, 1980; Watts and Stenner, 2012; Kim and Lee, 2023, pp. 207-243). The Q methodology aims to identify and understand new perspectives among research subjects, with the

minimum size of the P-set being just two (Kline, 2014). Rather than focus on the quantity of P samples, it is more important to secure an information-saturated group with with rich and different views and/or relevant characteristics (e.g., a certain type of academic degree, major, or occupation) that might be relevant to the study. In most cases,size of the P-set will be smaller than the Q-set, in this case, the 35 statements.

Table 12 **Details of Korean survey participants in Q methodology**

Number	Country (Nationality)	Gender	Age	Occupation	Field	Years of experience in the field
1	Korea	Male	40s	Researcher	Ecology	Less than 10 years
2		Male	40s	Office worker	Water resources	10 years or more
3		Male	40s	Public official	Environment	10 years or more
4		Male	40s	Civic organization	Ecology	10 years or more
5		Female	40s	Public official	Agriculture	10 years or more
6		Female	50s	Civic organization	Environment	10 years or more
7		Male	30s	Public official	Environment	10 years or more
8		Male	40s	Public official	Industries	10 years or more
9		Male	40s	Public official	Land	10 years or more
10		Female	40s	Office worker	Environment	10 years or more
11		Male	60 or older	Professor	Nuclear	10 years or more
12		Male	30s	Researcher	Urban engineering	10 years or more
13		Female	20s	Researcher	Disaster safety	Less than 1 year
14		Female	20s	Student	Medical	Less than 1 year
15		Female	60 or older	Homemaker	-	Less than 1 year
16		Male	40s	Civic organization	Environment	10 years or more
17		Male	40s	Public official	Environment	10 years or more
18		Male	20s	Researcher	Urban engineering	Less than 10 years
19		Female	20s	Researcher	Urban engineering	Less than 1 year
20		Female	20s	Researcher	Urban engineering	Less than 1 year

Source The authors.

In this study, the P-set was divided between Korea and Germany. The Korean P-set included experts and public officials familiar with CF reduction policy, as well as members of civic organizations and the general public, totaling 20 individuals (12 men, 8 women). Respondents included homemakers, researchers, office workers, and other professionals (professors and public officials). By age group, there were 5 participants under 20 (1 man, 4 women), 2 in their 30s (2 men), 10 in their 40s (8 men, 2 women), 1 in her 50s (1 woman), and 2 aged 60 or older (1 man, 1 woman).

Table 13 **Details of German survey participants in Q methodology**

Number	Country (Nationality)	Gender	Age	Occupation	Field	Years of experience in the field	Years in Germany
1	Germany (Israel)	Male	40s	Civic organization	Energy	Less than 10 years	Less than 10 years
2	Germany (United States)	Female	20s	Civic organization	Energy	Less than 10 years	Less than 10 years
3	Germany (Myanmar)	Female	30s	Researcher	Environment	Less than 10 years	Less than 10 years
4	Germany	Male	40s	Public official	Climate protection (building/urban planning)	10 years or more	10 years or more
5		Male	50s	Office worker	Management	10 years or more	10 years or more
6		Male	30s	Office worker	Management	Less than 10 years	10 years or more
7		Male	40s	Researcher		10 years or more	10 years or more
8		Female	40s	Researcher	Administration	Less than 10 years	10 years or more
9		Male	50s	Researcher		10 years or more	10 years or more
10		Male	50s	Professor		10 years or more	10 years or more
11		Female	40s	Office worker	Landscape Architecture	10 years or more	10 years or more
12		Male	40s	Office worker	Landscape Architecture	10 years or more	10 years or more
13		Female	50s	Public official		10 years or more	10 years or more
14		Male	20s	Student		Less than 1 year	10 years or more

Table 13 (continued)

Number	Country (Nationality)	Gender	Age	Occupation	Field	Years of experience in the field	Years in Germany
15	Germany (Korea)	Male	40s	Researcher		10 years or more	10 years or more
16		Male	40s	Researcher	Climate Energy	10 years or more	Less than 10 years
17		Male	40s	Public official	Climate protection (building/urban planning)	10 years or more	10 years or more
18		Male	40s	Researcher	Land and Environmental Planning	Less than 10 years	10 years or more
19		Male	40s	Researcher	Land	Less than 10 years	Less than 10 years
20		Female	30s	Researcher		Less than 10 years	10 years or more

Source The authors.

The German P-set included individuals of various nationalities, such as Israel, the United States, Myanmar, and South Korea. Koreans who had lived in Germany for less than one year were classified under Korea, while Koreans who had lived in Germany for more than one year were classified under the German perception type. Likewise, foreigners who had lived in Germany for more than one year were also categorized under Germany.

A total of 20 participants (14 men, 6 women) were were selected for the German P-set. They included experts and public officials in the field of carbon reduction policy, as well as members of civic organizations and the general public. Respondents included researchers, office workers, and other professionals (professors and public officials). By age, 2 participants were in their 20s or younger (1 man, 1 woman), 3 were in their 30s (1 man, 2 women), 11 were in their 40s (9 men, 2 women), 4 were in their 50s (3 men, 1 woman), and there were no participants aged 60 or older. Regarding the number of years residing in Germany, five participants had lived there for less than 10 years, while 15 had lived there for 10 years or more.

(3) Data collection and Q sorting

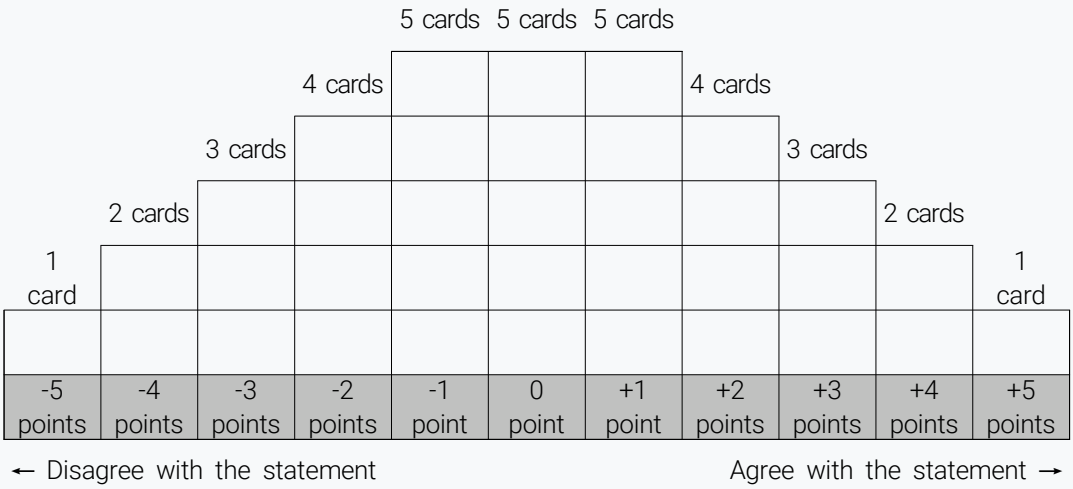
The selected P sample respondents were required to arrange and rank the 35 statements according to a predefined grid pattern, classifying agreement on an 11-point scale. The forced distribution method involves sorting the statement cards into three broad categories: agreement (+), neutral (0),

and disagreement (-). After this initial classification, participants reevaluate the sorted cards and further distribute them on an 11-point scale (Kim Soon-Eun, 2010, pp. 1-25).

For example, if respondents strongly agree with a particular Q statement, they place it on the right side of the grid (+5 points, positive direction). Conversely, if they strongly disagree, they position it on the left side of the grid (-5 points, negative direction). The number of statements assigned to each score varies, following a forced allocation that results in a normal distribution.

This method allows for a visual and quantitative representation of participants' subjectivity. The data extracted from the Q sorting process was analyzed using the PQ Method and the KADE (ver. 1.3.1) software package.

Figure 7 **Q sheet**

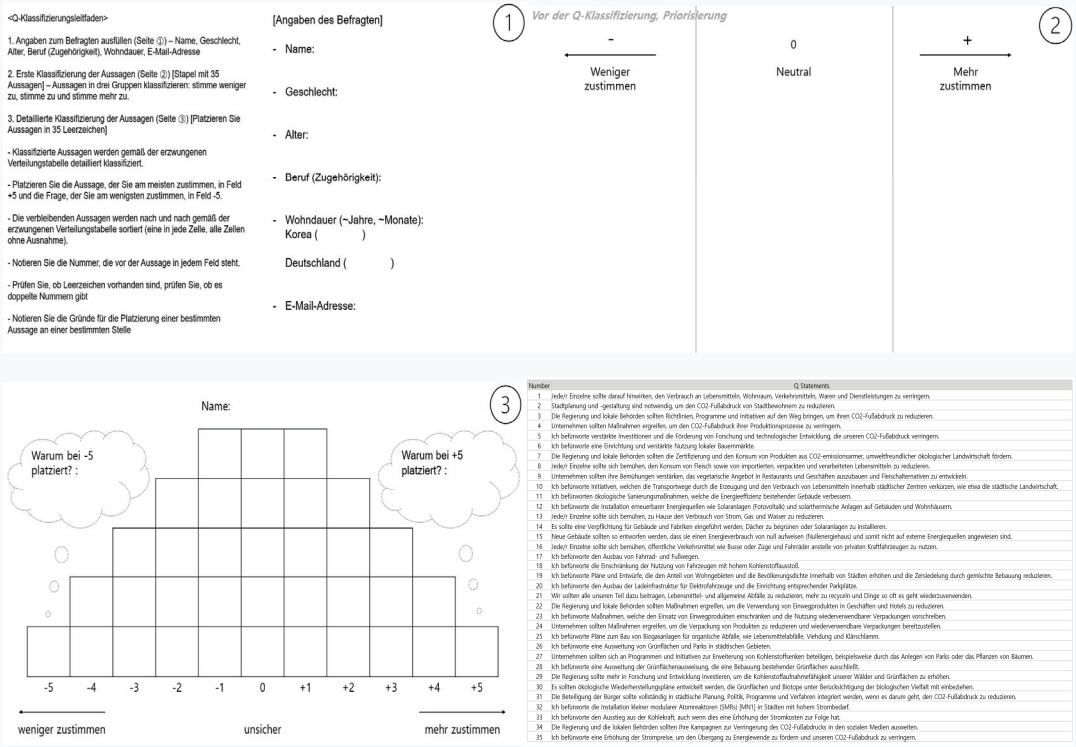


Source The authors.

Data collection was conducted through face-to-face interviews and online surveys. The face-to-face interviews were carried out during a visit to Dresden, Germany, as well as with residents in Sejong City and Seoul, Korea. The online survey was conducted using the Q-Sort[77] platform.

77) Q-Sortware, "Q-Methodology and Q-Sort Techniques for Online Data Collection", accessed on January 21, 2025.

Figure 8 Q sorting data



<Q-Klassifizierungsleitfaden>

1. Angaben zum Befragten ausfüllen (Seite ①) – Name, Geschlecht, Alter, Beruf (Zugehörigkeit), Wohndauer, E-Mail-Adresse

2. Erste Klassifizierung der Aussagen (Seite ②) [Stapel mit 35 Aussagen] – Aussagen in drei Gruppen klassifizieren: stimme weniger zu, stimme zu und stimme mehr zu.

3. Detaillierte Klassifizierung der Aussagen (Seite ③) [Platzieren Sie Aussagen in 35 Leerzeichen]

- Klassifizierte Aussagen werden gemäß der erzwungenen Verteilungstabelle detailliert klassifiziert.

- Platzieren Sie die Aussage, der Sie am meisten zustimmen, in Feld +5 und die Frage, der Sie am wenigsten zustimmen, in Feld -5.

- Die verbleibenden Aussagen werden nach und nach gemäß der erzwungenen Verteilungstabelle sortiert (eine in jede Zeile, alle Zellen ohne Ausnahme).

- Notieren Sie die Nummer, die vor der Aussage in jedem Feld steht.

- Prüfen Sie, ob Leerzeichen vorhanden sind, prüfen Sie, ob es doppelte Nummern gibt

- Notieren Sie die Gründe für die Platzierung einer bestimmten Aussage an einer bestimmten Stelle

[Angaben des Befragten]

- Name:
- Geschlecht:
- Alter:
- Beruf (Zugehörigkeit):
- Wohndauer (~Jahre, ~Monate):
  Korea ( )
  Deutschland ( )
- E-Mail-Adresse:

① Vor der Q-Klassifizierung, Priorisierung

-	0	+
Weniger zustimmen	Neutral	Mehr zustimmen

②

③

Name:

Warum bei -5 platziert? :

Warum bei +5 platziert? :

-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5

weniger zustimmen — unsicher — mehr zustimmen

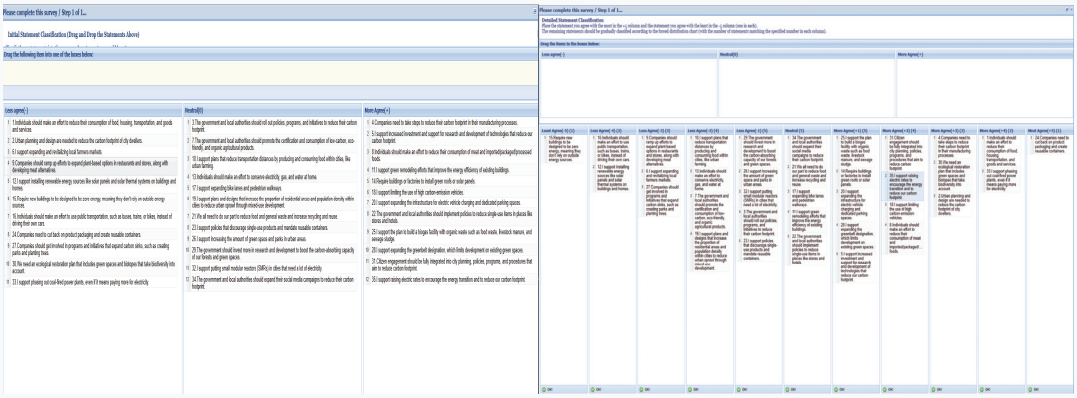
Number	Q Statements
1	Jede/r Einzelne sollte darauf hinwirken, den Verbrauch an Lebensmitteln, Wohnraum, Verkehrsmitteln, Waren und Dienstleistungen zu verringern.
2	Stadtplanung und -gestaltung sind notwendig, um den CO2-Fußabdruck von Stadtbewohnern zu reduzieren.
3	Die Regierung und lokale Behörden sollten Richtlinien, Programme und Initiativen auf den Weg bringen, um ihren CO2-Fußabdruck zu reduzieren.
4	Unternehmen sollten Maßnahmen ergreifen, um den CO2-Fußabdruck ihrer Produktionsprozesse zu verringern.
5	Ich befürworte verstärkte Investitionen und die Förderung von Forschung und technologischer Entwicklung, die unseren CO2-Fußabdruck verringern.
6	Ich befürworte eine Einrichtung und verstärkte Nutzung lokaler Bauernmärkte.
7	Die Regierung und lokale Behörden sollten die Zertifizierung und den Konsum von Produkten aus CO2-emissionsarmer, umweltfreundlicher ökologischer Landwirtschaft fördern.
8	Jede/r Einzelne sollte sich bemühen, den Konsum von Fleisch sowie von importierten, verpackten und verarbeiteten Lebensmitteln zu reduzieren.
9	Unternehmen sollten ihre Bemühungen verstärken, das vegetarische Angebot in Restaurants und Geschäften auszubauen und Fleischalternativen zu entwickeln.
10	Ich befürworte Initiativen, welchen die Transportwege durch die Erzeugung und den Verbrauch von Lebensmitteln innerhalb städtischer Zentren verkürzen, wie etwa die städtische Landwirtschaft.
11	Ich befürworten ökologische Sanierungsmaßnahmen, welche die Energieeffizienz bestehender Gebäude verbessern.
12	Ich befürworte die Installation erneuerbarer Energiequellen wie Solaranlagen (Fotovoltaik) und solarthermische Anlagen auf Gebäuden und Wohnhäusern.
13	Jede/r Einzelne sollte sich bemühen, zu Hause den Verbrauch von Strom, Gas und Wasser zu reduzieren.
14	Es sollte eine Verpflichtung für Gebäude und Fabriken eingeführt werden, Dächer zu begrünen oder Solaranlagen zu installieren.
15	Neue Gebäude sollten so entworfen werden, dass sie einen Energieverbrauch von null aufweisen (Nullenergiehaus) und somit nicht auf externe Energiequellen angewiesen sind.
16	Jede/r Einzelne sollte sich bemühen, öffentliche Verkehrsmittel wie Busse oder Züge und Fahrräder anstelle von privaten Kraftfahrzeugen zu nutzen.
17	Ich befürworte den Ausbau von Fahrrad- und Fußwegen.
18	Ich befürworte die Einschränkung der Nutzung von Fahrzeugen mit hohem Kohlenstoffausstoß.
19	Ich befürworte Pläne und Entwürfe, die den Anteil von Wohngebieten und die Bevölkerungsdichte innerhalb von Städten erhöhen und die Zersiedelung durch gemischte Bebauung reduzieren.
20	Ich befürworte den Ausbau der Ladeinfrastruktur für Elektrofahrzeuge und die Einrichtung entsprechender Parkplätze.
21	Wir sollten alle unseren Teil dazu beitragen, Lebensmittel- und allgemeine Abfälle zu reduzieren, mehr zu recyceln und Dinge so oft es geht wiederzuverwenden.
22	Die Regierung und lokale Behörden sollten Maßnahmen ergreifen, um die Verwendung von Einwegprodukten in Geschäften und Hotels zu reduzieren.
23	Ich befürworte Maßnahmen, welche den Einsatz von Einwegprodukten einschränken und die Nutzung wiederverwendbarer Verpackungen vorschreiben.
24	Unternehmen sollten Maßnahmen ergreifen, um die Verpackung von Produkten zu reduzieren und wiederverwendbare Verpackungen bereitzustellen.
25	Ich befürworte Pläne zum Bau von Biogasanlagen für organische Abfälle, wie Lebensmittelabfälle, Viehdung und Klärschlamm.
26	Ich befürworte eine Ausweitung von Grünflächen und Parks in städtischen Gebieten.
27	Unternehmen sollten sich an Programmen und Initiativen zur Erweiterung von Kohlenstoffsenken beteiligen, beispielsweise durch das Anlegen von Parks oder das Pflanzen von Bäumen.
28	Ich befürworte eine Ausweitung der Grünflächenausweisung, die eine Bebauung bestehender Grünflächen ausschließt.
29	Die Regierung sollte mehr in Forschung und Entwicklung investieren, um die Kohlenstoffaufnahmefähigkeit unserer Wälder und Grünflächen zu erhöhen.
30	Es sollten ökologische Wiederherstellungspläne entwickelt werden, die Grünflächen und Biotope unter Berücksichtigung der biologischen Vielfalt mit einbeziehen.
31	Die Beteiligung der Bürger sollte vollständig in städtische Planung, Politik, Programme und Verfahren integriert werden, wenn es darum geht, den CO2-Fußabdruck zu reduzieren.
32	Ich befürworte die Installation kleiner modularer Atomreaktoren (SMRs) (MNT) in Städten mit hohem Strombedarf.
33	Ich befürworte den Ausstieg aus der Kohlekraft, auch wenn dies eine Erhöhung der Stromkosten zur Folge hat.
34	Die Regierung und die lokalen Behörden sollten ihre Kampagnen zur Verringerung des CO2-Fußabdrucks in den sozialen Medien ausweiten.
35	Ich befürworte eine Erhöhung der Strompreise, um den Übergang zu Energiewende zu fördern und unseren CO2-Fußabdruck zu verringern.

Source The authors.

Figure 9 Face-to-face Q sorting

Source The authors.

Figure 10 Example of online Q sorting



Source The authors.

(4) Data interpretation stage

We employed the aforementioned KADE software for factor analysis. There are two methods for extracting factors: the centroid method (QCENT) and Principal Component Analysis (PCA). We employed the more commonly-used Principal Component Analysis (PCA) (Kim et al., 2015) along with Varimax rotation (Kim and Lee, 2023, pp. 207-244).

In this study, the Kaiser-Guttman rule was applied as the criterion for selecting the final number of factors, based on eigenvalues.[78] This rule considers factors with an eigenvalue of 1.00 or higher to be significant, meaning that the factor reflects the subjectivity of at least one member of the P-set in Q methodology (Watts and Stenner, 2012). Since eigenvalues are influenced by the number of variables (participants), it is also necessary to observe the total explained variance (in percentage)[79] of each factor.[80] In addition, to overcome the excessive factor generation issue (Wilson et al., 2008), we applied objective criteria, such as "factors that include at least two significant factor loadings," following Kim and Lee (2023).

3.2.3 Q methodology analysis results: Korea

(1) Selection process of policy acceptability types

For our analysis of the survey results from the Korean side, we employed Principal Component Analysis (PCA), and identified a total of five factors with eigenvalues greater than 1. The threshold for

78) Eigenvalue: The sum of squares of the loading values of the variables.
79) Explained variance: Eigenvalue divided by variable (number of people) as a percentage.
80) Kim (2008), p. 143.

a significant factor loading[81] was set at 0.4361, and factors with at least two loadings above this threshold (absolute value) and an explained variance of 5% or more were considered valid. Consequently, five factors (Factors 1 to 5) were selected. This indicates that the extracted factors have sufficient explanatory power and statistical validity.

Table 14 Unrotated factor matrix (Korea)

P-sample Nm	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8
1	0.6487	-0.1751	-0.2889	0.2592	-0.2826	-0.2887	-0.287	0.2846
2	0.6412	-0.401	-0.2297	0.035	-0.1808	0.2177	-0.2022	0.0669
3	0.4662	-0.4515	-0.027	0.302	-0.2366	-0.2164	0.5067	0.2195
4	0.6373	-0.1448	-0.144	0.25	-0.3958	-0.3958	-0.1208	-0.218
5	0.79	0.0696	-0.2452	-0.2155	0.3953	0.0561	-0.1475	-0.1475
6	0.3375	-0.0079	-0.2267	-0.1023	-0.3281	-0.139	-0.048	-0.048
7	0.3375	0.6255	-0.2267	0.3247	0.0346	-0.0991	-0.336	-0.336
8	0.5138	-0.4779	-0.0096	0.3247	0.3247	0.0346	0.0346	0.0346
9	0.3924	0.0878	0.0878	0.3331	0.0878	0.0878	0.0878	0.0878
10	0.0528	-0.2064	0.2685	0.0245	0.0245	0.0245	0.0245	0.0245
11	0.3396	0.3196	-0.0745	0.0842	0.0842	0.0842	0.0842	0.0842
12	0.3454	0.0744	0.7148	0.1582	0.1582	0.1582	0.1582	0.1582
13	0.5369	0.5126	0.4849	0.1552	0.1552	0.1552	0.1552	0.1552
14	0.3924	-0.1263	-0.1939	-0.2361	-0.2361	-0.2361	-0.2361	-0.2361
15	0.329	-0.1201	-0.2419	0.3137	0.3137	0.3137	0.3137	0.3137
16	0.525	0.0589	0.17	0.2141	0.2141	0.2141	0.2141	0.2141
17	0.3893	0.5747	0.4454	0.3317	0.3317	0.3317	0.3317	0.3317
18	0.5237	0.6555	-0.0952	-0.2131	-0.2131	-0.2131	-0.2131	-0.2131
19	0.3665	0.7327	-0.1207	-0.3317	-0.3317	-0.3317	-0.3317	-0.3317
20	0.7677	-0.3335	0.0264	-0.0276	-0.0276	-0.0276	-0.0276	-0.0276
Eigenvalues	5.6539	2.6714	2.3056	1.9073	1.4711	0.9603	0.8007	0.7486
% exp. var.	28	13	12	10	7	5	4	4
Cumulative % exp. var.	28	41	53	63	70	75	79	83

Note exp.: explained; var: variation.
Source The authors.

81) Factor loading value: 2.58 × $(1/\sqrt{Number\ of\ Q\ samples})$

Table 15 Factors after applying varimax rotation (Korea)

P-sample Nm	F1	F2	F3	F4	F5
11	**0.8633**	0.0582	0.0164	-0.1741	0.1767
18	**0.6567**	0.3615	-0.2496	0.3532	0.1155
8	**0.6552**	-0.095	0.0941	0.483	-0.0054
14	**0.5854**	-0.1542	0.1467	0.3522	0.3846
10	-0.2004	**0.7632**	-0.0371	-0.0901	0.0082
17	0.2752	**0.7413**	0.0244	-0.1631	-0.1483
16	0.1458	**0.6826**	0.2901	0.0863	0.2502
19	-0.2051	**0.6565**	-0.149	0.0971	0.4484
9	-0.04	0.1653	**0.7912**	0.1589	0.048
13	-0.0918	0.0494	**0.7717**	0.4399	0.1386
15	0.2494	-0.2459	**0.6263**	-0.1617	0.2575
7	-0.0225	0.0539	**0.58**	-0.3185	0.4748
1	0.1089	0.1625	-0.0699	**0.7409**	0.3314
12	0.0055	0.1576	0.3672	**0.7089**	-0.2685
3	0.0306	-0.1931	0.0879	**0.6992**	0.1854
2	0.3291	-0.1081	-0.0544	**0.6402**	0.3547
4	0.0342	0.1153	0.0511	0.0616	**0.8474**
5	0.2108	0.0588	0.2279	0.21	**0.7917**
6	0.2108	0.0588	0.2279	0.21	**0.7917**
20	0.2492	0.5145	0.1431	0.2934	**0.5375**

Source The authors.

Ultimately, the total explained variance was 70%, which accounts for more than 40% of the total variance (Kline, 2014), confirming that the analysis meets an appropriate level of adequacy. We then performed varimax rotation on these five factors. By categorizing P-set types according to each factor, we were able to more clearly analyze the characteristics of the factors and their relationships with the members of the P-set. The correlation analysis between factors revealed that the highest correlation was 0.3975, between Factor 4 and Factor 5. Since this value is below 0.5, it indicates minimal redundancy among the factors.

Table 16 Correlation of factor loadings after applying varimax rotation (Korea)

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Factor 1	1	0.0956	0.0711	0.3077	0.3621
Factor 2	0.0956	1	0.0909	0.0375	0.2692
Factor 3	0.0711	0.0909	1	0.2875	0.3799
Factor 4	0.3077	0.0375	0.2875	1	0.3975
Factor 5	0.3621	0.2692	0.3799	0.3975	1

Source The authors.

The Q statements z-scores, which serve as the basis for interpreting each perception type, are presented in Table 17.

Table 17 Q statement Z-scores by factor (Korea)

Q statements Nm	F1	F2	F3	F4	F5
1	-0.75	0.15	0.9	-0.53	-0.42
2	0.18	0.51	0.75	2.29	1.17
3	1.1	0.65	0.71	1.98	1.41
4	0.67	1.65	1.27	0.51	1.26
5	1.26	-0.21	0.11	0.98	0.49
6	0.87	-0.42	-0.84	-0.66	1.46
7	0.48	0.05	0.56	0.11	1.04
8	-1.62	0.16	-1.26	-1.56	-0.2
9	-1.2	-0.97	-1.15	-1.2	-0.52
10	-1.25	-1.02	-0.19	-0.43	0.68
11	0.78	0.55	-0.42	-0.61	0.03
12	0.25	1.49	-1.35	0.16	0.35
13	-1.58	-0.03	1.81	-0.27	-0.38
14	-1.77	1.25	-1.17	-0.27	-1.76
15	-0.97	0.11	-1.06	0.07	-1.63
16	-0.23	0.41	1.63	-0.89	-0.38
17	0.38	-0.54	0.8	0.1	-0.23
18	0.57	0.98	0.66	-0.11	-0.04
19	-1.56	-1.09	-0.4	1.11	-1.61
20	0.68	-0.65	-0.91	0.03	-1.39
21	-0.2	-0.7	2.02	-0.87	-0.42
22	-0.77	0.18	0	-0.35	1.55
23	-0.94	-0.32	0.64	-0.72	0.58
24	0.65	1.02	1.02	-0.11	0.97
25	0.68	0.2	-1.12	-0.34	-0.06
26	1.91	-0.28	0.78	1.32	1.31
27	-0.5	-0.56	1.22	0.79	-0.15

Table 17 (continued)

Q statements Nm	F1	F2	F3	F4	F5
28	-0.78	-0.68	-0.85	0.3	0.78
29	0.64	-1.18	0	1.39	-0.19
30	1.49	-0.17	0.16	1.28	1
31	0.8	-0.14	-0.85	0.81	-0.62
32	0.89	-2.53	-1.48	-2.34	-2.27
33	-0.62	2.04	-0.49	-0.89	-0.49
34	-0.61	-1.78	-0.45	0.25	-0.78
35	1.08	1.88	-1.06	-1.31	-0.54

Source The authors.

(2) Characteristics by policy acceptability type

a. Factor 1: Expert-Led

Factor 1 represents the expert-led perception type, which strongly supports increasing the proportion of green spaces and parks in urban areas (Statement 26, +5). This type also emphasizes that citizens should be adequately involved in the planning of urban policies, programs, and projects aimed at reducing CFs (Statement 30, +4).

On the other hand, the Factor 1 perception type showed the least agreement with the mandatory installation of green roofs or solar panels on buildings and factory rooftops (Statement 14, -5). It also disagreed with statements stressing individual efforts to reduce meat and processed food consumption (Statement 8, -4) and personal responsibility in conserving electricity, gas, and water at home (Statement 13, -4).

The research participant that most closely associated with the Factor 1 perception type voiced the following opinion on CF reduction policies during an in-person interview:

- *Looking at the current state of Seoul, the amount of CO_2 has increased, leading to a rising demand for green spaces that absorb CO_2. In the past, there were no dense forests or trees, but now, many green spaces, including Namsan and other urban areas, have been created, which is a great improvement. (Omitted) As cities develop, citizens become safer and healthier, making urban planning highly meaningful. (Omitted) Instead of focusing on individuals reducing meat consumption or conserving gas and water, real change will only come when industries and policies shift. (Omitted) Electricity prices are also too low, which is problematic. For power producers to fulfill their role, electricity rates need to be raised to an appropriate level. (Omitted) Additionally, rather than*

completely rejecting coal just because it is harmful, it is crucial to foster realistic alternatives like nuclear power. (Omitted).

Given these characteristics, we can see the Factor 1 perception type is one that emphasizes urban planning as a key element of CF reduction efforts. This type supports expert-led planning, policymaking, and citizen participation in efforts to reduce CFs.

Statistically, statements 32 and 13 showed a significant difference at the $p<0.01$ level compared to other factors. Specifically, perception type supported the installation of small modular reactors (SMRs) in urban areas (Statement 32). Conversely, this perception type also opposed the idea that individuals should conserve electricity, gas, and water at home as a means of reducing carbon emissions (Statement 13).

Table 18 **Characteristics of Factor 1 (Korea)**

Q Nm	Statements	Factor 1	Remarks
26	I support increasing the amount of green space and parks in urban areas.	+5	Highest Ranked Statements
30	We need an ecological restoration plan that includes green spaces and biotopes that take biodiversity into account.	+4	Positive Statements
5	I support increased investment and support for research and development of technologies that reduce our carbon footprint.	+4	
32	I support putting small modular reactors (SMRs) in cities that need a lot of electricity.	+3	D*
9	Companies should ramp up efforts to expand plant-based options in restaurants and stores, along with developing meat alternatives.	-3	Negative Statements (Con)
10	I support plans that reduce transportation distances by producing and consuming food within cities, like urban farming.	-3	
19	I support plans and designs that increase the proportion of residential areas and population density within cities to reduce urban sprawl through mixed-use development.	-3	
13	Individuals should make an effort to conserve electricity, gas, and water at home.	-4	D*
8	Individuals should make an effort to reduce their consumption of meat and imported/packaged/processed foods.	-4	
14	Require buildings or factories to install green roofs or solar panels.	-5	Lowest Ranked Statements

Note C (Consensus statements, non-significant at $p<0.01$, and * are at $p<0.05$), D (Distinguishing statements for each factor, $p<0.05$; * are at $p<0.01$), Factor Q-sort values are shown in parentheses ( ).

Source The authors.

b. Factor 2: Policy Compliance

Factor 2 represents the policy compliance perception type, which supports the gradual phase-out of coal-fired power plants, even if it leads to higher electricity prices (Statement 33). Indeed, Statement 33 was the most relevant statement for this factor and showed a statistically significant difference ($p < 0.01$) compared to other factors. In addition, this perception type actively supports policies promoting energy transition and electricity price increases as a means of reducing the carbon footprint (Statement 35).

On the other hand, the Factor 2 perception type strongly opposed the idea of introducing small modular reactors (SMRs) in urban areas to increase electricity production (Statement 32). It also expressed expressed negative opinions toward expanding government-led SNS campaigns aimed at reducing CFs (Statement 34).

The following is a quote excerpted from an interview with a participant that most strongly associated with the Factor 2 perception type:

- *I believe that transitioning from coal-fired power generation to eco-friendly energy sources is necessary. While there is a possibility of electricity price increases, survey results often show that many people support such price hikes. (Omitted) In Europe, nature-based solutions (NBS) such as green roofs and solar power generation are actively being promoted. However, in Seoul, many rooftops seem to be left unused. (Omitted) I am not opposed to the development of small modular reactor (SMR) technology itself, but I do not see it as a viable alternative in the immediate future, as it is not yet an accessible energy source. Given that we are not even fully utilizing existing technologies like wind and solar power, I am skeptical about making SMRs a major topic of discussion. (Omitted) The government has continuously promoted carbon reduction campaigns, but I do not believe they have had a significant impact. Rather than simple publicity efforts, I think it is more important to establish substantial policies and systems.*

Given these characteristics, we can interpret the Factor 2 perception type as a type that actively supports carbon reduction and renewable energy transition policies, even if it leads to increased costs. This type prioritizes substantial policy implementation and infrastructure development over simple promotional campaigns for carbon reduction policies, indicating a strong preference for practical and systemic changes rather than awareness-raising efforts alone.

Table 19 **Characteristics of Factor 2 (Korea)**

Q Nm	Statements	Factor 2	Remarks
33	I support phasing out coal-fired power plants, even if it means paying more for electricity.	5	Highest Ranked Statements (D*)
35	I support raising electric rates to encourage the energy transition and to reduce our carbon footprint.	4	Positive Statements (D)
4	Companies need to take steps to reduce their carbon footprint in their manufacturing processes.	4	
12	I support installing renewable energy sources like solar panels and solar thermal systems on buildings and homes.	3	D*
14	Require buildings or factories to install green roofs or solar panels.	3	D*
24	Companies need to cut back on product packaging and create reusable containers.	3	
9	Companies should ramp up efforts to expand plant-based options in restaurants and stores, along with developing meat alternatives.	-3	Negative Statements (C)
10	I support plans that reduce transportation distances by producing and consuming food within cities, like urban farming.	-3	
19	I support plans and designs that increase the proportion of residential areas and population density within cities to reduce urban sprawl through mixed-use development.	-3	
29	The government should invest more in research and development to boost the carbon-absorbing capacity of our forests and green spaces.	-4	D*
34	The government and local authorities should expand their social media campaigns to reduce their carbon footprint.	-4	D*
32	I support putting small modular reactors (SMRs) in cities that need a lot of electricity.	-5	Lowest Ranked Statements

Note C (Consensus statements, non-significant at $p<0.01$, and * are at $p<0.05$), D (Distinguishing statements for each factor, $p<0.05$; * are at $p<0.01$), Factor Q-sort values are shown in parentheses ( ).

Source The authors.

c. Factor 3: Individual Efforts

The Factor 3 perception type emphasizes individual efforts in carbon reduction. This type strongly supports reducing food and general waste while increasing recycling efforts (Statement 21). Indeed, Statement 21 was most relevant to the Factor 3 perception type, and showed a statistically significant difference ($p<0.01$). Those that most closely associated with the Factor 3 perception type believe

individuals should conserve electricity, gas, and water at home to reduce their carbon footprint (Statement 13), and that people should use public transportation, bicycle, and walk instead of using private cars (Statement 16).

On the other hand, the Factor 3 perception type strongly opposed the statement supporting the introduction of small modular reactors (SMRs) in urban areas to increase electricity production (Statement 32). While this type supports closing coal-fired power plants, they expressed a somewhat negative stance on electricity price increases (Statement 8). Moreover, they were strongly opposed ($p < 0.01$) to installing solar panels on homes and buildings.

Notably, among the P samples with the highest weighting in Factor 3, interview responses included the following statements regarding carbon reduction policies:

- *I believe that individual effort is the most important factor in carbon reduction. Rather than enforcing regulations through corporate or government policies, I think it is more effective to encourage voluntary participation from individuals. (Omitted) For example, I question the effectiveness of emphasizing the relationship between local farm markets and carbon reduction, as the direct connection to reducing carbon emissions does not seem significant. (Omitted) Similarly, I feel that efforts to reduce meat and processed food consumption may not have a substantial impact on carbon reduction. (Omitted) On the other hand, just as recycling culture has become more established in our country over time, I believe that campaigns and cultural initiatives promoting individual effort and behavior change are the most effective strategies. If carbon reduction is also approached from a cultural perspective, I think it could bring about more positive and lasting changes. (Omitted) Through my work in the transportation sector, I have observed that policies such as the introduction of electric buses, reduction of diesel vehicles, and expansion of CNG and LNG vehicles have had tangible effects. These policies not only reduce CO_2 emissions but also directly improve air quality, leading to noticeable environmental changes for the public. Therefore, approaching carbon reduction through public transportation policies rather than focusing solely on reducing private vehicle use would be more effective.*

We can see that the Factor 3 perception type strongly supports the idea that individual roles and behavior (e.g., conservation, recycling, and public transportation use) are essential to the success of CF reduction policies. We also noted that the type was modestly opposed to cost-increasing policies such as electricity price hikes and coal-fired power plant closures. Instead, they are more likely to respond positively to campaigns and incentives that encourage individual action, suggesting that behavior-driven initiatives may be the most effective approach for this group.

Table 20 **Characteristics of Factor 3 (Korea)**

Q Nm	Statements	Factor 3	Remarks
21	We all need to do our part to reduce food and general waste and increase recycling and reuse.	5	Highest Ranked Statements (D*)
13	Individuals should make an effort to conserve electricity, gas, and water at home.	4	Positive Statements (D*)
16	Individuals should make an effort to use public transportation, such as buses, trains, or bikes, instead of driving their own cars.	4	(D*)
27	Companies should get involved in programs and initiatives that expand carbon sinks, such as creating parks and planting trees.	3	
24	Companies need to cut back on product packaging and create reusable containers.	3	
25	I support the plan to build a biogas facility with organic waste such as food waste, livestock manure, and sewage sludge.	-3	Negative Statements (D)
9	Companies should ramp up efforts to expand plant-based options in restaurants and stores, along with developing meat alternatives.	-3	C
8	Individuals should make an effort to reduce their consumption of meat and imported/packaged/processed foods.	-4	
12	I support installing renewable energy sources like solar panels and solar thermal systems on buildings and homes.	-4	D*
32	I support putting small modular reactors (SMRs) in cities that need a lot of electricity.	-5	Lowest Ranked Statements (D)

Note C (Consensus statements, non-significant at $p<0.01$, and * are at $p<0.05$), D (Distinguishing statements for each factor, $p<0.05$; * are at $p<0.01$), Factor Q-sort values are shown in parentheses ( ).

Source The authors.

d. Factor 4: Planning-oriented

The Factor 4 perception type prioritizes government-led environmental policies and planning. This type believes that urban planning and design are essential to reducing the CF of city dwellers (Statement 2). Statement 2 showed a statistically significant difference ($p<0.01$) compared to the other factors. In addition, the Factor 4 perception type supports the view that governments and local authorities should implement policies, programs, and initiatives to reduce the carbon footprint (Statements 21 and 3).

On the other hand, Factor 4 showed the least agreement with the statement that companies should expand vegan options and develop meat substitutes (Statement 9), and there was no statistically significant difference at the $p<0.01$ level. This type also did not support the idea that individuals should reduce meat, imported, processed, and packaged food consumption (Statement 8) and opposed the gradual phase-out of coal-fired power plants if it leads to electricity price increases (Statement 32).

The participant most closely associated with the Factor 4 perception type offered the following during an in-person interview:

- *In Korea, it is difficult to establish sustainable policies solely through changes in individual awareness. The government and local authorities must take a strong initiative in implementing policies and operating pilot projects. A top-down approach is necessary to structure policies effectively, ensuring their stability and expansion. (Omitted) In Europe, environmental policies and resource circulation tend to be driven by civic consciousness. However, in Korea, citizens still face limitations in leading change voluntarily. This is especially true for the middle-aged and older generations, who tend to follow existing systems, making citizen education alone insufficient. Urban planning and design play a key role in carbon reduction and sustainable development. These efforts cannot rely solely on individual efforts or corporate initiatives but must be achieved through strong policy intervention in the public sector. (Omitted) Corporations can also be key players in implementing environmental policies, but fundamental change should be driven by public policies rather than relying on voluntary corporate efforts. Since businesses prioritize profitability, they tend to focus on economic benefits rather than environmental protection. Therefore, the government and local authorities must introduce regulations that encourage businesses to operate in environmentally friendly ways.*

The Factor 4 perception type seems to believe that, in order for environmental policies (including CF reduction policies) to succeed, strong policy frameworks provided by the government and local authorities are more critical than voluntary individual behavioral changes. A sustainable system should be established through urban planning, ensuring that policies naturally integrate into citizens' daily lives. The Factor 4 perception type believes that the most effective approach is for the government and local authorities to lead structural changes, while enabling citizens to engage naturally with policies. They also seem to have low expectations for corporate responsibility, and prefer solutions that utilize urban planning and the expansion of green space.

Table 21 **Characteristics of Factor 4 (Korea)**

Q Nm	Statements	Factor 4	Remarks
2	Urban planning and design are needed to reduce the carbon footprint of city dwellers.	5	Highest Ranked Statements (D*)
3	The government and local authorities should roll out policies, programs, and initiatives to reduce their carbon footprint.	4	Positive Statements
29	The government should invest more in research and development to boost the carbon-absorbing capacity of our forests and green spaces.	4	D
19	I support plans and designs that increase the proportion of residential areas and population density within cities to reduce urban sprawl through mixed-use development.	3	D*
34	The government and local authorities should expand their social media campaigns to reduce their carbon footprint.	1	D
33	I support phasing out coal-fired power plants, even if it means paying more for electricity.	-3	Negative Statements
16	Individuals should make an effort to use public transportation, such as buses, trains, or bikes, instead of driving their own cars.	-3	
9	Companies should ramp up efforts to expand plant-based options in restaurants and stores, along with developing meat alternatives.	-3	C
35	I support raising electric rates to encourage the energy transition and to reduce our carbon footprint.	-4	
8	Individuals should make an effort to reduce their consumption of meat and imported/packaged/processed foods.	-4	
32	I support putting small modular reactors (SMRs) in cities that need a lot of electricity.	-5	Lowest Ranked Statements

Note C (Consensus statements, non-significant at $p<0.01$, and * are at $p<0.05$), D (Distinguishing statements for each factor, $p<0.05$; * are at $p<0.01$), Factor Q-sort values are shown in parentheses ( ).

Source The authors.

e. Factor 5: Government Emphasis

Factor 5 represents a perception type that stresses the role of government and local authorities in implementing effective carbon reduction policies. For example, this type supports government regulations restricting single-use plastics in hotels (Statement 22), which showed a statistically significant difference ($p<0.01$) compared to other factors. This perception type also supports expanding and promoting local farmers' markets (Statement 6) and emphasizes that businesses must take measures to reduce carbon emissions during the manufacturing process (Statement 3). On the other hand, Factor 5 is modestly opposed to the introduction of small modular reactors (SMRs) in

cities with high electricity consumption (Statement 32). This type also opposes increasing electricity prices as a means to encourage energy transition and reduce the carbon footprint (Statement 15).

The member of the P-set most closely associated with the Factor 5 perception type voiced the following opinion during an in-person interview:

- *A purely technological approach to reducing carbon emissions is not enough to address the climate crisis. Fundamentally, it is crucial for people to actively participate and rethink their relationship with nature. (Omitted) Individual efforts are meaningful, but achieving carbon neutrality ultimately requires policy changes at the government and local authority levels. A good example is policies aimed at reducing single-use plastics. On the other hand, individual actions alone—such as using tumblers—have limitations. Without structural changes, solving the climate crisis will be difficult. (Omitted) It is also important to consider groups that may be negatively affected during the energy transition process. For example, workers in coal power plants could lose their jobs, and if they are not considered, resistance to policy changes will inevitably increase. Therefore, rather than simply pushing for energy transition, these social issues must be addressed alongside it. (Omitted) Technological solutions are important, but changing public perception should come first. While improving energy efficiency is crucial, I believe that preserving and restoring existing natural environments is the most fundamental solution.*

We can see that the Factor 5 perception type stresses that CF reduction policies require input and action from all stakeholders, including the government, business, and markets. However, we did observe a modest opposition to the use of SMRs by this perception type. In addition, the Factor 5 perception type seems to prefer sustainability strategies that influence consumer behavior through policies, such as promoting local farmers' markets and regulating single-use plastics. However, rather than favoring strong government intervention, this type prefers policies that naturally encourage eco-friendly changes within the market (such as corporate incentives, the promotion of recycling, and local market activation) indicating a preference for voluntary, market-driven initiatives over rigid regulatory measures.

Table 22 **Characteristics of Factor 5 (Korea)**

Q Nm	Statements	Factor 5	Remarks
22	The government and local authorities should implement policies to reduce single-use items in places like stores and hotels.	5	Highest Ranked Statements (D*)
6	I support expanding and revitalizing local farmers markets.	4	Positive Statements
3	The government and local authorities should roll out policies, programs, and initiatives to reduce their carbon footprint.	4	
7	The government and local authorities should promote the certification and consumption of low-carbon, eco-friendly, and organic agricultural products.	2	
8	I support expanding the greenbelt designation, which limits development on existing green spaces.	2	
10	I support plans that reduce transportation distances by producing and consuming food within cities, like urban farming.	1	D
20	I support expanding the infrastructure for electric vehicle charging and dedicated parking spaces.	-3	Negative Statements (D*)
19	I support plans and designs that increase the proportion of residential areas and population density within cities to reduce urban sprawl through mixed-use development.	-3	
15	Require new buildings to be designed to be zero energy, meaning they don't rely on outside energy sources.	-4	
32	I support putting small modular reactors (SMRs) in cities that need a lot of electricity.	-5	

Note C (Consensus statements, non-significant at $p<0.01$, and * are at $p<0.05$), D (Distinguishing statements for each factor, $p<0.05$; * are at $p<0.01$), Factor Q-sort values are shown in parentheses ( ).

Source The authors.

f. Commonalities and differences among factors

As described in the previous material, we classified the results of the Q methodology analysis into five Factors, each representing a different perception type. Some of the key differences and commonalities among the types are summarized below.

Factor 1 is an expert-led type that aims to expand green spaces and protect ecosystems. This type prefers urban planning and green space expansion through government and public sector intervention. The most relevant statement is Statement 26, which is on the expansion of green space in urban areas. The least relevant to the Factor 1 perception type, which showed no significant correlation, are businesses providing vegan options in restaurants and individual efforts.

Factor 2 is the policy compliance perception type, which prioritizes renewable energy and carbon reduction policies. This perception type supports renewable energy transition, strengthening carbon taxes, and closing coal-fired power plants, preferring strong regulation and policy intervention for energy transition. It also supports a transition to eco-friendly energy even at the cost of increased electricity prices but opposes the installation of SMRs in urban areas.

Factor 3 is the perception type that values individual efforts, emphasizing energy conservation, recycling, and the use of public transportation by everyday citizens. The Factor 3 type is characterized by a focus on personal practice and behavioral change but holds a somewhat negative opinion on electricity price increases.

Factor 4 is a planning-oriented type that prioritizes government-led policies. This type favors urban planning, eco-friendly infrastructure expansion, and strong public policy and administrative intervention by the government. The statement that urban planning and design are most necessary for reducing the carbon footprint received the most agreement from this type.

The Factor 5 perception type emphasizes the role of the government and local authorities but also supports voluntary environmental practices by corporations and consumer-driven changes. This type does however not support strong government regulation and prefers market-driven changes and incentive-based policies.

All factors agreed on the importance of carbon reduction, with Factors 1 and 4 supporting the necessity of urban planning and green space expansion. Factors 1, 2, and 4 actively call for government intervention, while Factors 3 and 5 prefer a market-centered approach but also show support for policy assistance.

Table 23 **Summary of key characteristics by Factor (Korea)**

Factor	Key themes	Most relevant statements	Least relevant statements
Factor 1 (Expert-Led)	Urban Green Space Expansion, Ecological Restoration, Carbon Reduction Technology Development	"I support increasing the amount of green space and parks in urban areas."	"Companies should ramp up efforts to expand plant-based options in restaurants and stores."
Factor 2 (Policy Compliance)	Renewable Energy Transition, Strengthening Carbon Tax, Coal-Fired Power Plant Closure	"I support phasing out coal-fired power plants, even if it means paying more for electricity."	"I support putting small modular reactors (SMRs) in cities that need a lot of electricity."

Table 23 (continued)

Factor	Key themes	Most relevant statements	Least relevant statements
Factor 3 (Individual Efforts)	Citizen Energy Conservation, Recycling, Public Transportation Use	"We all need to do our part to reduce food and general waste and increase recycling and reuse."	"I support raising electric rates to encourage the energy transition and to reduce our carbon footprint."
Factor 4 (Planning-Oriented)	Government-Led Urban Planning, Expansion of Eco-Friendly Infrastructure	"Urban planning and design is needed to reduce the carbon footprint of city dwellers."	"I support companies developing plant-based alternatives."
Factor 5 (Government Emphasis)	Government Policy Regulations, Corporate Voluntary Environmental Management, Consumer-Driven Changes	"Companies need to take steps to reduce their carbon footprint in their manufacturing processes."	"I support raising electric rates to encourage the energy transition and to reduce our carbon footprint."

Source The authors.

3.2.4 Q methodology analysis results: Germany

(1) Selection process of policy acceptability types

For our analysis of the survey results from the German side, we again employed the PCA approach, and through it identified a total of six factors with eigenvalues greater than 1.

The threshold for a significant factor loading[82] was set at 0.4361, and factors with at least two loadings above this threshold (absolute value) and an explained variance of 5% or more were considered valid. We ultimately selected four factors with sufficient explanatory power and validity.

The total explained variance was 59%, which accounts for more than 40% of the total variance (Kline, 2014), confirming that the analysis meets an appropriate level of adequacy. We then performed varimax rotation and categorized the P-set by factor.

82) Factor loading value: $2.58 \times (1/\sqrt{Nmber\ of\ Qsamples})$

Table 24 Unrotated factor matrix (Germany)

P-sample Number	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8
1	0.6323	-0.3359	0.2924	0.0112	0.1532	0.234	-0.3012	-0.1214
2	0.2314	0.5557	-0.4419	-0.0915	0.2354	0.0561	0.1938	0.0641
3	0.3369	-0.6177	-0.1521	0.0338	0.1695	0.3276	-0.3549	0.0364
4	0.5632	-0.5958	-0.1012	0.255	0.1743	0.1743	0.02	0.0472
5	0.6404	-0.4652	-0.2549	-0.0225	0.153	0.017	0.0367	0.0454
6	0.5206	-0.0123	-0.2008	-0.2232	-0.4239	0.3355	-0.0201	0.0787
7	0.5599	-0.3086	-0.0526	0.1377	-0.1602	-0.1913	-0.0913	0.0958
8	0.6595	0.4602	0.1023	-0.0377	-0.1602	0.0913	-0.2389	0.0973
9	0.7169	-0.0702	-0.0712	0.1003	-0.3542	-0.1114	0.3011	-0.1441
10	0.5475	-0.4749	-0.4584	0.449	-0.4309	0.0039	0.3073	0.0791
11	0.4238	-0.227	0.3158	0.2597	0.2887	-0.3731	-0.1782	-0.0913
12	0.2676	0.6585	0.4599	0.4068	0.2906	0.054	0.1064	0.0433
13	0.6055	0.663	0.0624	0.011	0.1136	0.0243	-0.2203	-0.1253
14	0.6403	0.3651	0.1952	0.3311	0.3087	0.1088	0.1088	-0.008
15	0.5643	-0.3643	-0.1586	0.1743	-0.5451	-0.0038	-0.008	-0.0089
16	0.5442	-0.2001	0.4892	-0.0898	0.03	-0.2941	-0.0919	-0.0333
17	-0.0518	0.0043	0.2847	0.6288	0.2541	0.4412	-0.2842	0.0639
18	0.5488	-0.1108	0.0512	0.1192	-0.3342	0.1239	-0.1534	-0.1681
19	0.433	-0.403	0.0832	0.2308	-0.2293	-0.1562	-0.1354	-0.0334
20	0.6796	-0.3273	0.178	-0.3472	0.1847	0.2394	-0.0915	-0.1952
Eigenvalues	**5.4399**	**3.0788**	**1.8672**	**1.5578**	1.2885	1.1046	0.9561	0.8005
% exp. var.	27	15	9	8	6	6	5	4
Cumlative % exp. var.	27	42	51	**59**	65	71	76	80

Note exp.: explained; var.: variation.
Source The authors.

Table 25 Factors after applying varimax rotation (Germany)

P-sample Nm	F1	F2	F3	F4
20	**0.8191**	0.0617	0.0994	-0.1914
1	**0.7291**	0.0082	0.2043	0.1578
16	**0.7285**	0.06	-0.059	0.214
8	**0.6063**	-0.04	0.5343	-0.089
15	**0.5954**	0.1621	0.0944	-0.0488
9	**0.5585**	0.1783	0.4885	0.0156

Table 25 (continued)

P-sample Nm	F1	F2	F3	F4
19	**0.5562**	-0.0942	0.1655	-0.4635
18	**0.4363**	0.1796	0.3072	0.1153
6	**0.368**	0.2849	0.2367	-0.2977
13	0.1757	**0.8657**	0.0678	0.1936
4	0.2265	**0.7859**	-0.0208	0.1144
7	0.1626	**0.7681**	0.1024	-0.0143
3	-0.0769	**0.714**	0.0604	-0.0046
2	-0.2212	**0.6413**	0.1511	-0.2879
14	0.4656	**0.605**	-0.1175	-0.011
10	0.0328	0.3626	**0.7737**	0.0519
5	0.3	-0.2774	**0.7714**	0.1185
11	0.0949	0.0731	**0.7277**	-0.1366
12	0.2991	0.1923	-0.1263	**0.8022**
17	-0.1051	-0.0702	0.1377	**0.6664**

Source The authors.

The correlation coefficient between Factor 1 and Factor 3 was 0.4238, which is below 0.5, indicating minimal redundancies among the factors. These results suggest that each factor operates independently, reinforcing the reliability of the analysis. As with the analysis of the Korean data in the previous section, we also identified statements that were most and least relevant to each Factor.

Table 26 Correlation of factor loadings after applying varimax rotation (Germany)

	Factor 1	Factor 2	Factor 3	Factor 4
Factor 1	1	0.2619	**0.4238**	0.1187
Factor 2	0.2619	1	0.1577	0.214
Factor 3	0.4238	0.1577	1	0.0103
Factor 4	0.1187	0.214	0.0103	1

Source The authors.

The z-scores for the Q statements are presented in Table 27 below.

Table 27 Q statement Z-scores by factor (Germany)

Q statements Nm	F1	F2	F3	F4
1	0.98	-0.85	2.51	-1
2	0.86	1.09	0.5	1.8
3	2.03	1.11	-0.07	0.79
4	1.38	0.7	1.22	-1.46
5	1.35	0.46	-0.93	-0.51
6	0.45	-1.17	-0.62	0.66
7	-0.53	-0.69	-0.68	0.32
8	-0.76	-1.43	1.11	0.02
9	-1.46	-1.52	-0.58	-1.95
10	-0.18	-1.11	-0.29	0.49
11	0.13	1.6	0.72	1.78
12	0.66	1.17	1.36	0.11
13	0.02	-1.17	1.29	0.19
14	-0.1	0.68	-0.47	-0.79
15	-0.77	1.11	0.25	-0.3
16	0.75	-0.69	1.15	-0.15
17	0.93	0.81	-0.43	0.3
18	-0.11	1.12	-0.21	-0.47
19	-0.39	-0.01	-0.43	0.3
20	-1.19	0.57	-0.5	0.47
21	0.16	-0.37	1.51	0.36
22	-0.24	-0.01	-0.18	-0.64
23	-0.14	0.24	1.15	-0.64
24	-0.04	-0.61	0	-1.44
25	-1.32	0.31	-0.68	1.15
25	-1.32	0.31	-0.68	1.15
26	1.02	0.12	-0.26	2.27
27	0.25	-0.89	-1.65	-1.29
28	0.2	-0.02	-0.07	-2.1
29	0.5	0	-1.22	-0.17
30	0.14	0.28	0.36	1.1
31	1.52	-0.61	0.42	0.66
32	-2.73	-2.55	-2.51	0
33	-1.15	1.74	-0.68	-0.34
34	-0.67	-0.53	-0.89	0.49
35	-1.54	1.12	-0.21	0

Source The authors.

(2) Characteristics by policy acceptability type

a. Factor 1: Business-Centered

The Factor 1 perception type prefers business-centered approach, supporting the idea that CF reduction efforts should be led by the government and public institutions (Statement 3). We also found that the Factor 1 type favors policy interventions that influence citizen behavior (Statement 31). The perception type also seems to believe that businesses should actively participate in CF reduction efforts, and stresses the importance of reducing carbon emissions in manufacturing processes (Statement 4). It supports investment in research and development (R&D) in carbon reduction technologies (Statement 5) and encourages corporate involvement in park creation and tree planting initiatives (Statement 27).

We also found that the Factor 1 perception type opposes high-density urban planning to address transportation and housing issues (Statement 19), indicating a stronger inclination toward policy and administrative measures rather than urban design when it comes to CF reduction. This perception type also strongly opposes the phase-out of coal-fired power plants and electricity price increases (Statements 33, 35), reflecting the belief that CF reduction policies should not impose excessive economic burdens. The Factor 4 perception type also opposes the introduction of SMRs as an energy supply alternative (Statement 32).

The member of the P-set most closely associated with Factor 1 offered the following statement:

- *Among government policies, regulatory measures and mandatory planning are the most effective tools for achieving carbon reduction goals. I believe that regulatory policies play a crucial role in driving systemic change by enforcing compliance, rather than relying solely on voluntary efforts by individual stakeholders. (Omitted) The government can promote research and technological development aimed at reducing the carbon footprint by providing financial support, tax benefits, and incentives. Facilitating the transition to sustainable industries should be achieved through collaborative efforts between the government, businesses, and public-private partnerships. Such investments and support will become key factors in reducing the carbon footprint. Ultimately, various government and local government initiatives will not only impact the industrial sector but also encourage citizen participation and drive change at the community level. (Omitted) I believe that urban green spaces are the optimal areas for implementing research and technological developments. For example, urban greening projects can lead to tangible changes in climate change mitigation, adaptation, and carbon sequestration through collaboration with local communities. (Omitted) While the demand for plant-based and alternative foods is gradually increasing, the overall*

vegetarian population remains small, and demand is still uncertain. In this context, indiscriminately expanding vegetarian options without clear market demand may result in high opportunity costs.

We can see that the Factor 1 perception type views government-led policy implementation as the key to reducing the carbon footprint. It emphasizes that carbon reduction measures should be pursued in a way that minimizes economic burdens. While the role of businesses is also considered important, this factor shows a preference for policy-driven solutions over market-based approaches.

Table 28 Characteristics of Factor 1 (Germany)

Q Nm	Statements	Factor 1	Remarks
3	The government and local authorities should roll out policies, programs, and initiatives to reduce their carbon footprint.	5	Highest Ranked Statements (D*)
31	Citizen engagement should be fully integrated into city planning, policies, programs, and procedures that aim to reduce carbon footprint.	4	Positive Statements (D)
4	Companies need to take steps to reduce their carbon footprint in their manufacturing processes.	4	
5	I support increased investment and support for research and development of technologies that reduce our carbon footprint.	3	D*
27	27.Companies should get involved in programs and initiatives that expand carbon sinks, such as creating parks and planting trees.	1	D*
19	I support plans and designs that increase the proportion of residential areas and population density within cities to reduce urban sprawl through mixed-use development.	-1	Negative Statements (C*)
15	Require new buildings to be designed to be zero energy, meaning they don't rely on outside energy sources.	-2	
33	I support phasing out coal-fired power plants, even if it means paying more for electricity.	-3	
20	I support expanding the infrastructure for electric vehicle charging and dedicated parking spaces.	-3	D
25	I support the plan to build a biogas facility with organic waste such as food waste, livestock manure, and sewage sludge.	-3	D
9	Companies should ramp up efforts to expand plant-based options in restaurants and stores, along with developing meat alternatives.	-4	

Table 28 **(continued)**

Q Nm	Statements	Factor 1	Remarks
35	I support raising electric rates to encourage the energy transition and to reduce our carbon footprint.	-4	D*
32	I support putting small modular reactors (SMRs) in cities that need a lot of electricity.	-5	Lowest Ranked Statements

Note C (Consensus statements, non-significant at $p<0.01$, and * are at $p<0.05$), D (Distinguishing statements for each factor, $p<0.05$; * are at $p<0.01$), Factor Q-sort values are shown in parentheses ( ).

Source The authors.

b. Factor 2: Regulatory Preference

The Factor 2 perception type prefers regulation for CF reduction, favoring renewable energy and energy transition policies. This reflects a view that energy transition policies must be actively promoted, supporting policies such as expanding renewable energy, reducing fossil fuel dependence, and enhancing energy efficiency. This perception type also prioritizes regulatory and policy-driven approaches by governments and businesses over individual behavioral changes. Participants associated with this Factor also support the phase-out of coal-fired power plants (Statement 33) and are willing to accept electricity price increases to achieve this goal (Statement 35). In addition, this perception type actively supports solar energy and eco-friendly architecture (Statement 12) and holds a positive view on increasing energy efficiency through building renovations (Statement 11).

On the other hand, the Factor 2 perception type shows little interest in shrinking CFs through lower local food consumption and urban agriculture (Statement 10), preferring carbon reduction strategies centered on energy transition and infrastructure changes. It values policy-driven approaches over individual efforts such as conserving electricity, gas, and water (Statement 13). This perception type also strongly opposes the introduction of SMRs as an energy supply alternative.

The research participant most closely associated with the Factor 2 perception type offered the following statement regarding CF reduction policies:

- *I strongly support the gradual phase-out of coal-fired power plants. To effectively respond to climate change, we must rapidly transition from coal to renewable energy. This transition may lead to higher electricity prices, but I believe it is a necessary cost to bear. (Omitted) The important issue is whether the government fulfills its promises to citizens during this transition process. For example, the German government announced plans to introduce "climate subsidies" (Klima-Geld) to offset rising*

electricity costs, but due to budget constraints, they have not yet been distributed. As a result, public trust in government policies has weakened, leading to growing opposition. (Omitted) I have a negative stance on nuclear power. I believe Germany's decision to phase out nuclear energy was the right one. More than the safety concerns of reactors themselves, the bigger issue is radioactive waste disposal. Even now, we do not have a proper solution for handling nuclear waste from existing power plants, so building new reactors seems highly inefficient. Moreover, not only Germany but also major industrial corporations do not see nuclear energy as a viable alternative. Large-scale energy-consuming industries such as steel and chemical manufacturing have already announced plans to transition toward green hydrogen and renewable energy rather than relying on nuclear power.

We can see that the Factor 2 perception type sees government-led energy transition policies as being critical to reducing CFs. There is a willingness to accept a greater economic burden in pursuit of environmentally friendly policies, and the participants most closely associated with this perception type view energy policy changes as more effective than dietary changes and prefer solutions driven by institutional and regulatory reforms rather than individual lifestyle modifications.

Table 29 **Characteristics of Factor 2 (Germany)**

Q Nm	Statements	Factor 2	Remarks
33	I support phasing out coal-fired power plants, even if it means paying more for electricity.	5	Highest Ranked Statements (D*)
11	I support green remodeling efforts that improve the energy efficiency of existing buildings.	4	Positive Statements (D)
12	I support installing renewable energy sources like solar panels and solar thermal systems on buildings and homes.	4	D*
35	I support raising electric rates to encourage the energy transition and to reduce our carbon footprint.	3	D*
18	I support limiting the use of high carbon-emission vehicles.	3	D*
15	Require new buildings to be designed to be zero energy, meaning they don't rely on outside energy sources.	2	D
10	I support plans that reduce transportation distances by producing and consuming food within cities, like urban farming.	-3	Negative Statements (D)
13	Individuals should make an effort to conserve electricity, gas, and water at home.	-3	D*

Table 29 (continued)

Q Nm	Statements	Factor 2	Remarks
6	I support expanding and revitalizing local farmers markets.	-3	
8	Individuals should make an effort to reduce their consumption of meat and imported/packaged/processed foods.	-4	D*
9	Companies should ramp up efforts to expand plant-based options in restaurants and stores, along with developing meat alternatives.	-4	
32	I support putting small modular reactors (SMRs) in cities that need a lot of electricity.	-5	Lowest Ranked Statements

Note C (Consensus statements, non-significant at $p<0.01$, and * are at $p<0.05$), D (Distinguishing statements for each factor, $p<0.05$; * are at $p<0.01$), Factor Q-sort values are shown in parentheses ( ).

Source The authors.

c. Factor 3: Individual Efforts

The Factor 3 perception type is one that prioritizes individual efforts to reduce CFs, and emphasizes personal actions as the key to environmental sustainability. The participants associated with this perception type strongly value reducing consumption and recycling, and encourage voluntary action by individuals rather than government intervention. This perception type strongly supports the idea that individuals should voluntarily reduce consumption and participate in environmental protection efforts (Statements 1, 21), and also favors personal adoption of renewable energy solutions (Statement 12) and policies aimed at reducing single-use plastics and increasing reusable products (Statement 23).

On the other hand, the Factor 3 perception type does not support the idea of reducing the consumption of meat and processed food as a means of CF reduction Statement 8). This suggests that the perception type does consider the reduction of consumption activities important, it does not agree that personal dietary changes are entirely necessary. In addition, the participants associated with this perception type opposed government promoting and/or certifying low-carbon, eco-friendly products (Statement 7), reflecting a belief in voluntary individual action over government-led initiatives. This perception type also strongly opposes the introduction of SMRs as an energy supply solution in urban areas.

The member of the P-set that was most closely associated with the Fact 3 perception type offered the following perspective on CF reduction:

- *I believe individuals must be the starting point for change. Transitioning to a sustainable society requires personal effort, and businesses also play a crucial role in this transformation. (Omitted) In Germany, the building sector accounts for a significant share of CO_2 emissions. Thus, renovating existing buildings is an effective reduction strategy. Methods such as upgrading heating systems and improving insulation can significantly reduce emissions, and support programs are available for these initiatives. For example, applying a special coating to walls can enhance insulation, reducing heating and cooling energy consumption. (Omitted) I do not support nuclear power. The biggest concern is the unsolved issue of nuclear waste disposal. As seen in the Chernobyl and Fukushima disasters, humans cannot fully control this technology, and the risks are too great. (Omitted) For CO_2 reduction, we should focus on Nature-Based Solutions (NBS) rather than technological storage methods. While the government is investing in research on carbon sequestration through forests and green spaces, extensive studies have already been conducted on how forests and peatlands naturally store carbon. The priority should not be additional research, but rather restoring and preserving these ecosystems.*

We may conclude that the Factor 3 perception type views behavioral changes by individuals as the most important strategy for reducing CFs, and emphasizes voluntary individual actions over government intervention. This factor shows little interest in dietary changes or corporate-led carbon reduction projects but places high importance on energy conservation and the adoption of renewable energy.

Table 30 **Characteristics of Factor 3 (Germany)**

Q Nm	Statements	Factor 3	Remarks
1	Individuals should make an effort to reduce their consumption of food, housing, transportation, and goods and services.	5	Highest Ranked Statements (D*)
21	We all need to do our part to reduce food and general waste and increase recycling and reuse.	4	Positive Statements (D*)
12	I support installing renewable energy sources like solar panels and solar thermal systems on buildings and homes.	4	
13	Individuals should make an effort to conserve electricity, gas, and water at home.	3	D
23	I support policies that discourage single-use products and mandate reusable containers.	3	D*

Table 30 **(continued)**

Q Nm	Statements	Factor 3	Remarks
8	Individuals should make an effort to reduce their consumption of meat and imported/packaged/processed foods.	2	D
7	The government and local authorities should promote the certification and consumption of low-carbon, eco-friendly, and organic agricultural products.	-3	Negative Statements
34	The government and local authorities should expand their social media campaigns to reduce their carbon footprint.	-3	
5	I support increased investment and support for research and development of technologies that reduce our carbon footprint.	-3	
29	The government should invest more in research and development to boost the carbon-absorbing capacity of our forests and green spaces.	-4	D
27	27.Companies should get involved in programs and initiatives that expand carbon sinks, such as creating parks and planting trees.	-4	
32	I support putting small modular reactors (SMRs) in cities that need a lot of electricity.	-5	Lowest Ranked Statements

Note C (Consensus statements, non-significant at $p<0.01$, and * are at $p<0.05$), D (Distinguishing statements for each factor, $p<0.05$; * are at $p<0.01$), Factor Q-sort values are shown in parentheses ( ).

Source The authors.

d. Factor 4: Green Development

The Factor 4 perception type emphasizes the role of government and local authorities in carbon reduction efforts. The participants associated with this perception type expanding green spaces and parks in urban areas (Statement 26). They also stress the need for green and ecological restoration plans that consider biodiversity (Statement 2). This perception type also showed a statistically significant distinction at the $p<0.01$ level in supporting the idea that governments should invest more in R&D to enhance the carbon absorption capacity of forests and green spaces.

On the other hand, the Factor 4 perception type a structural approach over individual behavioral changes. It favors government policies and urban planning-based solutions and opposes approaches that emphasize individual consumption reduction (Statement 1). The participants associated with this factor also place lower priority on corporate regulations and express a somewhat negative view of food-related policies.

Notably, among the P-set subjects most closely associated with Factor 4, interview responses included the following statements regarding CF reduction:

- *City planning is important and can be effective from a city-wide view to regulate building processes and city zones. I think, everyone has a little bit of power to change habits and e.g. reduce trash and over-consumption, also to install a way of thinking, maybe it will also effect our thinking when e.g. booking a vacation or buying a car etc. (Omitted) At least here in Berlin for the last years, everybody talks about how valuable green zone, parks etc are. But also the city motivates building companies to build more apartment houses, many of them on former green zone of residential area (Nachverdichtung in German / create higher density with buildings) - which is contrary to the first aim. (omitted) Considering the financial burden on both businesses and individuals, policies with lower financial impact tend to be prioritized during implementation. As a result, the most acceptable and neutral policy statement was "expanding the green belt in both directions," which needs to be linked to biodiversity conservation. (omitted) The expansion of green infrastructure is a topic that is widely acknowledged as sensitive, making it easier to reach policy consensus. In this context, discussions on energy-saving policies and green infrastructure expansion need to be conducted together.*

We have seen how the Factor 4 perception type emphasizes urban planning and eco-friendly infrastructure for CF reduction, stressing the role of governments and local authorities. The perception type also favors government-led policy implementation over individual behavioral changes and perceives urban environmental changes as more effective than corporate regulations. In addition, instead of focusing solely on preserving existing green spaces, the perception type advocates for a "sustainable urban expansion" strategy. Rather than compulsory development policies, such as expanding the green belt, the participants associated with this perception type suggest that carbon reduction measures through climate-resilient urban design and infrastructure improvements may be more effective.

Table 31 **Characteristics of Factor 4 (Germany)**

Q Nm	Statements	Factor 4	Remarks
26	I support increasing the amount of green space and parks in urban areas.	5	Highest Ranked Statements (D*)
2	Urban planning and design are needed to reduce the carbon footprint of city dwellers.	4	Positive Statements
11	I support green remodeling efforts that improve the energy efficiency of existing buildings.	4	
25	I support the plan to build a biogas facility with organic waste such as food waste, livestock manure, and sewage sludge.	3	D

Table 31 **(continued)**

Q Nm	Statements	Factor 4	Remarks
30	We need an ecological restoration plan that includes green spaces and biotopes that take biodiversity into account.	3	
34	The government and local authorities should expand their social media campaigns to reduce their carbon footprint.	2	D*
1	Individuals should make an effort to reduce their consumption of food, housing, transportation, and goods and services.	-3	Negative Statements
24	Companies need to cut back on product packaging and create reusable containers.	-3	D
4	Companies need to take steps to reduce their carbon footprint in their manufacturing processes.	-4	D*
9	Companies should ramp up efforts to expand plant-based options in restaurants and stores, along with developing meat alternatives.	-4	
28	I support expanding the greenbelt designation, which limits development on existing green spaces.	-5	Lowest Ranked Statements (D*)

Note C (Consensus statements, non-significant at $p<0.01$, and * are at $p<0.05$), D (Distinguishing statements for each factor, $p<0.05$; * are at $p<0.01$), Factor Q-sort values are shown in parentheses ( ).

Source The authors.

e. Commonalities and differences among the factors

As described in the previous pages, we categorized the German P-set into four perception types, or Factors. In the following material, we will summarize some of the key commonalities and differences between them.

The Factor 1 perception type is a business-oriented type that considers the key solution for carbon reduction. It emphasizes the importance of enhancing sustainability through citizen participation and urban planning, with a strong focus on the role of the government. The type exhibits a tendency to oppose policies that may increase economic burdens, such as electricity price hikes.

Factor 2 is a policy compliance type, which strongly prefers strengthening regulations on renewable energy and eco-friendly architecture. It is willing to accept increased electricity costs during the transition away from fossil fuels but holds a negative attitude toward changes in dietary habits and consumption patterns.

Factor 3 is a type that emphasizes individual efforts, believing that voluntary individual actions are crucial and that government intervention should be minimized. Rather than government policies, it highlights

the need for campaigns and incentives to encourage behavioral changes at the individual level.

Factor 4 emphasizes the role of the government and local authorities, recognizing the necessity of strengthening urban infrastructure and environmental policies for carbon reduction. Rather than focusing solely on technological advancements, it stresses the importance of sustainable urban development, considering securing carbon absorption spaces and ecological restoration as key solutions.

Table 32 **Summary of key characteristics by Factor (Germany)**

Factor	Key themes	Most relevant statements	Least relevant statements
Factor 1 (Business-Centered)	Active government intervention, public policy-centered approach	The government and local authorities should roll out policies, programs, and initiatives to reduce their carbon footprint.	I support putting small modular reactors (SMRs) in cities that need a lot of electricity.
Factor 2 (Regulatory Preference)	Expansion of renewable energy, elimination of fossil fuels	I support phasing out coal-fired power plants, even if it means paying more for electricity.	I support putting small modular reactors (SMRs) in cities that need a lot of electricity.
Factor 3 (Individual Efforts)	Emphasis on citizen-led practices	Individuals food, housing, transportation, and goods and services.	I support putting small modular reactors (SMRs) in cities that need a lot of electricity.
Factor 4 (Green Development)	Sustainable urban development	I support increasing the amount of green space and parks in urban areas.	I support expanding the greenbelt designation, which limits development on existing green spaces.

Source The authors.

All factors agree on the importance of CF. Factors 1, 2, and 4 tend to emphasize the expansion of urban green spaces and the establishment of sustainable infrastructure. They also acknowledge the necessity of government-led policies. Factor 3 does not completely dismiss the need for government support, either. This necessitates a hybrid approach where the government, businesses, and individuals share responsibilities and collaborate to address carbon reduction effectively.

3.3 Measuring acceptability: online survey

In addition to the Q methodology survey described in the previous section, for this study we also conducted a larger online survey featuring 500 participants from both Korea and Germany to aid our understanding of the acceptability of CF reduction policies. The findings highlight significant differences in acceptability levels based on demographic factors. We describe this survey in detail below.

3.3.1 Survey overview and respondent characteristics

For this survey, we first developed a structured questionnaire that incorporated the 35 statements from the Q methodology survey.

We contracted Macromill Embrain, a professional surveying firm with a large domestic and international respondent panel, to conduct the online survey in Germany and Korea. To ensure representativeness and reliability, a quota sampling method was applied based on gender and age distributions among the general adult populations in both countries.

In Korea, 250 out of 445 invited respondents (56.2%) completed the online survey from November 27 to November 30, 2024. In Germany, 250 out of 344 invited respondents (72.7%) participated in the survey on December 10, 2024, resulting in a total of 500 responses.

The characteristics of respondents from each country are presented in Table 33.

Table 33 **Survey respondent characteristics**

Category		Total		Korea		Germany	
		Case	%	Case	%	Case	%
Total		500	100	250	100	250	100
Age	20~29	85	17	41	16.4	44	17.6
	30~39	95	19	44	17.6	51	20.4
	40~49	99	19.8	53	21.2	46	18.4
	50~59	115	23	59	23.6	56	22.4
	60~69	106	21.2	53	21.2	53	21.2
Sex	Male	253	50.6	127	50.8	126	50.4
	Female	247	49.4	123	49.2	124	49.6
CF awareness	Heard of it	368	73.6	145	58	223	89.2
	Never heard of it	132	26.4	105	42	27	10.8
Number of Co-residents	1	104	20.8	35	14	69	27.6
	2~3	275	55	141	56.4	134	53.6
	4 or more	121	24.2	74	29.6	47	18.8
Occupation	Student	21	4.2	16	6.4	5	2
	Homemaker	54	10.8	38	15.2	16	6.4
	Employee	291	58.2	142	56.8	149	59.6
	Self-employed	25	5	14	5.6	11	4.4
	Freelancer	28	5.6	17	6.8	11	4.4
	Unemployed	39	7.8	22	8.8	17	6.8
	Other	42	8.4	1	0.4	41	16.4

Table 33 (continued)

Category		Total		Korea		Germany	
		Case	%	Case	%	Case	%
Workplace	Government/ Public Sector	45	15.5	21	14.8	24	16.1
	Company/ Business	210	72.2	112	78.9	98	65.8
	University/ Research Institute	6	2.06	4	2.82	2	1.34
	Other	25	8.59	0	0	25	16.8
	Educational Institution	3	1.03	3	2.11	0	0
	Hospital/ Medical Facility	2	0.69	2	1.41	0	0

Source The authors.

The largest age group among survey respondents was 50–59 years old (23.0%), followed by those aged 40–49 (19.8%) and 30–39 (19.0%), with each group representing a similar share of the sample. The age distribution was comparable between Korea and Germany, with no significant differences observed in the proportion of respondents across age groups. In terms of gender, 50.6% were male and 49.4% were female, showing a nearly balanced distribution, with similar trends in both countries.

Regarding CF awareness, 73.6% of respondents overall reported having heard of it. However, there was a significant difference between countries: while only 58.0% of Korean respondents were aware of the term, 89.2% of German respondents recognized it.

In terms of household size, the most common category among respondents was living with 2–3 people (55.0%). However, notable differences emerged between the two countries: single-person households were more prevalent in Germany (27.6%) than in Korea (14.0%), whereas households with four or more members were more common in Korea (29.6%) compared to Germany (18.8%).

By employment status, corporate and public sector employees accounted for 58.2% of survey respondents. The proportion of homemakers was higher in Korea (15.2%) than in Germany (6.4%), while more German respondents chose the “other” category (16.4%) than Koreans (0.4%).

By occupation, the majority of survey respondents (72.2%) were affiliated with companies and businesses, followed by government/public institutions (15.5%). Relatively fewer respondents were working in universities/research institutes (2.1%), other fields (8.6%), educational institutions (1.0%), and hospitals/medical facilities (0.7%).

A notable difference between the two sets of respondents was that a higher proportion of Korean respondents reported working for firms, universities, and educational institutions, while the German responses indicated more diverse occupational distribution, with a large share of respondents selecting the "other" category (16.8%).

Regarding monthly household income distribution, the most common income bracket in Korea was KRW 2–4 million (28.4%), whereas in Germany, the most common range was EUR 2,000–4,000 (approximately KRW 2.9–5.8 million) (42%) (See Table 34).

Table 34 **Monthly income of respondents in Korea and Germany**

Category	Range	Case	%
Monthly income (Korea)	Below 2 million KRW	23	9.2
	2–4 million KRW	71	28.4
	4–6 million KRW	64	25.6
	6–8 million KRW	56	22.4
	8–10 million KRW	19	7.6
	Above 10 million KRW	17	6.8
Monthly income (Germany)	Below 2,000 EUR	66	26.4
	2,000–4,000 EUR	105	42.0
	4,000–6,000 EUR	47	18.8
	6,000–8,000 EUR	17	6.8
	8,000–10,000 EUR	6	2.4
	Above 10,000 EUR	9	3.6

Source The authors.

Examining the educational background of survey respondents (see Table 35), we can observe that a strong majority of Korean respondents reported having obtained at least a Bachelor's degree (77.6%). In contrast, in Germany, a larger share of respondents had only obtained a secondary education (Realschulabschluss) (40%), while the proportion of those with a bachelor's degree or higher was relatively lower (23.6%).

Table 35 **Education level of respondents in Korea and Germany**

Category	Range	Case	%
Education level (Korea)	High school graduate or below (Including currently enrolled)	39	15.6
	Currently enrolled in University	17	6.8
	University graduate	168	67.2
	Graduate school enrollment or higher	26	10.4

Table 35 (continued)

Category	Range	Case	%
Education level (Korea)	High school graduate or below (Including currently enrolled)	39	15.6
	Currently enrolled in University	17	6.8
	University graduate	168	67.2
	Graduate school enrollment or higher	26	10.4
Education level (Germany)	Kein Abschluss	4	1.6
	Hauptschulabschluss	32	12.8
	Realschulabschluss	100	40.0
	Abitur	37	14.8
	Fachhochschulreife	18	7.2
	Bachelor-Abschluss	34	13.6
	Master-Abschluss	22	8.8
	Promotion	3	1.2

Source The authors.

3.3.2 Measurement of acceptability for CF reduction planning elements and policies[83)]

Before measuring the acceptability of CF reduction planning elements and policies, respondents were first asked general questions related to the concept of the carbon footprint before proceeding with the survey. These included questions that asked respondents they had heard of the term “carbon footprint“ before (A1), the extent to which they agreed with the idea that individuals should reduce consumption activities related to carbon emissions to address the global climate crisis and achieve carbon neutrality (A2), and how well they believed they understood how to reduce their own carbon footprints (A3).

To measure the acceptability of sector-specific CF reduction planning elements and policy items, we adopted the scale proposed in Danielson (2009). Survey items (A4-1 to A7-1) were structured using a 7-point Likert scale, with responses ranging from “strongly disagree” (1) to “strongly agree” (7).

To address the possibility that some respondents might assign the same score to every item—for example, consistently selecting the midpoint of 4—additional questions were included to help prioritize the relative acceptability of items within each sector and reveal clearer preference patterns.

83) The symbols in parentheses refer to the survey items included in the questionnaire attached in the appendix.

First, among the five CF reduction planning elements and policy items in each of the seven sectors, respondents were asked to select the statements they most strongly agreed with and the statements they most strongly disagreed with (A4-1~7-2, A4-1~7-3). The statements selected within each sector were then compared again, and respondents were asked to choose the two most and two least agreeable statements across all sectors (A5, A6). Subsequently, as in the Q methodology interviews, respondents were asked to explain their reasons for selecting their top two most and least agreeable statements.

Beyond measuring the acceptability of 35 specific items, we included additional questions to assess the level of personal engagement in reducing consumption across the four key CF reduction sectors—food, housing, transportation, and goods (A7)—as well as the perceived necessity of social restrictions (mandatory regulations), personal willingness to reduce consumption, and the practical effectiveness of such measures (A8).

We referenced survey items from previous studies (Lee et al., 2019; The Ministry of Environment, 2024) to examine perceptions of energy transition policies closely related to CF reduction policies. The survey included questions about awareness of carbon neutrality goals (B1), support for the government's current carbon neutrality targets (B2), awareness of the UN-led international effort to limit global warming to 1.5°C (B3), and support for this goal (B4). In addition, respondents were asked about their level of agreement with measures required to achieve the 1.5°C target (B5-1~6). Respondents were also asked to prioritize key energy transition policies, including the phase-out of nuclear power (safety), renewable energy (environment), decentralization (society), job creation (economy), and demand management (energy) (B6-1), as well as to identify which of these policies had achieved the most success (B6-2). Furthermore, respondents were asked to rank the importance of key stakeholders—government, corporations, citizens, NGOs, and researchers (B7-1)—and to indicate which stakeholder was currently playing the most significant role (B7-2). In addition, we included five environmental awareness items (B8) and seven social awareness items (B9) in the survey.

Finally, we incorporated questions related to the characteristics of the respondents into the survey, including region of residence (C1), number of household members (C2), household monthly income (C3), educational attainment (C4), occupation and workplace (C5, C5-1), trust in the current government (C6), political orientation (C7), and and views toward materialism (Kim, D. et al., 2022, p. 42) (C8).

Chapter 4

Key Findings and Policy Implications

4.1 Perception types and acceptability in Korea and Germany

The Q methodology revealed five distinct perception types in Korea and four in Germany. These perception types ranged from strong supporters of technology-driven solutions to those advocating for behavioral changes and stricter regulations.

4.1.1 Comparison of perception types (Q, survey)

(1) Comparison of perception types in Korea

The results the Q methodology survey of the South Korean P-set on carbon footprint (CF) reduction point to a wide range of opinions on the matter. This necessitates a hybrid approach cutting carbon. All of the perception types (Factors) we identified were found to support carbon reduction, and so we expect that a collaborative response, where the government, businesses, and individuals share responsibilities, would be most effective. A balanced approach is required, where the government engages in policy intervention, businesses focus on sustainable innovation, and individuals adopt behavioral and consumption changes.

We found that Factors 1, 2, and 4 favor government-led intervention, making strong legislation and policy enforcement essential, whereas Factors 3 and 5 consider voluntary corporate and individual actions more effective, necessitating market-driven incentive policies. Carbon reduction policies can be adjusted by balancing the roles of government, businesses, and individuals.

Factor 2 respondents accepted increased costs, such as higher electricity prices, while Factors 3 and 5 opposed such cost increases. Therefore, policy designs such as subsidies for eco-friendly technologies and tax incentives for low-carbon products are necessary to promote carbon reduction without increasing taxes or prices.

We also propose that the government and private businesses work together to transition to a more effective model of urban and infrastructure development. In the case of Factor 5, some respondents believe that both policies and market forces should actively contribute to building sustainable urban development. In conclusion, environmental protection measures require a hybrid model that reflects diverse interests rather than a unilateral, top-down approach.

Table 36 **Analysis of commonalities and differences in perception types in Korea**

Classification	KR1 (Expert-Led)	KR2 (Policy Compliance)	KR3 (Individual Efforts)	KR4 (Planning-Oriented)	KR5 (Government Emphasis)
Carbon Reduction Approaches	Expansion of urban green spaces, ecological restoration	Strengthening government regulations, expansion of renewable energy	Encouraging citizen behavioral change	Leading urban planning and policy initiatives	Encouraging voluntary innovation by businesses
Government Role	Moderate level	Highly proactive	Limited intervention	Highly proactive	Minimal intervention
Corporate Role	Limited interest	Regulated subject	Limited interest	Subject of policy implementation	Taking a leading role
Individual Role	Indirectly contribute through the urban environment	Tax burden possible (e.g., electricity rate increase)	Emphasis on direct practice	Participation as a policy beneficiary	Inducing behavioral change as a consumer
Attitudes Toward Renewable Energy	Important but not a primary concern	Strong support	Passive	Government-level energy policy required	Concern about the burden of cost increases
Willingness to Bear Economic Costs	Some compromise acceptable for environmental preservation	Accepting rate increases	Sensitive to cost increases	Consideration of the economic feasibility of policy implementation	Opposition to increased economic burden

Source The authors.

(2) Comparison of perception types in Germany

Our Q methodology survey of the German P-set also suggested that a hybrid approach to CF reduction would be most effective. Factor 2 respondents are willing to bear the financial burden of increased electricity costs, whereas Factor 3 respondents oppose this and require alternative methods to reduce carbon emissions without raising carbon taxes.

Factors 1 and 4 emphasize the necessity of urban development and public investment, while Factor 2 stresses the importance of transitioning cities to a renewable energy-based system. Factor 3 respondents perceive individual behavioral changes as the most crucial aspect of carbon reduction and advocate for the promotion of campaigns encouraging actions such as recycling and use of public transportation.

In addition, achieving carbon reduction targets requires minimizing tax burdens while creating policy incentives that encourage voluntary participation in environmental protection by both businesses and individuals.

Table 37 **Analysis of commonalities and differences in perception types in Germany**

Classification	DE1 (Business-Centered)	DE2 (Regulatory Preference)	DE3 (Individual Efforts)	DE4 (Green Development)
Carbon Reduction Approaches	Government-led policy implementation	Strict enforcement of laws and regulations	Citizen-centered behavioral change	Expansion of eco-friendly infrastructure
Government Role	Highly proactive	Highly proactive	Supportive role	Urban planning-centered intervention
Corporate Role	Relatively weak	Regulated subject	Limited	Subject of policy implementation
Individual Role	Beneficiary of the policy	Tax burden acceptable	Playing a key role	Support for the expansion of green spaces and parks in cities
Attitudes Toward Renewable Energy	Recognizes the necessity of a government-led transition	Strong support for transition, willing to bear the burden	Recognizes the necessity of renewable energy but opposes increased personal financial burden	Adopting renewable energy through eco-friendly architecture
Willingness to Bear Economic Costs	Possible tax increase for policy implementation	Willing to accept electricity rate increases	Sensitive to cost increases	Recognition of the need for infrastructure investment

Source The authors.

The comparison of CF perception types in Korea and Germany reveals that respondents from both countries favor a mixed approach, in which the government, businesses, and individuals collaborate. However, differences exist in the roles and levels of intervention for each entity.

Korean respondents government-led policy implementation and planning, while simultaneously encouraging corporate innovation and consumer behavior change. In contrast, Germany recognizes strict legal and regulatory enforcement and voluntary individual action as key elements.

Regarding the role of the government, KR2 (Policy Compliance) and KR4 (Planning-Oriented) strongly favor proactive intervention, whereas DE1 (Business-Centered) and DE2 (Regulatory Preference) in support strong governmental involvement. In terms of corporate responsibility, respondents from both countries seemed to favor regulating the private sector, but the German respondents eco-friendly infrastructure expansion through policy implementation (DE4 : Green Development), while the Korean respondents favored a more proactive role for businesses (KR5 : Government Emphasis). As for individual responsibility, KR3 (Individual Efforts) focuses on direct personal actions, whereas DE3 (Individual Efforts) emphasizes a leading role in sustainable practices, prioritizing eco-friendly architecture and public transportation.

Regarding attitudes toward renewable energy transition, the German respondents were generally more supportive. In terms of economic burden acceptance, both countries display a mix of attitudes: some groups (KR1, KR2, DE1, DE2) are willing to bear the financial burden, while others (KR3, KR5, DE3) are more sensitive to cost increases.

While there are some similar perception types in Korea and Germany regarding the roles and levels of intervention for different entities, most perception types exhibit distinct differences. Therefore, directly comparing national tendencies has its limitations. Hence, in the next section we further classify the Korean and German survey respondents based on their perception types.

Table 38 **Comparison of Korea and Germany type by classification category**

Classification	Korea (KR) type	Germany (DE) type
Carbon reduction approaches	KR1 (Expert-led, Urban green space expansion), KR2 (Stronger government regulation, renewable energy expansion), KR3 (Promotion of individual behavioral change), KR4 (Urban planning and policy-led), KR5 (Encouraging corporate autonomous innovation)	DE1 (Government-Led Policy Implementation), DE2 (Strong Legal and Regulatory Enforcement), DE3 (Citizen Behavior Change-Oriented), DE4 (Expansion of Eco-Friendly Infrastructure)
Government role	KR2, KR4 (Highly proactive intervention), KR1 (Moderate intervention), KR3 (Limited intervention), KR5 (Minimal intervention)	DE1, DE2 (Highly proactive intervention), DE3 (Supportive role), DE4 (Urban planning-focused intervention)

Table 38 (continued)

Classification	Korea (KR) type	Germany (DE) type
Corporate role	KR1, KR3 (Limited interest), KR2 (Regulatory target), KR4 (Policy implementation target), KR5 (Leading role)	DE3 (Limited role), DE1 (Relatively weak), DE2 (Regulatory target), DE4 (Policy implementation target)
Individual role	KR1 (Indirect contribution through urban environment), KR2 (Willing to bear tax burdens), KR3 (Emphasis on direct individual action), KR4 (Participation as policy beneficiaries), KR5 (Encouraging behavioral change as consumers)	DE1 (Policy beneficiary), DE2 (Willing to bear tax burdens), DE3 (Plays a key role), DE4 (Adopts renewable energy through eco-friendly architecture)
Attitude toward renewable energy	KR2 (Strong support), KR1 (Important but not a primary concern), KR3 (Passive attitude), KR4 (Requires government-level energy policies), KR5 (Concern over rising costs)	DE2 (Strong support for transition, willing to bear costs), DE1 (Recognizes the need for government-led transition), DE3 (Acknowledges the need for renewable energy but opposes increased individual burden), DE4 (Adopts renewable energy through eco-friendly architecture)
Willingness to bear economic burden	KR2 (Accepts price increases), KR1 (Partially willing to accept), KR3 (Sensitive to cost increases), KR4 (Considers economic feasibility), KR5 (Opposes increased economic burden)	DE2 (Accepts electricity price increases), DE1 (Accepts tax increases necessary for policy implementation), DE3 (Sensitive to cost increases), DE4 (Recognizes the need for infrastructure investment)

Source The authors.

(3) Perception types of survey respondents

We classify the survey respondents' perception types following Kim et al. (2015) as follows:

In Q methodology, each perception type is determined by analyzing representative statements with an absolute Z-score of 1 or higher. The survey responses to these representative statements are weighted by multiplying them with the corresponding Z-score. The weighted values are then summed, and the sum is standardized by dividing it by the total weight, resulting in the representative score (T_i) for each perception type (i). The formula for calculating each perception type's representative score is given in Equation 1, using an example calculation for Korea's Type 1 (KR1) representative score (T_1).[84)]

84) Here, A_n and D_n represent the survey response values for statement number n that the respondent agrees with and disagrees with, respectively (A 7-point Likert scale was used for these responses).

$$T_1 = Agreement\ Score + Disagreement\ Score = \frac{z_{26}A_{26} + z_{30}A_{30} + z_5A_5 + \cdots + z_{35}A_{35}}{z_{26} + z_{30} + z_5 + \cdots + z_{35}} + \frac{z_9D_9 + z_{10}D_{10} + z_{19}D_{19} + \cdots + z_{14}D_{14}}{z_9 + z_{10} + z_{19} + \cdots + z_{14}}$$

Equation 1

For each perception type, the representative score (T_i) is calculated as described above, and the type with the highest representative score is assigned to each respondent as their acceptability type. This approach, which integrates Q methodology with survey research, offers the advantage of estimating the population distribution of each type by applying Q-analysis to a relatively large sample (Kim et al., 2015, pp. 83-84). The frequency and proportion of survey respondents classified by Q-type are presented in Table 39.

Table 39 **Survey respondent Q type classification results**

Country	Type		Frequency	Ratio
Korea	KR3	Individual Efforts	73	29.2%
	KR5	Government Emphasis	55	22.0%
	KR1	Expert-Led	53	21.2%
	KR4	Planning-Oriented	26	10.4%
	KR2	Policy Compliance	21	8.4%
	Unknown	Unclassified	22	8.8%
	Total		228	100.0%
Germany (Deutschland)	DE4	Green Development	117	46.8%
	DE3	Individual Efforts	83	33.2%
	DE2	Regulatory Preference	23	9.2%
	DE1	Business-Centered	13	5.2%
	Unknown	Unclassified	14	5.6%
	Total		236	100.0%

Source The authors.

In Korea, the largest proportion of respondents fell under Type 3 (KR3: Individual Efforts), with 73 individuals (29.2%). This was followed by Type 5 (KR5: Government Emphasis), with 55 respondents (22.0%), and Type 1 (KR1: Expert-Led), with 53 respondents (21.2%).

In Germany, the majority of respondents were categorized under Type 4 (DE4: Green Development) and Type 3 (DE3: Individual Efforts), accounting for 117 (46.8%) and 83 (33.2%) individuals, respectively, together making up 80% of the total sample.

In Germany, Type 4 (DE4: Green Development) and Type 3 (DE3: Individual Efforts) accounted for the

majority (80%), with 117 respondents (46.8%) and 83 respondents (33.2%), respectively.

A small portion of respondents (22 Koreans (5.6%) and 14 Germans (8.8%)) provided identical response values for all statements (e.g., selecting only the midpoint value of 4 or the maximum value of 7). As a result, their representative scores were equal, making it impossible to classify them into a single acceptability type.

A summary of the Q-type classifications of survey respondents reveals contrasting patterns between Korea and Germany. In Korea, responses reflect a pluralistic model, with a relatively balanced distribution across individual efforts (29.2%), government and local authority emphasis (22.0%), and expert-led approaches (21.2%). In Germany, by contrast, a larger share of respondents emphasized the role of green development (46.8%), while individual efforts (33.2%) also accounted for a significant portion.

In addition, we found that the Korean respondents seemed to prefer expert-led (21.2%) and planning-centered approaches (10.4%), whereas the German respondents favored regulation (9.2%) and business-centered approaches (5.2%). Regarding policy attitudes, the Korean respondents exhibited some policy compliance tendencies (8.4%), while while the Germans preferred a business-centered approach, rather than strict policy adherence.

Table 40 below summarizes the mode values of respondent characteristics for the Korean respondents.

Table 40 Respondent characteristics by perception type (Korea)

Korea	KR0 Unclassified	KR1 Expert-Led	KR2 Policy Compliance	KR3 Individual Efforts	KR4 Planning-Oriented	KR5 Government Emphasis
Ratio	8.8%	21.2%	8.4%	29.2%	10.4%	22.0%
Age	40~49, 50~59	40~49	20~29	60~69	30~39	30~39
Gender	Male	Female	Male	Female	Male	Male
Monthly income	400~600 million KRW	600~800 million KRW	400~600 million KRW	200~400 million KRW	400~600 million KRW	200~400 million KRW
Education level	University Graduate	University Graduate	University Graduate	University Graduate	University Graduate	University Graduate
Occupation	Office Worker	Office Worker	Office Worker	Office Worker	Office Worker	Office Worker
Workplace	Company, Corporate	Company, Corporate	Company, Corporate	Company, Corporate	Company, Corporate	Company, Corporate

Table 40 **(continued)**

Korea	KR0 Unclassified	KR1 Expert-Led	KR2 Policy Compliance	KR3 Individual Efforts	KR4 Planning-Oriented	KR5 Government Emphasis
Government trust	Neutral	Distrust	Distrust	Neutral	Distrust, Neutral	Distrust
Political	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Materialism	Mixed Type	Mixed Type	Mixed Type	Mixed Type	Mixed Type	Mixed Type

Source The authors.

We can see that mode values vary by perception type. By age group, the KR2 (Policy Compliance) type had the highest number of respondents in their 20s, while the KR3 (Individual Efforts) type had the most respondents in their 60s. Regarding gender, KR1 (Expert-Led) and KR3 (Individual Efforts) types had more female respondents than male respondents, whereas all other types had more male respondents. In terms of household monthly income, respondents in the KR1 (Expert-Led) type were most commonly in the KRW 6-8 million range, whereas KR3 (Individual Efforts) and KR5 (Government Emphasis) types had the most respondents in the KRW 2-4 million range.

Across all perception types, the majority of respondents were college graduates and corporate employees. Most perception types showed the highest concentration of responses at the lowest end of the scale (distrust = 1). Notably, KR3 (Individual Efforts) had the largest number of neutral responses, while KR4 (Planning-Oriented) showed an even split between distrust (3) and neutral (4), with eight respondents in each category. When grouping scores 1-3 as "untrustworthy," 4 as "neutral," and 5-7 as "trustworthy," we found that distrust was the most common sentiment across all perception types.

In terms of political orientation and materialism/post-materialism, a moderate political stance and mixed value orientations were the most frequently selected responses across all groups.

Our findings point to a great diversity of perception types, and suggests that policy makers could take this diversity into account. Since the Policy Compliance (KR2) type is more prevalent among younger respondents in their 20s, and the Individual Efforts (KR3) type more common among those in their 60s, differentiated policy approaches by age group are necessary. Since distrust of government was observed among all perception types, we recommend governments take proactive steps to improve policy credibility.

In Germany, the DE1 (Business-Centered) type was most common among respondents in their 20s, DE3 (Individual Efforts) in their 50s, and DE4 (Green Development) in their 60s, necessitating

differentiated policy approaches by age group. Men tended to favor business-oriented policies and policies and individual effort, while women preferred a regulation-based approach and eco-friendly policies.

In the DE1 (Business-Centered) type, respondents came from a wide range of income levels below the EUR 4,000 per month mark, whereas DE2 (Regulatory Preference) respondents were predominantly higher earners (EUR 4,000-6,000 per month). Most respondents reported that they had obtained a *Realschulabschluss* (general high school diploma) and were corporate employees. Among perception types, only the DE (Business-Centered) type indicated a high level of trust in government (5 points), while DE3 (Individual Efforts) and DE4 (Green Development) showed the highest level of distrust. In all types, the most common political stance was moderate, and values were predominantly mixed.

These findings indicate that in Germany, policy acceptance varies by age, gender, and economic background, necessitating tailored policy approaches. For perception types with low levels of trust in government, autonomy-based policies may be more effective than regulatory policies. Since we observed political views to be overall quite moderate, practical and balanced policies are likely to achieve higher acceptance.

Table 41 **Respondent characteristics by perception type (Germany)**

Germany	DE0 Unclassified	DE1 Business-Centered	DE2 Regulatory Preference	DE3 Individual Efforts	DE4 Green Development
Ratio	5.6%	5.2%	9.2%	33.2%	46.8%
Age	40~49	20~29	30~39	50~59	60~69
Gender	Female	Male	Female	Male	Female
Monthly income	2,000~4,000 Euro	less than 4,000 Euro	4,000~6,000 Euro	2,000~4,000 Euro	2,000~4,000 Euro
Education level	Hauptschulab schluss	Realschulab schluss	Realschulab schluss	Realschulab schluss	Realschulab schluss
Occupation	Office Worker	Office Worker	Office Worker	Office Worker	Office Worker
Workplace	Company, Corporate	Company, Corporate	Company, Corporate	Company, Corporate	Company, Corporate
Government trust	Neutral	Trust	Neutral	Distrust	Distrust
Political	Moderate	Moderate	Moderate	Moderate	Moderate
Materialism	Post-Materialism, mixed-type	Mixed type	Mixed type	Mixed type	Mixed type

Source The authors.

In summary, we found a mixed system with a range of approaches among the Korean respondents,

while the German respondents tended to prefer a policy model that emphasizes both green development and individual efforts. That said, some respondents did not fit clearly into a single perception type, and even within the same type, levels of agreement with individual statements varied.

In the next section, we explore how respondents in Korea and Germany ranked individual statements, comparing the degree of acceptance by analyzing which items participants agreed with the most (and least) within each sector.

4.1.2 Comparison of survey response acceptability means (t-test)

In the survey, a 7-point Likert scale was used to measure responses, and a t-test was conducted to compare the statistical differences in means between the Korean and German respondent groups. The results are presented in Table 42.

Table 42 Comparison of acceptability for CF reduction planning elements and policies

Questions		Korea	Germany	Germany -Korea	T-Statistic	P-Value
A1. Before this survey, had you ever heard of a "carbon footprint"? (No = 1, Yes = 2)		1.42	1.108	0.312	8.44	0.00
A2. How much do you agree that we should reduce our personal consumption activities related to carbon emissions in order to combat the global climate crisis and become carbon neutral?		5.656	5.016	0.64	4.70	0.00
A3. How much do you think you know about what you can do to reduce your carbon footprint?		4.084	4.408	-0.324	-2.52	0.01
A4-1-1. Overall	1. Individuals food, housing, transportation, and goods and services.	5.568	5.156	0.412	2.90	0.00
	2. Urban planning and design is needed to reduce the carbon footprint of city dwellers.	5.744	5.208	0.536	4.08	0.00
	3. The government and local authorities should roll out policies, programs, and initiatives to reduce their carbon footprint.	5.844	5.112	0.732	5.34	0.00
	4. Companies need to take steps to reduce their carbon footprint in their manufacturing processes.	6.004	5.492	0.512	3.99	0.00
	5. I support increased investment and support for research and development of technologies that reduce our carbon footprint.	5.76	5.184	0.576	4.56	0.00

Table 42 (continued)

Questions		Korea	Germany	Germany -Korea	T-Statistic	P-Value
A4-2-1. Food	6. I support expanding and revitalizing local farmers markets.	5.596	5.436	0.16	1.34	0.18
	7. The government and local authorities should promote the certification and consumption of low-carbon, eco-friendly, and organic agricultural products.	5.632	5.264	0.368	2.85	0.00
	8. Individuals meat and imported/packaged/ processed foods.	5.172	5.128	0.044	0.30	0.76
	9. Companies should ramp up efforts to expand plant-based options in restaurants and stores, along with developing meat alternatives.	5.136	4.48	0.656	4.58	0.00
	10. I support plans that reduce transportation distances by producing and consuming food within cities, like urban farming.	5.2	5.3	-0.1	-0.78	0.44
A4-3-1. Housing	11. I support green remodeling efforts that improve the energy efficiency of existing buildings.	5.676	5.16	0.516	4.04	0.00
	12. I support installing renewable energy sources like solar panels and solar thermal systems on buildings and homes.	5.696	5.292	0.404	3.01	0.00
	13. Individuals should make an effort to conserve electricity, gas, and water at home.	5.656	5.392	0.264	1.96	0.05
	14. Require buildings or factories to install green roofs or solar panels.	5.296	4.668	0.628	4.12	0.00
	15. Require new buildings to be designed as zero-energy buildings, meaning they do not rely on external energy sources.	5.268	5.232	0.036	0.27	0.79
A4-4-1. Travel	16. Individuals should make an effort to use public transportation, such as buses, trains, or bikes, instead of driving their own cars.	5.492	4.744	0.748	5.24	0.00
	17. I support expanding bike lanes and pedestrian walkways.	5.5	5.056	0.444	3.16	0.00
	18. I support limiting the use of high carbon-emission vehicles.	5.452	4.428	1.024	6.91	0.00

Table 42 **(continued)**

Questions		Korea	Germany	Germany -Korea	T-Statistic	P-Value
A4-4-1. Travel	19. I support plans and designs that increase the proportion of residential areas and population density within cities to reduce urban sprawl through mixed-use development.	5.16	4.556	0.604	4.34	0.00
	20. I support expanding the infrastructure for electric vehicle charging and dedicated parking spaces.	5.064	4.704	0.36	2.55	0.01
A4-5-1. Waste	21. We all need to do our part to reduce food and general waste and increase recycling and reuse.	5.696	5.592	0.104	0.79	0.43
	22. The government and local authorities should implement policies to reduce single-use items in places like stores and hotels.	5.432	5.216	0.216	1.52	0.13
	23. I support policies that discourage single-use products and mandate reusable containers.	5.436	5.272	0.164	1.21	0.23
	24. Companies need to cut back on product packaging and create reusable containers.	5.948	5.64	0.308	2.53	0.01
	25. I support the plan to build a biogas facility with organic waste such as food waste, livestock manure, and sewage sludge.	5.716	5.28	0.436	3.56	0.00
A4-6-1. Sink	26. I support increasing the amount of green space and parks in urban areas.	5.84	5.536	0.304	2.50	0.01
	27. Companies should get involved in programs and initiatives that expand carbon sinks, such as creating parks and planting trees.	5.792	5.432	0.36	2.94	0.00
	28. I support expanding the greenbelt designation, which limits development on existing green spaces.	5.408	5.2	0.208	1.53	0.13
	29. The government should invest more in research and development to boost the carbon-absorbing capacity of our forests and green spaces.	5.756	5.368	0.388	3.10	0.00
	30. We need an ecological restoration plan that includes green spaces and biotopes that take biodiversity into account.	5.7	5.42	0.28	2.26	0.02

Table 42 (continued)

Questions		Korea	Germany	Germany -Korea	T-Statistic	P-Value
A4-7-1. issue	31. Citizen engagement should be fully integrated into city planning, policies, programs, and procedures that aim to reduce carbon footprint.	5.408	4.912	0.496	3.81	0.00
	32. I support putting small modular reactors (SMRs) in cities that need a lot of electricity.	4.892	4.404	0.488	3.10	0.00
	33. I support phasing out coal-fired power plants, even if it means paying more for electricity.	4.504	4.024	0.48	2.96	0.00
	34. The government and local authorities should expand their social media campaigns to reduce their carbon footprint.	5.256	4.652	0.604	4.35	0.00
	35. I support raising electric rates to encourage the energy transition and to reduce our carbon footprint.	4.316	3.308	1.008	6.01	0.00

Source The authors.

(1) Perception of carbon footprint (A1, A2, A3)

In examining CF perceptions (A1), agreement on the necessity of reducing consumption activities (A2), and awareness of CF reduction methods (A3), Korean respondents demonstrated a higher level of awareness of the the carbon footprint concept compared to German respondents (1.42 > 1.108). They also expressed stronger agreement with the necessity of reducing personal consumption activities (5.656 > 5.016). However, German respondents had a higher level of awareness of specific methods to reduce their CFs. (4.084 < 4.408).

This suggests that in Korea, public awareness and consensus on the importance of environmental issues have grown rapidly in recent years, leading to increased conceptual recognition and agreement on the necessity of action. However, education and public outreach regarding specific reduction methods may still be lacking. In contrast, Germany has long engaged in discussions on concrete sustainability practices, likely contributing to a higher level of public understanding of specific carbon footprint reduction methods.

As a result, in Korea, educational programs and public awareness campaigns focused on specific actions for CF reduction may be necessary. Meanwhile, in Germany, citizens are already well-informed about reduction methods, so there may be greater interest in structural and policy-level changes

rather than individual behavioral shifts. These differences may stem from variations in environmental policies, education systems, and media coverage in each country, indicating the need for tailored policies and communication strategies that reflect these contextual factors.

(2) Sectoral comparison (differences)

For this section, we conducted a comparative analysis of with p-values below 0.05 and high t-values, indicating statistically significant differences in acceptability between Korea and Germany across seven sectors.

- (Overall) Necessity of CF reduction policies by governments and local authorities (Item 3)
  - Korea (5.844) > Germany (5.112), Difference: +0.732, t = 5.34, $p < 0.05$
  - The survey results suggest that Korean respondents support government-led carbon reduction policies more strongly than the German respondents. In Korea, there is a strong societal perception that policy intervention is necessary, whereas in Germany the emphasis seems to be on voluntary responses from individuals and businesses.

- (Food) Necessity of promoting the development of plant-based alternative foods by companies (Item 9)
  - Korea (5.136) > Germany (4.480), Difference: +0.656, t = 4.58, $p < 0.05$
  - The Korean respondents indicated a stronger preference for the development of plant-based alternatives to meat than the German respondents. While vegan culture is already well-established in Germany, the plant-based food market in Korea remains in its infancy, which may contribute to higher expectations among the survey respondents. However, item 9 had the lowest acceptability scores in the food sector for both countries.
- (Housing) Mandatory installation of green roofs and solar panels in buildings and factories (Item 14)
  - Korea (5.296) > Germany (4.668), Difference: +0.628, t = 4.12, $p < 0.05$
  - The Korean respondents were more supportive of mandatory eco-friendly retrofits and installations in the building sector than the Germans. Germany already enforces strict eco-friendly building standards, while Korea is in the early stages of implementing such policies, leading to stronger calls for policy reinforcement. Notably, item 14 had the lowest acceptability in the residential sector in Germany.

- (Travel) Necessity of restrictions on high-carbon emission vehicles (Item 18)
  - Korea (5.452) > Germany (4.428), Difference: +1.024, t = 6.91, $p < 0.05$
  - The Korean respondents were more supportive of restrictions on carbon-intensive vehicles

than the Germans. This may be due to concerns over air pollution and growing interest in eco-friendly vehicle transition policies in Korea. In Germany, item 18 had the lowest acceptability in the transportation sector, which may be influenced by the strong presence of the automotive industry.

- (Waste) Necessity of constructing biogas facilities utilizing food waste (Item 25)
  - Korea (5.716) > Germany (5.280), Difference: +0.436, t = 3.56, $p < 0.05$
  - The Korean respondents were found to be more supportive of new biogas facilities based on food waste than the German respondents. This may be due to the severity of food waste issues in Korea and the increasing movement toward utilizing waste as an energy resource.

- (Sinks) Necessity of government investment in research and development to enhance the carbon absorption capacity of forests and green areas (Item 29)
  - Korea (5.756) > Germany (5.368), Difference: +0.388, t = 3.10, $p < 0.05$
  - We found Korean survey respondents were more supportive of efforts to invest in forest and green space carbon sink R&D than the German respondents. This may be due to limited green spaces in Korea and the high demand for urban green expansion policies.

- (Issues) Encouraging energy transition through electricity price increases (Item 35)
  - Korea (4.316) > Germany (3.308), Difference: +1.008, t = 6.01, $p < 0.05$
  - Overall, the Korean respondents were more supportive of electricity price hikes than the German respondents. We suspect this is because Germany already has relatively high electricity prices, leading to greater opposition to further increases. In contrast, Korea has relatively lower electricity rates, and there is a perception that higher prices may be necessary to promote energy transition. However, item 35 had the lowest acceptability scores in the issue sector for both countries, so these results should be interpreted conservatively.

In the following material we briefly summarize some of the major differences in policy preferences between the Korean side and the German side. The Korean respondents support government-led intervention and policy reinforcement for carbon reduction more strongly, while the German respondents prefer voluntary responses by individuals and businesses. In addition, Korea strongly demands corporate-driven plant-based food development and mandatory eco-friendly infrastructure in buildings, while the German respondents were more lukewarm to the idea, likely owing to the fact that Germany already has already established these kinds of policies.

In the travel sector, the Korean side strongly supports restricting high-carbon vehicle usage, whereas the Germans were more resistant to the idea, likely due to the influence of the automotive industry.

Regarding the energy transition, the Koreans were more accepting of electricity price increases as a means of promoting transition, but the German respondents—already paying high electricity prices—were strongly opposed to further increases.

In terms of expanding carbon sinks, we found the Korean respondents were strongly supportive of investment in R&D to enhance the carbon absorption capacity of forests and green spaces while in Germany—which has already implemented forest conservation policies at scale—the respondents saw less need for additional investment in these areas. These differences may be attributed to variations in policy environments, industrial structures, and societal perceptions between the two countries.

(3) Sectoral comparison (similarities)

For this section, we conducted a comparative analysis of items with p-values above 0.05 or small absolute t-values, indicating the least difference in responses between the two countries (items 1, 8, 15, 20, 21, 28, and 33).

The items with the least response differences between respondents were Food (Item 8, P=0.76, t=0.3) and Housing (Item 15, P=0.79, t=0.27), where there was almost no difference in opinions between the two countries. In contrast, the responses on miscellaneous issues related to the phase-out of coal-fired power plants and electricity price increases (Item 33, P=0.00, t=2.96) showed the smallest response difference, but still exhibited a statistically significant difference.

Personal effort (Item 1) and waste-related policies (Item 21) also showed relatively consistent opinions across both countries. Similarly, the level of support for green space preservation (Item 28) and the expansion of electric vehicle infrastructure (Item 20) were relatively similar.

In conclusion, we observed a rough consensus among the respondents from both countries form with regards to practical efforts, such as reducing personal food consumption (Item 1), adopting zero-energy building technologies in the housing sector (Item 8), and individual waste reduction (Item 21). However, we did notice a significant divergence in opinions with regards to policy, such as the phase-out of coal-fired power plants and increased electricity prices (Item 33).

4.1.3 Comparison of survey response acceptability rankings (nominal)

(1) Comparative analysis of the most agreed items by sector

The most widely agreed-upon items in each sector—along with their respective response rates—are summarized in Table 43. These top-ranked statements reflect the items that received the highest level

of agreement from survey respondents in Korea and Germany across the five sectors.

In the overall carbon footprint category (A4-1-2), Korean respondents showed the strongest support (33.2%) for the statement: "Companies need to take steps to reduce their carbon footprint in their manufacturing processes." In contrast, the top response in Germany (32.4%) was: "Individuals should make an effort to reduce their consumption of food, housing, transportation, and goods and services."

For the food sector (A4-2-2), the most agreed-upon item in Korea (35.6%) was: "The government and local authorities should promote the certification and consumption of low-carbon, eco-friendly, and organic agricultural products." Meanwhile, in Germany, the leading response (27.6%) was: "Individuals should make an effort to reduce their consumption of meat and imported/packaged/processed foods."

In the housing sector (A4-3-2), both Korea and Germany shared the same top-ranked item: "Individuals should make an effort to conserve electricity, gas, and water at home," with agreement levels of 32.4% and 34%, respectively.

For the transportation sector (A4-4-2), Koreans most frequently agreed (37.2%) with the statement: "Individuals should make an effort to use public transportation, such as buses, trains, or bikes, instead of driving their own cars." In Germany, the most supported item (29.2%) was: "I support expanding bike lanes and pedestrian walkways."

In the waste sector (A4-5-2), the highest agreement in Korea (34.8%) went to: "Companies need to cut back on product packaging and create reusable containers." German respondents most often agreed (35.2%) with: "We all need to do our part to reduce food and general waste and increase recycling and reuse."

For the sinks sector (A4-6-2), both Korean and German respondents most strongly supported: "I support increasing the amount of green space and parks in urban areas," with 26.0% and 26.4% agreement, respectively. Finally, in the miscellaneous issues sector (A4-7-2), both countries again shared the same top-ranked item: "Citizen engagement should be fully integrated into city planning, policies, programs, and procedures that aim to reduce carbon footprint," selected by 32.4% of Korean and 34.0% of German respondents.

Table 43 **Items with high acceptability by sector and response rates**

Index	Korea	%	Germany	%
A4-1-2. Overall	4. Companies need to take steps to reduce their carbon footprint in their manufacturing processes.	33.2	1. Individuals should make an effort to reduce their consumption of food, housing, transportation, and goods and services.	32.4
A4-2-2. Food	7. The government and local authorities should promote the certification and consumption of low-carbon, eco-friendly, and organic agricultural products.	35.6	8. Individuals should make an effort to reduce their consumption of meat and imported/packaged/processed foods.	27.6
A4-3-2. Housing	13. Individuals should make an effort to conserve electricity, gas, and water at home.	32.4	13. Individuals should make an effort to conserve electricity, gas, and water at home.	34
A4-4-2. Travel	16. Individuals should make an effort to use public transportation, such as buses, trains, or bikes, instead of driving their own cars.	37.2	17. I support expanding bike lanes and pedestrian walkways.	29.2
A4-5-2. Waste	24. Companies need to cut back on product packaging and create reusable containers.	34.8	21. We all need to do our part to reduce food and general waste and increase recycling and reuse.	35.2
A4-6-2. Sink	26. I support increasing the amount of green space and parks in urban areas.	26	26. I support increasing the amount of green space and parks in urban areas.	26.4
A4-7-2. Issue	31. Citizen engagement should be fully integrated into city planning, policies, programs, and procedures that aim to reduce carbon footprint.	38.4	31. Citizen engagement should be fully integrated into city planning, policies, programs, and procedures that aim to reduce carbon footprint.	31.6

Note %: Response rates for the item among the five items in each sector.
Source The authors.

Overall, we found that the Korean respondents more strongly corporate responsibility in CF reduction, whereas the Germans placed greater importance on individual actions. Respondents from both countries recognized the crucial role of governments and local authorities in promoting sustainable food consumption, and they generally agreed that individual efforts to conserve energy at home are essential in the residential sector.

In the travel sector, Koreans emphasized the use of public transportation, while Koreans emphasized more on infrastructure improvements, such as the expansion of bicycle lanes and pedestrian spaces. Regarding waste management, the Korean respondents stressed the need for more corporate responsibility in reducing packaging and increasing recyclability, whereas the Germans placed more importance on individual efforts in waste sorting and recycling.

the Germans placed strongly support the expansion of green spaces in urban areas and the need to involve local residents and community members in CF reduction suggesting a universal policy-making, emphasizing the need for policy interventions to create sustainable urban environments. Considering these differences, Korea may benefit from stronger corporate regulations and policy support, while Germany may require infrastructure expansion to encourage proactive individual participation in carbon reduction efforts.

(2) Comparative analysis of the least agreed items by sector

The least agreed-upon items in each sector—along with their corresponding response rates—are summarized in Table 44. These statements reflect the items with the highest levels of disagreement among survey respondents in Korea and Germany.

In the overall carbon footprint category (A4-1-3), Korean respondents most frequently disagreed (38.0%) with the statement: “Individuals should make an effort to reduce their consumption of food, housing, transportation, and goods and services.” In Germany, the highest level of disagreement (28.4%) was with the statement: “The government and local authorities should roll out policies, programs, and initiatives to reduce their carbon footprint.”

For the food sector (A4-2-3), the most disagreed-upon item in Korea (34.0%) was: “Individuals should make an effort to reduce their consumption of meat and imported/packaged/processed foods.” In Germany, the top disagreement (36.0%) was with the statement: “Companies should ramp up efforts to expand plant-based options in restaurants and stores, along with developing meat alternatives.”

In the housing sector (A4-3-3), Korean respondents most often disagreed (29.6%) with: “Require new buildings to be designed to be zero energy, meaning they don’t rely on outside energy sources.” In Germany, the most disagreed-upon item (34.8%) was: “Require buildings or factories to install green roofs or solar panels”

For the transportation sector (A4-4-3), the highest disagreement in Korea (31.2%) was with: “I support expanding the infrastructure for electric vehicle charging and dedicated parking spaces.” In Germany, the statement receiving the most disagreement (28.8%) was: “°I support plans and designs that

increase the proportion of residential areas and population density within cities to reduce urban sprawl through mixed-use development."

In the waste sector (A4-5-3), Korean respondents most disagreed (28.0%) with: "The government and local authorities should implement policies to reduce single-use items in places like stores and hotels." In Germany, the highest disagreement (26.4%) was with: "I support the plan to build a biogas facility with organic waste such as food waste, livestock manure, and sewage sludge."

In the sinks sector (A4-6-3), Korean respondents showed the highest level of disagreement (40.4%) with the statement: "I support expanding the greenbelt designation, which limits development on existing green spaces." In Germany, the most disagreed-upon item (26.4%) was: "The government should invest more in research and development to boost the carbon-absorbing capacity of our forests and green spaces."

Finally, in the miscellaneous issues sector (A4-7-3), both Korean and German respondents most strongly disagreed with the same statement: "I support raising electric rates to encourage the energy transition and to reduce our carbon footprint," with 42.8% and 42.4% disagreement, respectively.

Table 44 **Items with low acceptance by sector and response rate**

Index	Korea	%	Germany	%
A4-1-3. Overall	1. Individuals should make an effort to reduce their consumption of food, housing, transportation, and goods and services.	38	3. The government and local authorities should roll out policies, programs, and initiatives to reduce their carbon footprint.	28.4
A4-2-3. Food	8. Individuals should make an effort to reduce their consumption of meat and imported/packaged/processed foods.	34	9. Companies should ramp up efforts to expand plant-based options in restaurants and stores, along with developing meat alternatives.	36
A4-3-3. Housing	15. Require new buildings to be designed as zero-energy buildings, meaning they do not rely on external energy sources.	29.6	14. Require buildings or factories to install green roofs or solar panels.	34.8
A4-4-3. Travel	20. I support expanding the infrastructure for electric vehicle charging and dedicated parking spaces.	31.2	19. I support plans and designs that increase the proportion of residential areas and population density within cities to reduce urban sprawl through mixed-use development.	28.8

Table 44 (continued)

Index	Korea	%	Germany	%
A4-5-3. Waste	22. The government and local authorities should implement policies to reduce single-use items in places like stores and hotels.	28	25. I support the plan to build a biogas facility with organic waste such as food waste, livestock manure, and sewage sludge.	26.4
A4-6-3. Sink	28. I support expanding the greenbelt designation, which limits development on existing green spaces.	40.4	29. The government should invest more in research and development to boost the carbon-absorbing capacity of our forests and green spaces.	26.4
A4-7-3. Issue	35. I support raising electric rates to encourage the energy transition and to reduce our carbon footprint.	42.8	35. I support raising electric rates to encourage the energy transition and to reduce our carbon footprint.	42.4

Note %: Response rates for the item among the five items in each sector.
Source The authors.

The results of this study highlight differences in perceptions of carbon footprint reduction between Korea and Germany, with a key finding being the contrast in acceptance levels between policy intervention and individual action.

In Korea, there was relatively higher resistance to changes in personal consumption and lifestyle, with particularly strong opposition to expanding electric vehicle infrastructure and restricting green space development. In Germany, while government and corporate roles were acknowledged, there was greater resistance to policy regulations and urban planning changes compared to Korea.

These differences may stem from variations in social values, economic conditions, and trust in policies in each country. The findings suggest that for effective CF reduction policies, a tailored approach that considers national characteristics and public acceptance levels is essential.

(3) Comprehensive analysis of acceptability ranking comparison

When comparing the acceptability of CF reduction measures across sectors between the two countries, a notable finding is that the most agreed-upon and least agreed-upon items were often reversed between Korea and Germany.

For example, in the Overall and Food sectors, the statements “Individuals should make an effort to reduce their consumption of food, housing, transportation, and goods and services” (Overall) and “Individuals should make an effort to reduce their consumption of meat and imported/packaged/processed foods”

(Food) received the highest levels of agreement among German respondents. In contrast, these same statements were the least agreed-upon items among respondents in Korea.

This result suggests that differences in cultural values, trust in policies, and perceptions of individual responsibility significantly influence the acceptability of CF reduction actions. The German respondents seemed to view individual behavioral changes as a key solution, emphasizing voluntary actions, whereas the Korean side placed greater importance on the role of governments and businesses rather than individual responsibility.

Table 45 below presents a ranking of the most and least agreed-upon items by sector, based on the survey responses.

Table 45 Items with the highest and lowest acceptability across all sectors and their response rates

Index	Korea	%	Germany	%
A5-1. Most agree (Rank 1)	(Overall)3. The government and local authorities should roll out policies, programs, and initiatives to reduce their carbon footprint.	10.4	(Waste)21. We all need to do our part to reduce food and general waste and increase recycling and reuse.	8.8
A5-2. Most agree (Rank 1+2)	(Waste)24. Companies need to cut back on product packaging and create reusable containers.	18.8	(Housing)13. Individuals should make an effort to conserve electricity, gas, and water at home.	17.6
A6-1. Least agree (Rank 1)	(Issue)35. I support raising electric rates to encourage the energy transition and to reduce our carbon footprint.	11.2	(Issue)35. I support raising electric rates to encourage the energy transition and to reduce our carbon footprint.	11.2
A6-2. Least agree(Rank 1+2)	(Issue)35. I support raising electric rates to encourage the energy transition and to reduce our carbon footprint.	20	(Issue)35. I support raising electric rates to encourage the energy transition and to reduce our carbon footprint.	17.6

Note %: Response rates for each item.
Source The authors.

Across all sectors, both Korea and Germany selected waste-related items as the top priorities in the most agreed-upon statements (A5-1, A5-2)—with item 24 in Korea and item 21 in Germany ranking first and first and second, respectively. However, a key difference is that the Korean respondents emphasized corporate responsibility, while the German respondents highlighted individual efforts within these items. In addition, the Korean side ranked government and local government roles in overall carbon footprint reduction (item 3) as the top priority, whereas the Germans prioritized individual roles in the housing sector (item 13) as the first and second priorities. This aligns with

previous findings comparing sectoral reduction priorities between the two countries, where Korean and German respondents differed in their perceptions of individual, government, and corporate responsibilities.

In Korea, the most agreed-upon item was: "The government and local authorities should roll out policies, programs, and initiatives to reduce their carbon footprint" (10.4%), reflecting a strong expectation for government leadership in addressing environmental issues. In open-ended responses, the most frequently cited reason was "Government involvement is effective," followed by "Government-led policies are necessary" and "There are limitations to individual efforts."

In the combined first- and second-priority responses in Korea, the statement "Companies need to cut back on product packaging and create reusable containers" (18.8%) was most frequently selected as a key CF reduction measure. This reflects a strong public perception that corporations bear primary responsibility for environmental protection. The most common reason given was "Companies are the biggest carbon emitters," followed by "Corporate participation is effective." Other frequently cited responses included: "Investment in energy-efficient facilities can reduce emissions," "There are limits to individual efforts," and "Changes in the production process are necessary."

In Germany, the top-ranked item was "We all need to do our part to reduce food and general waste and increase recycling and reuse" (8.8%), while "Individuals should make an effort to conserve electricity, gas, and water at home" (17.6%) was widely recognized as an important practical action. These responses suggest a strong emphasis on personal responsibility and voluntary action in German environmental attitudes—in line with the country's broader commitment to sustainability and eco-conscious living.

German respondents gave a range of reasons for selecting these items, including: "Individual action is essential for environmental protection," "Small efforts lead to significant changes," "Shared responsibility," "Easy to do, anyone can participate," "Low cost, no financial burden," and "Not everything should be enforced; voluntary participation is important."

In contrast, one of the strongest points of agreement between respondents in Korea and Germany was their opposition to raising electricity prices as a means of promoting energy transition and CF reduction. The same item—"I support raising electric rates to encourage the energy transition and to reduce our carbon footprint"—received the highest level of disagreement in both countries (Korea: 20.0%, 17.6%; Germany: 11.2%, 11.2%).

In Korea, the most common reasons for opposing electricity price increases included: "Burden of

electricity price hikes," "Direct impact on low-income households," "Ineffectiveness," and "Unrelated to reducing carbon footprint." In Germany, cited reasons included: "Already high electricity costs," "Concerns about economic inequality," "Need for alternative solutions," "Impact on economic and industrial competitiveness," and "Structural issues such as shifting responsibility and effectiveness."

This suggests that when energy transition policies directly lead to financial burdens, public acceptance decreases. Therefore, to achieve CF reduction goals, complementary policies such as subsidies, tax benefits, or phased pricing adjustments must be considered. Based on the comprehensive comparative analysis of policy acceptability in the previous pages, we can reach a handful of conclusions with implications for policy. We describe these conclusions in the following pages.

Differences in perceptions of government vs. individual responsibility

Among the Korean respondents, we observed a strong expectation the government and corporations should lead CF reduction efforts, and a greater resistance to reducing individual consumption. In contrast, the German respondents were more supportive of the idea that individuals should contribute to CF reduction through food consumption, recycling, and energy conservation. This indicates that Korea is more accustomed to policy-driven changes and institutional intervention, whereas in Germany there seems to be a greater emphasis on voluntary action by individuals and businesses.

Differences in environmental protection approaches

The Korean side placed more emphasis on corporate responsibility and policy intervention, while the German respondents focused more on lifestyle changes and energy conservation at an individual level. In other words, the Koreans seemed to view the government and businesses as the primary actors in CF reduction efforts, whereas the Germans were more likely to believe that individual daily efforts are essential.

Shared concerns over the economic burden

Respondents from both countries voiced strong opposition to electricity price increases intended to promote an energy transition, suggesting that financial burdens could be a major barrier to implementing CF reduction policies. Therefore, instead of directly increasing electricity prices, alternative solutions such as subsidies, tax incentives, phased price adjustments, and energy efficiency improvements should be introduced to mitigate the economic burden on households and businesses and enhance policy acceptance.

In conclusion, we find that Koreans and Germans differ in their preferred approaches to CF reduction, and that sociocultural backgrounds significantly influence policy acceptance.

Korean respondents expected the government and private sector corporations to take the lead in CF reduction efforts, and favor policy-driven approaches, whereas the German side emphasized the importance of individual voluntary actions and lifestyle changes. However, the German side emphasized the importance of strongly oppose CF reduction policies that impose financial burdens, such as electricity price increases, highlighting the need for publicly acceptable policy designs.

Our findings suggest that in order to implement effective CF reduction strategies, a tailored approach that reflects national characteristics is necessary. In Korea, a combination of regulatory enforcement and policy incentives may be more effective. In Germany, campaigns encouraging individual participation and support for technological innovations could be more suitable. In both countries, finding ways to reduce the financial burden of CF reduction efforts will be a key factor in increasing public acceptance of policies.

4.2 Policy recommendations for CF reduction

In this section, we proposed a suite of policy recommendations based on the findings of the analyses described in the previous material. They include strategies to increase public engagement in policy development, improve communication with stakeholders to enhance policy acceptability, and integrate more green spaces into urban planning to incentivize more sustainable behaviors.

4.2.1 Key planning elements and policies by country

The acceptance of CF reduction policies in Korea and Germany varies according to their social and cultural differences. We found that Koreans tend to government and corporate-led policy interventions, whereas Germans are more likely to emphasize individual actions as the main driver of change. In addition concerns about economic burdens play a significant role in both countries, with strong resistance particularly toward policy measures such as electricity price increases. Therefore, for effective CF reduction policies, tailored strategies considering national characteristics are essential. In Korea, a combination of policy incentives and regulations is crucial, while in Germany, we recommend promoting individual participation and infrastructure expansion initiatives.

Based on the results of the Q methodology analysis and the online survey, we categorized CF planning elements into groups based on the priorities of the various perception types, and the distribution of those perception types in each country (See Table 46).

Table 46 **Comparison of response ratios by perception type and key statements in Korea and Germany**

Category	KR 1	KR 2	KR 3	KR 4	KR 5	Q statements	DE 1	DE 2	DE 3	DE 4
Ratio (%)	21	8	29	10	22		5	9	33	47
Overall			D (+2)			1. Individuals should make an effort to reduce their consumption of food, housing, transportation, and goods and services.			D* (+5)	
				D* (+5)		2. Urban planning and design is needed to reduce the carbon footprint of city dwellers.				
						3. The government and local authorities should roll out policies, programs, and initiatives to reduce their carbon footprint.	D* (+5)		D (0)	
						4. Companies need to take steps to reduce their carbon footprint in their manufacturing processes.				D* (-4)
						5. I support increased investment and support for research and development of technologies that reduce our carbon footprint.	D* (+3)			
Food						6. I support expanding and revitalizing local farmers markets.				
						7. The government and local authorities should promote the certification and consumption of low-carbon, eco-friendly, and organic agricultural products.				D (+1)
						8. Individuals should make an effort to reduce their consumption of meat and imported/packaged/processed foods.		D* (-4)	D (+2)	
	C (-3)	C (-3)	C (-3)	C (-3)		9. Companies should ramp up efforts to expand plant-based options in restaurants and stores, along with developing meat alternatives.				
					D (+1)	10. I support plans that reduce transportation distances by producing and consuming food within cities, like urban farming.		D (-3)		

Table 46 (continued)

Category	KR 1	KR 2	KR 3	KR 4	KR 5	Q statements	DE 1	DE 2	DE 3	DE 4
Housing						11. I support green remodeling efforts that improve the energy efficiency of existing buildings.				
		D* (+3)	D* (-4)			12. I support installing renewable energy sources like solar panels and solar thermal systems on buildings and homes.				
	D* (-4)		D* (+4)			13. Individuals should make an effort to conserve electricity, gas, and water at home.		D* (-3)	D (+3)	
	(-5)	D* (+3)				14. Require buildings or factories to install green roofs or solar panels.		D* (+1)		
						15. Require new buildings to be designed as zero-energy buildings, meaning they do not rely on external energy sources.		D (+2)		
Travel			D* (+4)			16. Individuals should make an effort to use public transportation, such as buses, trains, or bikes, instead of driving their own cars.				
						17. I support expanding bike lanes and pedestrian walkways.				
						18. I support limiting the use of high carbon-emission vehicles.		D* (+3)		
				D* (+3)		19. I support plans and designs that increase the proportion of residential areas and population density within cities to reduce urban sprawl through mixed-use development.	C* (-1)		C* (-1)	C* (+1)
						20. I support expanding the infrastructure for electric vehicle charging and dedicated parking spaces.	D (-3)			

Table 46 (continued)

Category	KR 1	KR 2	KR 3	KR 4	KR 5	Q statements	DE 1	DE 2	DE 3	DE 4
Waste			D* (+5)			21. We all need to do our part to reduce food and general waste and increase recycling and reuse.			D* (+4)	
					D* (+5)	22. The government and local authorities should implement policies to reduce single-use items in places like stores and hotels.		C* (0)	C* (0)	C* (-2)
						23. I support policies that discourage single-use products and mandate reusable containers.			D* (+3)	
				D (0)		24. Companies need to cut back on product packaging and create reusable containers.				D(-3)
			D (-3)			25. I support the plan to build a biogas facility with organic waste such as food waste, livestock manure, and sewage sludge.	D (-3)			D (+3)
Sink	(+5)	D* (-1)				26. I support increasing the amount of green space and parks in urban areas.				D* (+5)
						27. Companies should get involved in programs and initiatives that expand carbon sinks, such as creating parks and planting trees.	D* (+1)			
						28. I support expanding the greenbelt designation, which limits development on existing green spaces.				D* (-5)
		D* (-4)		D (+4)		29. The government should invest more in research and development to boost the carbon-absorbing capacity of our forests and green spaces.			D (-4)	
						30. We need an ecological restoration plan that includes green spaces and biotopes that take biodiversity into account.				

Table 46 (continued)

Category	KR 1	KR 2	KR 3	KR 4	KR 5	Q statements	DE 1	DE 2	DE 3	DE 4
Issue						31. Citizen engagement should be fully integrated into city planning, policies, programs, and procedures that aim to reduce carbon footprint.	D (+4)	D* (-1)		
	D* (+3)	(-5)	D (-5)	(-5)	(-5)	32. I support putting small modular reactors (SMRs) in cities that need a lot of electricity.	(-5)	(-5)	(-5)	D*(0)
		D* (+5)				33. I support phasing out coal-fired power plants, even if it means paying more for electricity.		D* (+5)		
		D* (-4)		D (+1)		34. The government and local authorities should expand their social media campaigns to reduce their carbon footprint.				D* (+2)
		D (+4)				35. I support raising electric rates to encourage the energy transition and to reduce our carbon footprint.	D* (-4)	D* (+3)		

Note 1) Red – Most agreed statement (+5), Blue – Least agreed statement (-5), Yellow C (Consensus) – Statement showing no difference from other types, D (Distinguish) – Statement distinguishing from other types ($P<0.05$; * indicates significance level $P<0.01$). Numbers in parentheses represent factor Q-sort scores.

2) KR1: Expert-Led, KR2: Policy Compliance, KR3: Individual Efforts, KR4: Planning-Oriented, KR5: Government Emphasis, DE1: Business-Centered, DE2: Regulatory Preference, DE3: Individual Efforts, DE4: Green Development.

Source The authors.

(1) Korea

In examining the consensus among perception types in Korea, respondents classified as KR1–KR4 showed a low level of agreement (-3) with the item stating that businesses should develop meat alternatives and expand vegetarian options in restaurants and stores (Item 9). According to the survey results, respondents belonging to these four perception types account for 69.2% of the total 250 respondents, indicating that over two-thirds of Korean respondents belong to perception types that exhibit low agreement with the corporate role in reducing CFs in the food sector.

Analyzing the distinguishing (D) items that differentiate perception types, KR2 (Policy Compliance) respondents agreed (+3) with installing renewable energy sources such as solar panels and solar heating systems in buildings and homes (Item 12), whereas KR3 (Individual Efforts) respondents

showed lower agreement (-4). Looking at the distribution, 29% of all respondents belong to KR3, which has low acceptance of renewable energy installation in buildings, while only 8% belong to KR2, which supports this measure—a difference of over 3.6 times.

Furthermore, among the five perception types, KR2 (Policy Compliance) was the only type that showed a positive attitude (+3) toward mandating rooftop greening or solar panel installations on buildings and factory roofs (Item 14). However, KR2 (Policy Compliance) respondents accounted for only 8% of all respondents, the lowest proportion among all types. This suggests that renewable energy policies in the building sector may be perceived as a burden by the majority of the population, highlighting the need for more segmented approaches and communication strategies when formulating policies.

Regarding household energy conservation efforts (Item 13), KR3 (Individual Efforts) respondents showed the highest agreement (+4), making up 29% of the total respondents. However, KR1 (Expert-Led), which accounts for 21% of respondents, disagreed (-3), presenting a stark contrast. In addition, KR1 (Expert-Led) respondents tend to support technological solutions such as the installation of SMRs, (Item 32), which other perception types least agreed with (-5). This contrast illustrates a difference in perception between behavioral strategies focused on individual energy conservation and technological solutions, emphasizing the need to reassess the balance and prioritization of these approaches in policy decisions.

For government-led investment in research and technology development, as well as increasing carbon absorption capacity (Item 29) and expanding social media campaigns (Item 34), KR4 (Planning-Oriented) respondents showed support (+4 and +1, respectively), whereas KR2 (Policy Compliance) respondents seemed to voice more opposition to such policies (-4 for both items). Instead, KR2 (Policy Compliance) strongly supported (+5) coal phase-out policies (Item 33), even if it meant enduring electricity price increases. This indicates that some groups prefer direct and aggressive policy measures over indirect government support or awareness campaigns, suggesting that policy decisions must account for varying stakeholder expectations and concerns.

In conclusion, the majority of Korean respondents (about 70%) corporate efforts to develop meat alternatives. However, a substantial proportion (21.2%) of KR1 (Expert-Led) voiced support for SMRs. We also observed significant differences in perception with regards to renewable energy in the building sector, individual energy-saving efforts, and advanced technological solutions. Therefore, the government must design tailored environmental policies that balance strong, direct measures with strategies that encourage individual efforts while addressing conflicting stakeholder expectations and concerns.

(2) Germany

In Germany, certain items showed relatively little variation across perception types. For example, in response to Item 19—which concerns urban planning policies to increase residential density and reduce urban sprawl through mixed-use development—DE1 (Business-Centered) and DE3 (Individual Efforts) respondents expressed mild disagreement (–1), while DE4 (Green Development) respondents indicated slight agreement (+1). These differences were minimal, suggesting a broadly shared or neutral stance on this policy across perception types. Notably, these three types together represent 85.2% of the German sample.

Similarly, for Item 22 (government and local authorities restricting the use of disposable products in stores and accommodations), DE2–DE4 respondents mostly responded neutrally (0) or somewhat negatively (-2). This indicates that instead of taking extreme stances on restricting disposable product use, respondents tend to hold moderate or slightly negative views, showing a lack of strong opinion differences in this area. These three types represent 89.2% of respondents.

The lack of significant differences in perception types for both items suggests that the government and local authorities could implement environmental policies such as urban planning and disposable product regulations with the expectation of broad public consensus and without the need to cater to the interests of specific stakeholders or groups.

In addition, the fact that respondents' attitudes are not highly polarized but rather neutral or slightly negative suggests that there may not yet be strong awareness or clear opinions on these policies. To enhance policy effectiveness, public outreach and efforts to encourage social engagement should be implemented. Notably, DE1 (Business-Centered), DE2 (Regulatory Preference) , and DE3 (Individual Efforts) respondents (47.6%) strongly opposed (-5) SMR installation, whereas DE4 (Green Development) respondents (46.8%) remained neutral (0). This points to a lack of agreement on the topic of SMRs, and these could become a point of contention.

The strong opposition among multiple perception types implies significant concerns about safety and environmental risks related to SMRs energy-intensive urban areas. Meanwhile, the neutral stance of DE4 (Green Development) suggests either uncertainty or a need for additional information regarding SMR policies. Given the nearly equal polarization of opinion, a comprehensive approach that incorporates various stakeholder perspectives is necessary to ensure that SMR-related policies do not disproportionately favor a specific group.

Examining the differences in distinguishing items (D) among perception types, DE2 (Regulatory Preference) respondents showed lower agreement (-4, -3) with reducing meat and processed food

consumption (Item 8) and household energy conservation (Item 13), whereas DE3 (Individual Efforts) respondents were more positive (+2, +3). This suggests opposing views on the role of personal responsibility in CF reduction efforts, indicating that policy-making should balance individual behavioral incentives with regulatory measures.

For building biogas facilities using organic waste (Item 25), DE1 (Business-Centered) respondents showed lower agreement (-3), whereas DE4 (Green Development) respondents supported the policy (+3). This reflects that business-focused groups prioritize economic and operational aspects, whereas green development-focused groups prioritize environmental benefits, emphasizing the need for a balanced approach when formulating energy and waste management policies.

Regarding ensuring citizen participation in urban planning and policy-making (Item 31) and supporting electricity price increases (Item 35), DE1 (Business-Centered) respondents strongly supported citizen participation (+4) but opposed electricity price increases (-4), whereas DE2 (Regulatory Preference) respondents were less supportive of citizen participation (-1) but agreed with raising electricity prices (+3). This highlights a fundamental divide between groups favoring voluntary citizen engagement in policy changes and those preferring direct regulatory interventions. To navigate these contrasting viewpoints, a policy approach that accommodates diverse stakeholder interests and mediates differences in implementation strategies is essential.

(3) Comparison of Korea and Germany

We observed the following differences the items for which consensus was strongest between the various perception types in Korea and Germany.

In Korea, four perception types comprising 69.2% of all respondents consistently showed lower agreement (-3) with corporate efforts to develop meat alternatives and expand vegetarian options (Item 9). In contrast, in Germany, responses to Item 19 (urban planning) were more varied, with 46.8% agreeing (+1) and 38.4% disagreeing (-1). Similarly, for Item 22 (single-use products regulation), 42.4% responded neutrally (0), while 46.8% showed lower agreement (-2), demonstrating a wider range of opinions on policy matters.

In addition, while both countries generally opposed (-5) installing SMRs to address energy consumption in urban areas (Item 32), 21.2% of Korean respondents fell into a perception type that agreed (+3), whereas 46.8% of German respondents were classified as neutral (0). This indicates differences in national attitudes toward technological adoption and policy acceptance.

A comparison of the key differentiating items across perception types in each country reveals the following.

In Korea, sharp differences emerged in perception types regarding technology- and behavior-related items, such as installing renewable energy in buildings and homes, SMR installation, and personal energy conservation. KR2 (Policy Compliance) respondents supported renewable energy installation in buildings, whereas KR3 (Individual Efforts) respondents showed lower agreement, indicating a higher perception of policy burden in the building sector. KR3 (Individual Efforts) strongly agreed with personal energy-saving efforts, while KR1 (Expert-Led) respondents held a negative stance, highlighting a contrast between individual actions and technological solutions.

In Germany, divergent opinions were most evident in regulatory measures, personal efforts, and civic participation. DE2 (Regulatory Preference) and DE3 (Individual Efforts) held opposing views on reducing meat and processed food consumption and household energy conservation. DE1 (Business-Centered) and DE4 (Green Development) showed clear differences regarding the use of biogas facilities from waste, urban planning policies, citizen participation, and electricity price increases. Thus, while perception type differences in Korea primarily focus on technology adoption and behavioral changes, Germany exhibits clearer conflicts regarding the division of responsibilities between regulation, individual efforts, and civic participation.

4.2.2 Strategies for incorporating key planning elements into domestic legal systems

(1) Key planning elements for domestic CF reduction reflecting acceptance levels

Our comparative analysis of CF reduction policy acceptance in Korea and Germany shows that while both countries favor a mixed approach involving government, businesses, and individuals, they differ in the level of policy intervention and perceptions of each subject's role. We found that the Korean respondents were more likely to consider government intervention and corporate action crucial, whereas the German respondents tended to see behavioral changes by individuals as the primary solution.

Strengthening government-led policies and incentives

Korean respondents strongly support government intervention in CF reduction and prefer a policy-driven approach to encourage corporate This contrasts with the German respondents' focus on changing individual behavior. Survey results indicate that Koreans place significant importance on

the government's role in policy formulation and implementation, whereas Germans highlight voluntary changes and urban-scale approaches. Especially in Korea, government-led initiatives such as support for eco-friendly technology development and tax benefits to promote corporate sustainability innovation were viewed as key CF reduction strategies. This suggests that corporate-driven CF reduction policies may be more effectively accepted in Korea.

Accelerating eco-friendly transformation in the transportation sector

One of the most significant differences between Korea and Germany in the transportation sector is support for high-emission vehicle restrictions and the expansion of eco-friendly transport options. Korean respondents strongly support policies restricting high-emission vehicles, particularly highlighting the necessity of government support for electric vehicle (EV) infrastructure expansion. In Germany, stricter regulations on the automotive industry were perceived as a potential economic burden, leading to greater resistance to such measures. This contrast can be attributed to growing concerns in Korea over air pollution and increasing interest in green transportation, which has led to strong public support for public transport incentives and eco-friendly mobility policies. Since Germany already has a well-established eco-friendly transportation infrastructure, additional regulations were viewed as less critical, with more focus on expanding bicycle lanes and improving daily transportation environments.

Strengthening waste management and the circular economy

Both Korean and German respondents recognize the need improve waste management techniques and transition to a circular economy, but their perceptions of who should be responsible for these efforts differ. Koreans emphasize corporate responsibility, believing that businesses should actively reduce carbon emissions and adopt eco-friendly products and packaging. Germans focus more on individual responsibility, considering food waste reduction and recycling as essential actions for CF reduction. This suggests that corporate-led environmental protection efforts are more likely to be accepted in Korea, requiring policy designs that reflect this preference. For instance, Korea could introduce tax breaks for companies adopting eco-friendly packaging and reusable containers, along with stronger incentives for the recycling industry.

Expanding carbon sinks and strengthening urban green space policies

Korean respondents expressed stronger support for government intervention in expanding carbon sinks, particularly through urban park expansion and increasing green spaces. This may reflect Korea's relative lack of urban greenery and the growing policy focus on urban green space expansion as part of climate change adaptation strategies. Germany, with its well-established forest conservation

policies and abundant green spaces, prioritizes ecosystem protection over additional green area expansion. In Korea, greater investment in R&D for forest conservation and carbon sequestration is necessary, along with active public-private partnerships for urban green space development.

Cautious approach to electricity price increases

Both Korean and German respondents expressed strong resistance to electricity price hikes. However, Korean respondents did exhibit greater recognition of the necessity of electricity price increases for CF reduction, likely due to Korea's relatively lower electricity prices. Germans, who already face high electricity costs, strongly opposed further increases, highlighting the need for alternative policies. These findings indicate that policies that impose direct economic costs on the public, such as electricity price increases, may face strong resistance, making government-supported renewable energy transitions a more effective approach. In Korea, a careful review of electricity pricing policies is needed, along with complementary measures to mitigate the financial costs incurred by lower-income groups along with economic incentives to encourage corporate energy efficiency.

In Korea, an effective approach to CF reduction will involve government- and business-led policy interventions, combined with incentives and regulations to encourage voluntary individual efforts. Active intervention is particularly necessary in the transportation, waste management, and carbon sink expansion sectors. Policies that impose economic burdens, such as electricity price increases, should be approached cautiously.

Active enhancing public trust in policies through proactive communication and outreach is essential. Clearly defining the roles of the government, businesses, and individuals is crucial to ensuring policy effectiveness. To achieve this, Korea should focus on promoting corporate eco-friendly innovation, strengthening government policy interventions and expanding green spaces and improving urban infrastructure.

The following table summarizes the key policy elements in connection with the 35 statements derived from this study.

Table 47 Key priorities and policy elements for carbon footprint reduction

Key priorities	CF 35 statements number	Key policy elements
1. Strengthening government policies and incentives	3, 29, 31	• Establishing and legislating carbon footprint reduction targets • Supporting research and technology for carbon absorption • Expanding citizen and corporate participation
2. Accelerating eco-friendly transportation	16, 18, 20	• Expanding public and low-carbon transportation • Supporting EV and eco-friendly vehicle transition • Providing CF reduction incentives in transportation
3. Enhancing waste management and circular economy	22, 24, 25	• Strengthening regulations on corporate packaging and disposables • Expanding the use of organic waste • Improving recycling and resource circulation systems
4. Expanding carbon sinks and urban green spaces	26, 27, 28	• Expanding urban green spaces and carbon sinks • Encouraging corporate and private green space initiatives • Strengthening green space conservation and ecosystem restoration
5. Cautious approach to electricity price increases	33, 35	• Gradually implementing electricity price increases • Supporting coal phase-out and renewable energy expansion • Expanding subsidies and incentives to ease economic burdens

Source The authors.

(2) Strategies for incorporating CF reduction strategies into domestic legal systems

To enhance the effectiveness of CF reduction policies in both Korea and Germany, we propose incorporating elements of urban planning CF reduction strategies into the legal systems and policy development frameworks of both countries. Doing so will help to ensure the consistent implementation of carbon neutrality strategies. This will enable collaboration between the government, businesses, and individuals to establish a sustainable CF reduction framework. To achieve this, we propose the following measures.

Revise the guidelines for metropolitan (basic) local government environmental planning

Based on the survey results on public acceptance and perception types in Korea and Germany, environmental justice and climate (resilience) policies should incorporate sector-specific CF reduction planning elements and policies. For Korea specifically, during the local government

environmental planning process, sectoral CF reduction factors should be aligned with provincial and municipality-level carbon neutrality and green growth master plans, outlooks, and implementation strategies. The guidelines should be revised to focus on climate resilience policies while considering public acceptance. See Table 48 and Table 49.

Table 48 **Proposed revision of formulation guidelines for *Si* (city) and *do* (region) Environmental Preservation Plans**

Before revision	After revision
1-3-3. (Spatial Planning) The Si/Do Environmental Preservation Plan is a spatial plan that enhances and specifies spatial elements to ensure the sustainable integration of national land and environmental management by aligning with and sharing the outlook and implementation strategies of the Do Comprehensive Plan and Urban Master Plan (hereinafter referred to as the "Si/Do National Land Plan").	1-3-3. (Spatial Planning) The Si/Do Environmental Preservation Plan is a spatial plan that enhances and specifies spatial elements to ensure the sustainable integration of national land and environmental management, considering carbon neutrality and public acceptance, by aligning with and sharing the outlook and implementation strategies of the Do Comprehensive Plan and Urban Master Plan (hereinafter referred to as the "Si/Do National Land Plan"), as well as the Si/Do Carbon Neutrality and Green Development Master Plan.
4-6-1. The spatial environmental structure plan is established based on the national ecological axis (national land ecological axis) and regional spatial environmental strategies presented in the Comprehensive National Environmental Plan, whereas comprehensively considering the natural ecology, scenic conservation value, biodiversity enhancement, and regional development direction of the Si/Do.	4-6-1. The spatial environmental structure plan is established based on the national ecological axis (national land ecological axis) and regional spatial environmental strategies presented in the Comprehensive National Environmental Plan, whereas comprehensively considering the natural ecology, scenic conservation value, biodiversity enhancement, regional development direction, carbon neutrality goal, and public acceptance of the Si/Do. ※ The Si/Do Carbon Neutrality and Green Development Master Plan's carbon neutrality goals and implementation measures should be spatially integrated to maximize the plan's acceptability by designating appropriate zones.

Source Compiled by the authors based on the National Legal Information Center, Joint Instruction on Integrated Management of National Land Plans and Environmental Plans.

Table 49 **Proposed revision of formulation guidelines for Si/Gun/Gu Environmental Preservation Plan**

Before revision	After revision
1-3-3. (Spatial Planning) The Si/Gun/Gu Environmental Preservation Plan is a spatial plan that enhances and specifies spatial elements to ensure the sustainable integration of national land and environmental management by aligning with and sharing the outlook and implementation strategies of the Urban or Gun Master Plan.	1-3-3. (Spatial Planning) The Si/Gun/Gu Environmental Preservation Plan is a spatial plan that enhances and specifies spatial elements to ensure the sustainable integration of national land and environmental management, considering carbon neutrality and public acceptance, by aligning with and sharing the outlook and implementation strategies of the Urban or Gun Master Plan as well as Si/Gun/Gu Carbon Neutrality and Green Development Master Plan.
Section 6: Spatial Environmental Structure Plan 4-6-1. The spatial environmental structure plan, including the designation of conservation areas and local ecological axes, should be formulated based on the national ecological axis (national land ecological axis) and regional spatial environmental strategies outlined in the Comprehensive National Environmental Plan, as well as the metropolitan ecological axes presented in the Si/Do Environmental Plan. It should comprehensively consider the natural ecology, scenic conservation value, biodiversity enhancement, and regional development direction of the Si/Gun/Gu.	Section 6: Spatial Environmental Structure Plan 4-6-1. The spatial environmental structure plan, including the designation of conservation areas and local ecological axes, should be formulated based on the national ecological axis (national land ecological axis) and regional spatial environmental strategies outlined in the Comprehensive National Environmental Plan, as well as the metropolitan ecological axes presented in the Si/Do Environmental Plan. It should comprehensively consider the natural ecology, scenic conservation value, biodiversity enhancement, regional development direction, carbon neutrality goals, and plan acceptability of the Si/Gun/Gu.

Source The author based on the National Legal Information Center, Joint Instruction on Integrated Management of National Land Plans and Environmental Plans.

Following the proposals outlined in Kim et al. (2024), public participation should be expanded, and public-private cooperation frameworks should be established to achieve regional CF reduction targets. This will allow local governments in Korea formulate CF reduction policies that incorporate regional characteristics and public perception differences, enabling effective spatial planning and design tailored to each locality.

Utilization in the formulation of relevant plans for the Framework Act on Carbon Neutrality and Green Growth for Coping with the Climate Crisis

In accordance with Article 4 of the Framework Act on Carbon Neutrality and Green Growth for Coping with the Climate Crisis—which outlines the responsibilities of the state and local governments—sector-specific CF reduction planning elements related to social acceptance (see Table 50) should be

incorporated into the National Framework Plan for Carbon Neutrality, as well as into provincial and municipal carbon neutrality plans. Given Korea's policy landscape, which places strong emphasis on government intervention and corporate responsibility, these plans should be adapted to strengthen support for corporate eco-friendly transitions and introduce locally tailored reduction measures. In addition, incentives for green technology development and R&D on CF reduction strategies should be expanded.

In addition, when committees on Carbon Neutrality and Green Growth—whether national or local—conduct policy evaluation reviews, they should adjust CF policies in consideration of their regional effectiveness. In the food sector, policy incentives should promote local food consumption and environmentally friendly agricultural products. Corporate CF reduction efforts should also be assessed, and tax incentives considered.

Furthermore, given lukewarm public acceptance of energy transition policies and electricity price increases, a step by step rate adjustment approach should be implemented alongside enhanced renewable energy support policies. In particular, energy cost support measures for low-income groups should be implemented alongside incentive policies to promote a transition to renewable energy by corporations.

Table 50 **Proposed revision of the Framework Act on Carbon Neutrality and Green Growth for Coping with the Climate Crisis**

Before revision	After revision
Article 4 (Responsibilities of the State and Local Governments)	Article 4 (Responsibilities of the State and Local Governments)
(2) The State and local governments shall comprehensively consider the impacts on climate crisis, harmonious development of economy and environment, etc. in the process of formulating various plans and implementing projects.	(2) The State and local governments shall comprehensively consider the impacts on climate crisis, harmonious development of economy and environment, social acceptance, etc. in the process of formulating various plans and implementing projects.

Source The author based on the National Legal Information Center, Framework Act on Carbon Neutrality and Green Growth for Coping with Climate Crisis.

Application in carbon-neutral city development under the Framework Act on Carbon Neutrality and Green Growth for Coping with the Climate Crisis

Pursuant to Article 29 (Designation of Carbon-Neutral Cities) and Article 28, Paragraph 5 of the Enforcement Decree of the Framework Act on Carbon Neutrality and Green Growth for Coping with the Climate Crisis, CF reduction strategies related to transportation, housing, and waste management

should be explicitly integrated into carbon-neutral city development projects. Urban initiatives should prioritize the expansion of public transportation infrastructure, the promotion of low-carbon building practices, increased use of green energy, and the development of green spaces. Given the high level of public support in Korea for restricting high-emission vehicles and expanding eco-friendly transportation, these measures should be actively incorporated into urban planning frameworks.

When formulating spatial environmental plans for carbon-neutral city development, we recommend implementing the following measures. First, analyze regional carbon emission characteristics to classify area-specific emission profiles and develop an inventory of carbon neutrality implementation measures. This should be accompanied by the establishment of a climate-adaptive spatial planning framework. Based on these analyses, spatial environmental planning should integrate CF reduction, carbon sequestration, climate adaptation, and supporting policy infrastructure.

To strengthen the role of businesses in achieving CF reductions, policies should be introduced that mandate the use of eco-friendly architecture and energy-efficient facilities in industrial complexes and commercial zones. In addition, participatory urban planning procedures should be established to actively involve local residents in shaping CF reduction strategies, ensuring the implementation of regionally tailored approaches.

Integration into national land-environment planning management

In accordance with Article 8 (Integrated Management of National Plans), integrated management measures should be incorporated to establish a low-carbon national land development strategy in response to the climate crisis. This strategy should include provisions for cutting carbon emissions, carbon sequestration, and climate adaptation, with a focus on expanding green spaces and developing eco-friendly infrastructure.

Considering the high level of public acceptance of urban green space expansion in Korea, incentives for urban greenery projects and the expansion of public green areas should be set as key objectives. In particular, policies should be introduced to encourage corporate participation in park and green space development as part of carbon neutrality initiatives. In addition, measures should be taken to conserve the greenbelt space in order to maximize the ability of urban spaces to store carbon.

Incorporation into the revised draft of the 5th National Comprehensive Environmental Plan (2020–2040)

In accordance with 2025 update to the National Basic Plan for Carbon Neutrality and Green Growth (Ministry of Land, Infrastructure, and Transport) and Article 16-2 of the Framework Act on

Environmental Policy, policies need to adopt a more proactive response. Currently, policies do not sufficiently consider carbon neutrality and a national response to the climate crisis; they need to be revised so that these two elements are key objectives. In particular, policies should incorporate measures to expand carbon sinks and include plans for ecological restoration that consider biodiversity conservation.

By integrating the CF reduction planning elements and policy-related statements identified in this study into Korea's domestic legal and institutional framework, we can strengthen the overall effectiveness of carbon neutrality policies. Clearly defining the roles of government, businesses, and individuals will help ensure the successful implementation of sector-specific CF reduction targets. In particular, we recommend prioritizing policies with high levels of public acceptance, as this will support the development of a sustainable carbon neutrality strategy grounded in principles of environmental justice and climate resilience.

Chapter 5
Conclusions

5.1 Summary of key findings and implications

5.1.1 Q methodology and survey analysis summary

(1) Comparison of perception types (Q methodology)

In the previous chapter, we described some of the major differences between South Korean and German survey respondents with regards to carbon footprint (CF) reduction and the energy transition.

Using a Q methodology analysis, we identified five distinct perception types in Korea: Expert-Led (KR1), Policy Compliance (KR2), Individual Efforts (KR3), Planning-Oriented (KR4), and Government Emphasis (KR5). For the German sample, we observed four types: Business-Centered (DE1), Regulatory Preference (DE2), Individual Efforts (DE3), and Green Development (DE4).

The classification of CF reduction perception types is based on the attitudes of survey respondents toward the proper roles of the government, businesses, and individuals with regards to the transition to renewable energy and their willingness to bear the economic costs of such a burden.

We noted that the survey respondents voiced two distinct views of the role of government; there were those who preferred a strong, interventionist government and those who preferred a more limited government presence. Similarly, the respondents were roughly divided into two camps when it came to perceptions of the appropriate role of private sector businesses. Some felt that businesses should be forced to comply with regulatory measures; others saw businesses as entities that should take the lead through voluntary innovation activities. We also observed different attitudes among the

respondents with regards to the role of the individual. Some emphasized the importance of active individual contributions and efforts to change personal behavior, while others saw individuals more as passive policy targets.

Regarding the renewable energy transition, some respondents voiced strong support and individuals with regards to the for government-led initiatives, while others acknowledged the necessity but were concerned about the costs. Some respondents expressed a willingness to accept higher taxes and fees for the sake of reducing CFs, whereas others are highly sensitive to rising costs. These differences significantly impact policy acceptance and effectiveness.

(2) Summary of survey response acceptability mean comparison (t-test)

A comparison of the acceptance of CF reduction policies and behaviors between Korean and German respondents through a survey revealed distinct tendencies. The Korean respondents showed stronger support for government-led intervention and policy reinforcement, whereas The German side emphasized autonomous responses from individuals and businesses.

Korean respondents had higher awareness of the CF concept and the need to reduce personal consumption than their German counterparts, but the Germans exhibited a better understanding of how to reduce CFs. In addition, Korean respondents expressed stronger support than their German counterparts for a range of policies, including the promotion of plant-based food development by businesses, mandatory installation of eco-friendly building facilities, restrictions on high-emission vehicles, construction of biogas facilities using food waste, and electricity price increases to support the energy transition.

In contrast, the German respondents showed less demand for additional regulations in areas where policies were already well established, and were more resistant to hikes in electricity prices, likely due to the fact that they already pay comparatively high costs for energy. Respondents from both countries consensus on reducing personal food consumption, zero-energy buildings, and waste reduction. Respondents from both countries differences between Korea and Germany were more pronounced in terms of policy preferences, but not so different when it comes to practical behaviors.

(3) Summary of survey response acceptability rank comparison (nominal comparison)

Our analysis of the survey results on policy acceptability revealed a clear contrast: Korean respondents emphasized the role of businesses and government in CF reduction, while German respondents were more inclined to support individual actions.

Korean respondents most strongly supported the idea that businesses should reduce their CFs in the

production process, whereas German respondents most agreed that individuals should reduce consumption in the food, housing, and travel sectors. Moreover, Korean respondents showed more support for government-led initiatives promoting the consumption of low-carbon agricultural products, while the German respondents more heavily emphasized the need for individuals to reduce their own consumption of meat and processed foods. In the housing sector, survey respondents from both countries considered individual energy-saving efforts important. In the transportation sector, Koreans supported the use of public transportation, whereas Germans favored the expansion of bicycle lanes. In the waste sector, Koreans stressed corporate responsibility in reducing packaging materials and improving recycling measures, while the German respondents focused on individuals' efforts in waste separation and recycling.

Respondents from both countries supported the expansion of green spaces and greater efforts to include everyday people in planning processes. The surveyed residents from both countries voiced opposition to CF reduction policies that would increase electricity prices. These differences reflect the distinct policy approaches and cultural perceptions of each country. In Korea, policies that strengthen the roles of the government and businesses may be more effective, while in Germany, policies that encourage voluntary individual participation could be more successful.

(4) Implications

The results of the Q methodology analysis—in which 20 individuals from diverse backgrounds in each country completed a forced Q-sort by selecting the statements they most and least agreed with from a set of 35—may not fully align with the findings from the larger online survey of 250 members of the general public. In the online survey, respondents were asked to rate their level of agreement with each statement and to identify the most and least agreed-upon items within each sector.

The differences between the results point to the difficult of capturing public opinion using a single metric. This suggests that future policy-making and public opinion analysis should incorporate multiple research methods for more precise interpretations. The differences we uncovered between the various perception types in both countries emphasize the need for tailored approaches and communication strategies that consider the needs of each group of stakeholders. Our findings also highlight the necessity of balanced role-sharing among businesses, governments, and individuals.

Furthermore, the varied attitudes among different perception types suggest that a single approach to environmental and energy-related policies may have limitations. Policymakers should recognize the importance of customized communication strategies based on diverse perception types and design policies that appropriately combine individual efforts with regulatory reinforcements. On the other hand, the absence of significant divisions among perception types on certain environmental and

urban planning issues does give governments and public institutions some room to maneuver in designing and implementing policies and effective communication strategies.

5.1.2 Policy recommendations

(1) Key urban planning elements and policies by country

Next, we summarize some of our analytical findings on the views and attitudes of survey respondents in both countries toward CF reduction policies.

Overall, we found that the sociocultural differences between Germany and Korea greatly influenced CF reduction policy acceptability among respondents from both countries. Koreans emphasize government and corporate-led policy interventions, whereas Germans focus more on voluntary individual actions. These fundamentally different attitudes carry the following implications for policy.

First, we observed a difference in the way Koreans and Germans perceive as the proper roles of the government and businesses. In Korea, there is a high awareness of the importance of the government and businesses in CF reduction efforts, and relatively strong resistance to changing personal consumption behaviors and lifestyles. In contrast, in Germany, people see personal behavioral changes, such as reducing food consumption, recycling, and energy conservation, as key elements of CF reduction.

Second, we noted a difference in the way Korean and German respondents view the concept of environmental protection. Koreans tend to focus on corporate responsibility and policy intervention, recognizing the government and businesses as the primary agents of CF reduction. On the other hand, the German respondents emphasize personal-level efforts, such as lifestyle changes and energy conservation.

Third, both Koreans and Germans share concerns about the economic of CF reduction and the transition to renewable energy. Both countries show low acceptance of policies that involve economic costs, such as electricity price increases. Therefore, customized strategies such as subsidies, tax benefits, gradual price increases, and energy efficiency improvements are required to compensate for these economic burdens.

Overall, Koreans exhibited a preference for government-led and corporate-led policy interventions. Korean policymakers should duly consider adopting a strategy that combines regulations and incentives to induce sustainable innovation in businesses and industries. Since policies that impose a high economic burden (e.g., electricity price increases) may face strong public resistance, tax

benefits, subsidies, and support for technological development should be used as major policy tools to implement policies gradually.

German policymakers, on the other hand, should strongly consider pursuing public awareness and educational campaigns as well as infrastructure improvements to encourage individual behavioral changes that also facilitate active participation by local communities and governments. We recommend actively using subsidies and tax incentives to expand eco-friendly technologies and renewable energy. To support this transition, German policymakers should design climate policies in ways that are socially acceptable and encourage community-led initiatives.

Table 51 **Comparison of key urban planning elements and policies between Korea and Germany**

Classification	Korea	Germany
Policy acceptability	Preference for government and corporate-led intervention	Emphasis on voluntary individual actions
Government and corporate roles	Government and corporate-centered policy implementation	Citizen and local government-centered policies
Individual roles	Strong resistance to changes in individual consumption and lifestyle	Recognition of individual actions (e.g., food consumption reduction, recycling, energy conservation) as key factors
Environmental protection approach	Corporate responsibility and policy intervention-focused approach	Focus on individual lifestyle changes and energy conservation
Major policy measures	Combination of regulations and incentives (promoting corporate innovation)	Encouraging behavioral change through campaigns, education, and infrastructure improvements
Financial support methods	Tax benefits, subsidies, and technology development support	Active utilization of subsidies and tax incentives
Social acceptability	Strong resistance to policies with high economic burdens, such as electricity price increases	Resistance exists to policies involving economic burdens
Community roles	Relatively low, as policies are government and corporate-centered	Activation of community-led projects
Commonalities	• Resistance to policies with high economic burdens exists • Customized strategies needed to offset economic burdens (subsidies, tax benefits, gradual price increases, energy efficiency policies) • Sustainable CF reduction policies required	

Source The authors.

In conclusion, Korean policymakers should follow a strategy that promotes government policy intervention and corporate participation, while German decision-makers should strongly consider launching campaigns that encourage active individual participation and support for technological innovation. Both countries need customized climate change response strategies that reflect their respective economic and social characteristics, and pursuing effective CF reduction policies while alleviating economic burdens will be an important factor in increasing policy acceptance.

Our policy recommendations are summarized in Table 51.

(2) Measures for reflecting key planning elements in the Korean legal system

Based on our comparative analysis of policy acceptability in Korea and Germany, we identified five priority areas for carbon footprint reduction: (1) strengthening government-led policies and incentives, (2) accelerating the eco-friendly transformation of the transportation sector, (3) improving waste management and advancing the circular economy, (4) expanding carbon sinks and enhancing urban green space policies, and (5) approaching electricity price increases with caution.

The corresponding policy elements for each of these categories were outlined earlier in the study (see Section 4.2.2(1)) and can serve as a foundation for incorporating effective urban planning strategies into the legal and institutional frameworks of both countries.

In the following pages we propose five methods to achieve this in Korea.

First, Korea should amend its environmental planning guidelines for metropolitan and local governments to clearly integrate carbon neutrality and public acceptability into spatial planning. Linking existing environmental plans with the Framework Plan for Carbon Neutrality would greatly strengthen the government's ability to sustainably manage the environment.

Second, in Article 4 of the Framework Act on Carbon Neutrality and Green Growth for Coping with Climate Crisis, the national and local carbon neutrality and green growth plans should be revised to emphasize corporate responsibility, promote eco-friendly technology development and R&D, expand local food and eco-friendly agricultural consumption, and gradually phase out coal-fired power plants. To alleviate the costs burden of the transition to renewable energy, policies should include assistance for low-income groups and corporate renewable energy incentives.

Third, in Article 29 of the Framework Act on Carbon Neutrality and Green Growth for Coping with the Climate Crisis, when establishing the carbon neutral city development plan, policies should actively incorporate expansion of renewable energy use in buildings and factories, strengthen eco-friendly building standards, design cities centered on public transportation, and restrict high-carbon-emission

vehicles. Moreover, localized CF reduction strategies should be introduced through Second, in Article 4 of the Framework Act on Carbon Neutrality and Green Growth for Coping with the Climate Crisis, the national and local carbon neutrality and green growth plans should be revised to emphasize corporate responsibility, promote eco-friendly technology development and R&D, expand local food and eco-friendly agricultural consumption, and gradually phase out coal-fired power plants. To alleviate the costs burden of the transition to renewable energy, policies should include assistance for low-income groups and corporate renewable energy incentives.

Fourth, to advance low-carbon national land development, we recommend revising the Joint Directive on Integrated Management of National Land and Environmental Plans, currently implemented by the Ministry of Land, Infrastructure and Transport and the Ministry of Environment. The revision should include measures to expand carbon sinks in urban areas, promote corporate participation in the creation of green spaces, strengthen green space conservation, and establish ecological restoration plans aimed at enhancing urban carbon absorption capacity.

Finally, revisions to the Fifth National Environmental Comprehensive Plan (based on Article 16-2 of the Framework Act on Environmental Policy) should go beyond low-carbon policies and place carbon neutrality at the core of national policy. This should include ecological restoration plans that consider biodiversity and the expansion of carbon sinks to enhance long-term sustainability.

Table 52 **Measures for integrating carbon footprint reduction planning elements and policies into the domestic legal system**

Legal system integration items		Relevant CF 35 statements	Measures for integrating into the legal system
Amendment of environmental planning guidelines for metropolitan and local governments		1, 2, 3	• Establish climate (resilience) policies focused on sector-specific CF reduction elements • Develop a system to expand public participation
Framework Act on Carbon Neutrality and Green Growth for Coping with the Climate Crisis	Incorporation into national and local carbon neutrality basic plans	4, 5, 7	• Clarify corporate responsibility for CF reduction • Promote eco-friendly technology development and CF reduction R&D • Encourage local food and eco-friendly agricultural product consumption • Gradually phase out coal-fired power plants and adjust electricity rates • Provide support for low-income groups and incentives for corporate renewable energy transition

Table 52 (continued)

Legal system integration items		Relevant CF 35 statements	Measures for integrating into the legal system
Framework Act on Carbon Neutrality and Green Growth for Coping with the Climate Crisis	Integration into carbon-neutral city development project plans	12, 14, 16, 18, 29, 30, 31	• Expand renewable energy use in buildings and factories • Strengthen eco-friendly building standards and introduce energy-efficient facilities • Design cities centered on public transportation and restrict high-carbon-emission vehicles • Review and enhance sector-specific elements of spatial and environmental planning for carbon-neutral cities • Develop CF reduction urban planning based on public participation
Reflection in low-carbon national land development under the 'Joint Directive on Integrated Management of National Land and Environmental Plans'		26, 27, 28	• Expand carbon sinks and strengthen urban green space conservation • Encourage corporate participation in park and green space development
Incorporation into the revision of '5th National Environmental Comprehensive Plan'		33, 35	• Integrate ecological restoration plans that expand carbon sinks and preserve biodiversity

Source The authors.

Through these measures, Korea can enhance the effectiveness of its carbon neutrality policies and establish a sustainable carbon neutrality strategy that considers environmental justice and climate resilience.

5.2 Limitations and future research

5.2.1 Limitations of the study

The main constraints of this study are described as follows:

First, the main analyses of the study were surveys of residents of South Korea and Germany. The perceptions of residents of these two countries may not represent global perceptions of environmental and energy policy; caution should be exercised in interpreting the study's findings.

Second, the main analyses of the study were surveys of residents of South Korea and Germany.

The perceptions of residents of these two countries may not represent global perceptions of environmental and energy policy; caution should be exercised in interpreting the study's findings. This difference stems from the distinct purposes of each approach: Q methodology is designed to capture the subjective and nuanced cognitive structures of individual respondents, while the online survey was intended to identify broader trends across a larger sample.

Third, while for this study we examined the acceptability of CF reduction policies by categorizing various factors, we did not conduct an in-depth analysis of the specific influences and interactions among the factors.

5.2.2 Future research

We identified the following key tasks for future research.

First, future studies should expand to include a wider range of countries and regions in order to examine differences in CF reduction awareness and policy acceptability across diverse cultural and social contexts. This would contribute to the development of more globally informed CF reduction strategies.

Second, a more in-depth comparison between the Q methodology and online survey results is needed to clarify the strengths and limitations of each approach. Future research should also explore how these methods can be used in a complementary way.

Third, there is a need to develop more sophisticated quantitative research models to analyze the interactions and influence among key factors shaping policy acceptability. In particular, strategic frameworks should be designed to strengthen the balance and synergy between the roles of individuals, businesses, and governments.

Fourth, future research should focus on creating targeted communication and engagement strategies to help translate the findings of this study into practical policy outcomes. Customized approaches for different countries and stakeholder groups—supported by analysis of successful case studies—will be especially important for improving policy implementation.

In sum, while this study offers important insights into country- and type-specific patterns of policy acceptability, additional research is needed to build on these findings and further enhance the effectiveness of CF reduction policymaking and implementation.

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Appendix

4. Survey questionnaire

SQ1. What is your age? Year of birth (_____) [Survey target: ages 20–60]

SQ2. What is your gender? 1) Male 2) Female

4.1 Acceptance of carbon footprint reduction policies

A1. Before this survey, have you ever heard of the term “carbon footprint?”

1) Yes 2) No

> What is a carbon footprint?
> A carbon footprint is an indicator that represents the amount of carbon emissions produced by an individual or household through daily energy use and consumption activities. It measures the emissions of greenhouse gases, especially carbon dioxide (CO_2), generated through various activities such as the food we eat, housing energy we use, transportation methods, and goods and services we purchase.

A2. How much do you agree with the opinion that individual consumption activities related to carbon emissions should be reduced to respond to the global climate crisis and achieve carbon neutrality?

Disagree	----------Neutral----------					Agree
1	2	3	4	5	6	7

A3. How much do you think you know about actions to reduce the carbon footprint?

Unaware	----------Neutral----------					Very aware
1	2	3	4	5	6	7

A4-1-1. Please indicate how much you agree with the following actions for reducing the carbon footprint.

Overall carbon footprint: In order to reduce residents' carbon footprints, the roles of individuals, businesses, and governments (both central and local) are important, along with urban planning (design) and research (technology) development. Please respond to the following items with this in mind.

Actions for reducing the carbon footprint	Disagree ← Neutral → Agree						
	1	2	3	4	5	6	7
1. Individuals should make an effort to reduce their consumption of food, housing, transportation, and goods and services.							
2. Urban planning and design is needed to reduce the carbon footprint of city dwellers.							
3. The government and local authorities should roll out policies, programs, and initiatives to reduce their carbon footprint.							
4. Companies need to take steps to reduce their carbon footprint in their manufacturing processes.							
5. I support increased investment and support for research and development of technologies that reduce our carbon footprint.							

A4-1-2. Please select only one item you agree with the most from the following.

A4-1-3. Please select only one item you agree with the least from the following.

Actions for reducing the carbon footprint	Most agree	Least agree
1. Individuals should make an effort to reduce their consumption of food, housing, transportation, and goods and services.		
2. Urban planning and design is needed to reduce the carbon footprint of city dwellers.		
3. The government and local authorities should roll out policies, programs, and initiatives to reduce their carbon footprint.		
4. Companies need to take steps to reduce their carbon footprint in their manufacturing processes.		
5. I support increased investment and support for research and development of technologies that reduce our carbon footprint.		

A4-2-1. Please indicate how much you agree with the following actions for reducing the carbon footprint.

Food: Most of the energy used in food production is consumed during transportation, processing, packaging, and storage from the harvest site to the market. Please respond to the following items with this in mind.

Actions for reducing the carbon footprint	Disagree ← Neutral → Agree						
	1	2	3	4	5	6	7
6. I support expanding and revitalizing local farmers markets.							
7. The government and local authorities should promote the certification and consumption of low-carbon, eco-friendly, and organic agricultural products.							
8. Individuals should make an effort to reduce their consumption of meat and imported/packaged/processed foods.							
9. Companies should ramp up efforts to expand plant-based options in restaurants and stores, along with developing meat alternatives.							
10. I support plans that reduce transportation distances by producing and consuming food within cities, like urban farming.							

A4-2-2. Please select only one item you agree with the most from the following.

A4-2-3. Please select only one item you agree with the least from the following.

Actions for reducing the carbon footprint	Most agree	Least agree
6. I support expanding and revitalizing local farmers markets.		
7. The government and local authorities should promote the certification and consumption of low-carbon, eco-friendly, and organic agricultural products.		
8. Individuals should make an effort to reduce their consumption of meat and imported/packaged/processed foods.		
9. Companies should ramp up efforts to expand plant-based options in restaurants and stores, along with developing meat alternatives.		
10. I support plans that reduce transportation distances by producing and consuming food within cities, like urban farming.		

A4-3-1. Please indicate how much you agree with the following actions for reducing the carbon footprint.

Housing: To reduce carbon emissions generated from energy used for maintaining building temperature, lighting, and heating, it is necessary to reduce energy consumption or use energy sources that emit less (or no) carbon. Please respond to the following items with this in mind.

Actions for reducing the carbon footprint	Disagree ← Neutral → Agree						
	1	2	3	4	5	6	7
11. I support green remodeling efforts that improve the energy efficiency of existing buildings.							
12. I support installing renewable energy sources like solar panels and solar thermal systems on buildings and homes.							
13. Individuals should make an effort to conserve electricity, gas, and water at home.							
14. Require buildings or factories to install green roofs or solar panels.							
15. Require new buildings to be designed to be zero energy, meaning they don't rely on outside energy sources.							

A4-3-2. Please select only one item you agree with the most from the following.

A4-3-3. Please select only one item you agree with the least from the following.

Actions for reducing the carbon footprint	Most agree	Least agree
11. I support green remodeling efforts that improve the energy efficiency of existing buildings..		
12. I support installing renewable energy sources like solar panels and solar thermal systems on buildings and homes.		
13. Individuals should make an effort to conserve electricity, gas, and water at home.		
14. Require buildings or factories to install green roofs or solar panels.		
15. Require new buildings to be designed to be zero energy, meaning they don't rely on outside energy sources.		

A4-4-1. Please indicate how much you agree with the following actions for reducing the carbon footprint.

Travel: To reduce carbon emissions generated from energy used for commuting or transportation, it is necessary to reduce travel distance or use transportation methods and energy sources that emit less (or no) carbon. Please respond to the following items with this in mind.

Actions for reducing the carbon footprint	Disagree ← Neutral → Agree						
	1	2	3	4	5	6	7
16. Individuals should make an effort to use public transportation, such as buses, trains, or bikes, instead of driving their own cars.							
17. I support expanding bike lanes and pedestrian walkways.							
18. I support limiting the use of high carbon-emission vehicles.							
19. I support plans and designs that increase the proportion of residential areas and population density within cities to reduce urban sprawl through mixed-use development.							
20. I support expanding the infrastructure for electric vehicle charging and dedicated parking spaces.							

A4-4-2. Please select only one item you agree with the most from the following.

A4-4-3. Please select only one item you agree with the least from the following.

Actions for reducing the carbon footprint	Most agree	Least agree
16. Individuals should make an effort to use public transportation, such as buses, trains, or bikes, instead of driving their own cars.		
17. I support expanding bike lanes and pedestrian walkways.		
18. I support limiting the use of high carbon-emission vehicles.		
19. I support plans and designs that increase the proportion of residential areas and population density within cities to reduce urban sprawl through mixed-use development.		
20. I support expanding the infrastructure for electric vehicle charging and dedicated parking spaces.		

A4-5-1. Please indicate how much you agree with the following actions for reducing the carbon footprint.

Waste: To reduce carbon emissions generated from energy used for product manufacturing and waste disposal, it is necessary to reduce product consumption or waste generation, or increase the proportion of recycling and reuse. Please respond to the following items with this in mind.

Actions for reducing the carbon footprint	Disagree ← Neutral → Agree						
	1	2	3	4	5	6	7
21. We all need to do our part to reduce food and general waste and increase recycling and reuse.							
22. The government and local authorities should implement policies to reduce single-use items in places like stores and hotels.							
23. I support policies that discourage single-use products and mandate reusable containers.							
24. Companies need to cut back on product packaging and create reusable containers.							
25. I support the plan to build a biogas facility with organic waste such as food waste, livestock manure, and sewage sludge.							

A4-5-2. Please select only one item you agree with the most from the following.

A4-5-3. Please select only one item you agree with the least from the following.

Actions for reducing the carbon footprint	Most agree	Least agree
21. We all need to do our part to reduce food and general waste and increase recycling and reuse.		
22. The government and local authorities should implement policies to reduce single-use items in places like stores and hotels.		
23. I support policies that discourage single-use products and mandate reusable containers.		
24. Companies need to cut back on product packaging and create reusable containers.		
25. I support the plan to build a biogas facility with organic waste such as food waste, livestock manure, and sewage sludge.		

A4-6-1. Please indicate how much you agree with the following actions for reducing the carbon footprint.

Sink: A carbon sink is a place that absorbs GHGs from the atmosphere. To reduce emitted carbon, it is necessary to increase the amount of carbon absorbed. Please respond to the following items with this in mind.

Actions for reducing the carbon footprint	Disagree ← Neutral → Agree						
	1	2	3	4	5	6	7
26. I support increasing the amount of green space and parks in urban areas.							
27. Companies should get involved in programs and initiatives that expand carbon sinks, such as creating parks and planting trees.							
28. I support expanding the greenbelt designation, which limits development on existing green spaces.							
29. The government should invest more in research and development to boost the carbon-absorbing capacity of our forests and green spaces.							
30. We need an ecological restoration plan that includes green spaces and biotopes that take biodiversity into account.							

A4-6-2. Please select only one item you agree with the most from the following.

A4-6-3. Please select only one item you agree with the least from the following.

Actions for reducing the carbon footprint	Most agree	Least agree
26. I support increasing the amount of green space and parks in urban areas.		
27. Companies should get involved in programs and initiatives that expand carbon sinks, such as creating parks and planting trees.		
28. I support expanding the greenbelt designation, which limits development on existing green spaces.		
29. The government should invest more in research and development to boost the carbon-absorbing capacity of our forests and green spaces.		
30. We need an ecological restoration plan that includes green spaces and biotopes that take biodiversity into account.		

A4-7-1. Please indicate how much you agree with the following actions for reducing the carbon footprint.

Issue: In the process of reducing the carbon footprint, there are key issues such as public participation, nuclear technology, coal phase-out policies, campaigns, and electricity rate increases. Please respond to the following items with this in mind.

Actions for reducing the carbon footprint	Disagree ← Neutral → Agree						
	1	2	3	4	5	6	7
31. Citizen engagement should be fully integrated into city planning, policies, programs, and procedures that aim to reduce carbon footprint.							
32. I support putting small modular reactors (SMRs) in cities that need a lot of electricity.							
33. I support phasing out coal-fired power plants, even if it means paying more for electricity.							
34. The government and local authorities should expand their social media campaigns to reduce their carbon footprint.							
35. I support raising electric rates to encourage the energy transition and to reduce our carbon footprint.							

A4-7-2. Please select only one item you agree with the most from the following.

A4-7-3. Please select only one item you agree with the least from the following.

Actions for reducing the carbon footprint	Most agree	Least agree
31. Citizen engagement should be fully integrated into city planning, policies, programs, and procedures that aim to reduce carbon footprint.		
32. I support putting small modular reactors (SMRs) in cities that need a lot of electricity.		
33. I support phasing out coal-fired power plants, even if it means paying more for electricity.		
34. The government and local authorities should expand their social media campaigns to reduce their carbon footprint.		
35. I support raising electric rates to encourage the energy transition and to reduce our carbon footprint.		

A5. Please select two items in the order of your agreement.

1st( ), 2nd( )

Provide reponse of A4-1-2, A4-2-2, A4-3-2, A4-4-2, A4-5-2, A4-6-2, A4-7-2 as options

A5-1. What is the reason you selected the item you agree with the most in A5?

A6. Please select two items in the order of your lesser agreement.

1st( ), 2nd( )

Provide reponse of A4-1-3, A4-2-3, A4-3-3, A4-4-3, A4-5-3, A4-6-3, A4-7-3 as options

A6-1. What is the reason you selected the item you agree with the least in A6?

A7. How actively are you practicing activities to reduce consumption in the following areas? Please rank them in order from the one you practice the most.

1st( ), 2nd( )

1) Food: Reducing consumption of meat, imported, packaged, and processed foods

2) Housing: Saving electricity, gas, and water; reducing heating and cooling energy use

3) Travel: Using public transportation such as buses, subways, and bicycles instead of personal cars

4) Product: Choosing eco-friendly products, reducing waste, recycling, and reusing

A8. Which of the following sectors do you think is the most important for reducing the carbon footprint? Please select two in order of importance.

1st( ), 2nd( )

This sector should be socially restricted (made mandatory) to reduce consumption.	1) Food 2) Housing 3) Travel 4) Product
I personally have a strong willingness to reduce consumption in this sector.	1) Food 2) Housing 3) Travel 4) Product
This sector is realistically effective in reducing the carbon footprint in our country.	1) Food 2) Housing 3) Travel 4) Product

A9. Besides the items mentioned above, are there any other ways to reduce people's consumption or carbon footprint? Please feel free to write anything.

4.2 Awareness of energy transition policies

B1. How much do you think you know about the government's current carbon neutrality goals?

Unaware	Neutral					Very aware
1	2	3	4	5	6	7

B2. Do you agree with the government's current carbon neutrality goals?

Greenhouse gas reduction (by 2030): Korea — 40% reduction compared to 2018,

Germany — 65% reduction compared to 1990

Carbon neutrality achievement: Korea by 2050, Germany by 2045

Disagree	---------- Neutral ----------					Agree
1	2	3	4	5	6	7

B3. How much do you think you know about the "limiting global warming to 1.5℃" goal promoted by the international community led by the UN?

Unaware	Neutral					Very aware
1	2	3	4	5	6	7

B4. Do you agree with the "limiting global warming to 1.5℃" goal promoted by the international community led by the UN?

※ Limiting the Earth's temperature rise to within 1.5℃ compared to pre-1900 levels can significantly reduce damages caused by climate change. To achieve the 1.5℃ goal, a rapid transition in the energy sector that emits GHGs is required.

Disagree	---------- Neutral ----------					Agree
1	2	3	4	5	6	7

B5. How much do you agree with the following actions for achieving the 1.5℃ target?

Actions	Disagree		Neutral			Agree	
	1	2	3	4	5	6	7
1) We should accept electricity rate increases to significantly expand the share of renewable energy (solar and wind) instead of fossil fuels.							
2) Consumption of carbon-intensive foods such as meat, dairy, and packaged or processed products should be reduced.							
3) Coal power plants, which emit large amounts of greenhouse gases, should be phased out within 20 years.							
4) Fossil fuel vehicles such as gasoline and diesel cars should be phased out within 20 years.							
5) Insulation standards for new and existing buildings should be strengthened, and even with higher costs, heating and cooling energy use should be minimized.							
6) A carbon tax proportional to GHG emissions should be introduced to encourage companies to reduce emissions.							

B6-1. Please select two important items in energy transition policies in order of importance.

B6-2. Please select two items from the energy transition policies that you think are showing successful results, in order of priority.

1st( ), 2nd( )

1) Nuclear phase-out (safety): Reducing the share of nuclear power to lower potential risks (accidents, health impacts, etc.)

2) Renewable energy (environment): Reducing dependence on fossil fuels and increasing the share of renewable energy

3) Decentralization (society): Enabling citizens or local communities to participate in balanced energy production and consumption

4) Jobs (economy): Promoting economic development by creating new industries and jobs through energy transition

5) Demand management (energy): Reducing energy consumption and improving energy production efficiency (technological innovation)

B7-1. Whose role do you think is most important for the successful establishment of energy transition policies? Please select two in order of importance.

B7-2. Who do you think is currently playing the biggest role in the successful establishment of energy transition policies? Please select two in order of priority.

1st( ), 2nd( )

1) Government: Establishing systems for active promotion, information disclosure, and communication (such as setting up public deliberation committees)

2) Companies: Creating new industries and jobs through active investment

3) Citizens: Directly expressing opinions and participating through online and offline channels (petitions, public hearings, etc.)

4) NGO: Indirect participation and consultation through non-governmental organizations (involvement of organization representatives)

5) Research: Policy formation based on objective and scientific research (involvement of public, private, and university research institutions)

B8. The following questions are about environmental awareness. How much do you agree with each of the following items?

Items	Disagree		Neutral			Agree	
	1	2	3	4	5	6	7
1) I am very interested in the environment (environmental issues) in daily life.							
2) Environmental conservation is very important to me.							
3) The world's population is approaching the limits of what the Earth can sustain.							
4) I am willing to buy eco-friendly products even if they are a bit more expensive.							
5) I am practicing actions for environmental conservation (such as saving electricity and resources).							

B9. The following questions are about social awareness. How much do you agree with each of the following items?

Items	Disagree		Neutral			Agree	
	1	2	3	4	5	6	7
1) I believe that most people can be trusted in relationships.							
2) I have many people I can rely on for help in difficult times.							
3) I respect the thoughts and opinions of others.							
4) I feel a strong sense of belonging to the community where I currently live.							
5) I participate in activities through clubs, groups, or organizations.							
6) Conflicts are not severe in our country.							
7) Discrimination against minority groups is not severe in our country.							

4.3 Respondent characteristics

C1. Where do you currently live?

1) Seoul 2) Busan 3) Daegu 4) Incheon 5) Gwangju 6) Daejeon 7) Ulsan 8) Gyeonggi-do 9) Gangwon-do 10) Chungcheongbuk-do 11) Chungcheongnam-do 12) Jeollabuk-do 13) Jeollanam-do 14) Gyeongsangbuk-do 15) Gyeongsangnam-do 16) Jeju Special Self-Governing Province 17) Sejong City	1) Baden-Württemberg 2) Bayern 3) Berlin 4) Brandenburg 5) Bremen 6) Hamburg 7) Hessen 8) Mecklenburg-Vorpommern 9) Niedersachsen 10) Nordrhein-Westfalen 11) Rheinland-Pfalz 12) Saarland 13) Sachsen 14) Sachsen-Anhalt 15) Schleswig-Holstein 16) Thüringen

C2. How many people, including yourself, currently live in your household? _____ people

C3. What is your household's average monthly income before tax?

1) Below 2 million KRW or Below 2,000 EUR
2) 2–4 million KRW or 2,000–4,000 EUR
3) 4–6 million KRW or 4,000–6,000 EUR
4) 6–8 million KRW or 6,000–8,000 EUR
5) 8–10 million KRW or 8,000–10,000 EUR
6) Above 10 million KRW or Above 10,000 EUR

C4. What is your highest level of education?

1) Elementary school graduate or dropout

2) Middle school graduate or dropout (including currently enrolled)

3) High school graduate or dropout (including currently enrolled)

4) Currently enrolled in University

5) University graduate

6) Graduate school enrollment or higher

C5. What is your occupation?

1) Student 2) Homemaker

3) Employee 4) Self-employed

5) Freelancer 6) Unemployed

7) Other( )

C5-1. [For respondents who answered C5=3 only] What is your workplace?

1) Government, Public Sector

2) Company, Business

3) University, Research Institute

4) Other( )

C6. How much do you trust the current government?

Distrust	---------- Neutral ----------					Trust
1	2	3	4	5	6	7

C7. What is your political orientation?

Progressive	---------- Moderate ----------					Conservative
3	2	1	0	1	2	3

C8. Please select the item you consider most important.

1st( ), 2nd( )

1) High level of economic growth

2) Strong national defense

3) Increased participation in the workplace and community

4) Making cities and rural areas more pleasant

주민 탄소발자국 감축 도시계획요소 및 정책 수용성 비교 연구
한국과 독일을 대상으로

김태현 외

1. 서론: 연구배경 및 목적

국제사회에서 논의된 1.5°C 기후변화 정책목표 달성을 위해 탈탄소 전환이 시급한 상황에서 글로벌 탈탄소 전환 기조에 대응하는 도시 시스템 전환의 필요성이 강조되고 있다. 하지만 탈탄소 전환을 위한 과정에서 유럽연합의 온실가스 배출량 감축 정책에 반대하는 농민시위가 발생하거나 청정에너지로의 전환을 위한 전기요금 인상 등 사회적 이슈 및 난제가 발생하고 있다. 따라서 정의로운 전환 관점에서 탈탄소 전환 대응 정책에 대한 대중의 수용성을 고려할 필요가 있다.

특히, 에너지, 발전, 산업정책 등 생산기준 탄소배출 감축에 초점을 두고 있는 국가계획과 더불어 상업, 가정, 수송, 폐기물 등 지자체에 관리 권한이 있는 소비기준 주민 탄소발자국 감축 정책이 중요하다. 가정 부문에서 발생하는 직접적인 탄소 배출량의 비중이 산업 부문에 비해 상대적으로 작아 보일 수 있으나, 탄소발자국 관점에서는 거주자의 음식, 주거, 교통, 상품 및 서비스 소비를 지탱하기 위해 에너지, 발전, 산업, 상업, 수송, 폐기물 등 거의 모든 부문에서 발생하는 탄소 배출량에 간접적인 영향을 미치기 때문이다.

음식, 주거, 교통, 폐기물 등 소비 부문별 탄소발자국을 줄이기 위한 행태 개선뿐만 아니라 행태에 영향을 주는 공간구조 개선을 동시에 고려할 필요가 있다. 전 세계적으로 글로벌 탈탄소 전환 기조에 대응하기 위한 도시계획과 탄소중립 정책이 적극 추진 중이나 독일과 우리나라는 전환 실태 및 의식 수준에서 많은 차이가 날 것으로 예상된다. 따라서 글로벌 탈탄소 전환 기조에 대응하기 위한 계획 및 정책 연구 협력을 주도할 수 있도록 한국과 독일 비교 연구를 위해 해외 선진 연구기관 및 연구진과의 공동 연구와 네트워크 구축이 필요하다.

본 연구의 목적은 한국과 독일을 대상으로 탄소발자국을 줄이기 위한 도시계획요소 및 정책에 대한 주민 수용성을 비교, 글로벌 탈탄소 전환 대응 탄소중립 정책 수립에 기여하는 것이다. 구체적인 연구 목적과 보고서 구성에 따른 전체적인 연구내용(그림 1)은 다음과 같다.

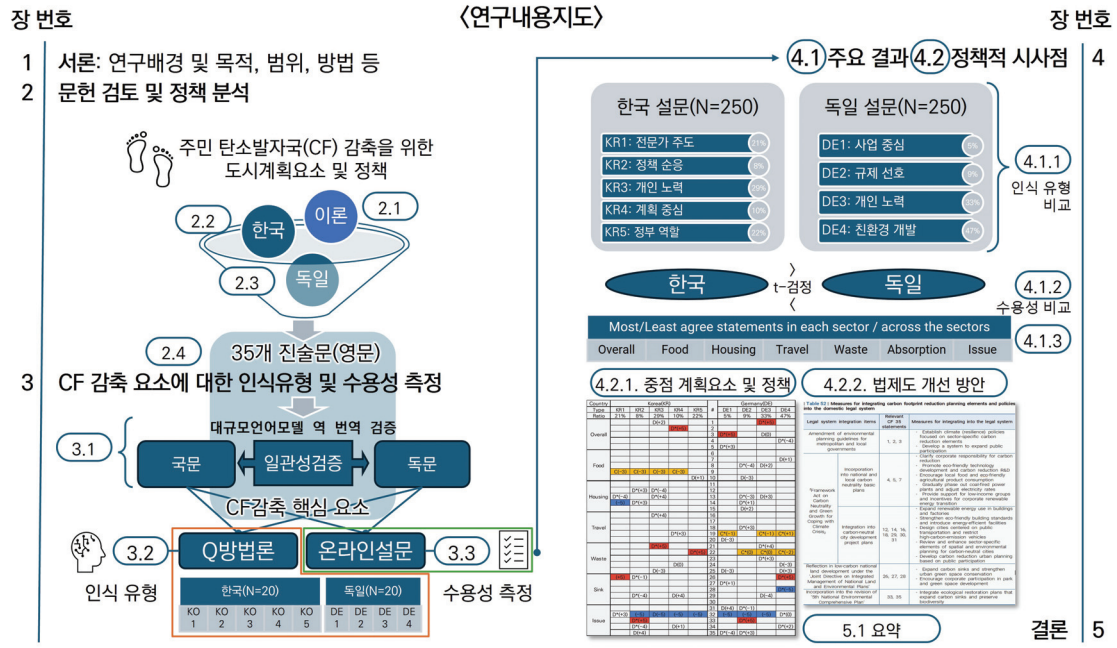
첫째, 한국과 독일의 탄소발자국(Carbon Footprint, CF) 감축 연구 및 정책을 조사한다.

둘째, 음식, 주거, 교통, 폐기물, 물 등 소비부문별 탄소발자국 감축 계획요소를 도출한다.

셋째, 탄소발자국 감축 계획요소 및 정책에 대한 인식유형과 수용성을 조사하고 분석한다.

넷째, 한국과 독일의 인식유형 및 수용성 조사 결과 비교 분석을 통해 정책적 활용방안을 제시한다.

그림 1 연구내용지도



자료: 저자 작성.

2. 탄소발자국 감축을 위한 도시계획요소와 정책

2.1 이론적 배경

도시 거주자는 도시 외부로부터 공급되는 자원에 의존하여 식량 및 에너지를 소비하기 때문에 탄소발자국이 크게 나타난다. 1970년대 석유 파동 이후 에너지 사용을 줄이고 효율성을 높이는 도시계획에 관한 논의가 이루어졌으며, 대중교통 중심, 복합 용도, 고밀 개발 등의 기법들이 제안되었다. 그러나 일부 복합 용도, 고밀 개발은 식품 소비 패턴에 영향을 주어 오히려 거주자의 탄소발자국을 늘릴 수 있다는 연구도 있다.

최근에는 1인 가구와 다인 가구의 주거 부문 탄소발자국의 차이, 아파트 형태에 따른 계절별 탄소발자국의 차이, 교외화가 탄소발자국에 미치는 영향 등 다양한 도시 특성과 탄소발자국 간의 관계에 대한 분석도 수행되고 있다. 실제 사례로 미국 캘리포니아 주에서는 탄소발자국 기반 도시계획 모델을 통해 가구 단위 평균 탄소발자국을 지도화하고, 이를 기반으로 온실가스 배출 감축을 위한 공간계획 전략을 수립하고 있다.

2.2 한국

탄소발자국 저감과 관련하여 한국의 도시 계획 정책은 제로에너지 건물 인증이나 스마트 시티 기술 적용을 통한 에너지 효율 향상, 녹색 인프라 확대, 지속 가능한 교통 시스템 구축에 중점을 두고 온실가스 감축이나 기후변화 대응을 위한 탄소 중립과 같은 목표를 달성하고 있다.

이와 관련하여 지역 단위 탄소중립 이행 전략에 따른 감축 인벤토리 연구와 함께 탄소중립을 고려한 지자체 국토-환경계획 통합관리 원칙과 전략, 구체적인 계획 기법들을 제시한 연구를 중심으로 탄소발자국 감축을 위한 도시계획요소들을 정리하였다.

탄소발자국 감축을 위한 정책으로는 환경부에서 도시 유형 및 특성을 고려하여 제시한 온실가스 감축 전략과 함께 기존 연구에서 감축 부문별, 지역 유형별로 나누어 제시한 지자체 단위 탄소배출 감축 정책들을 검토하였다. 또한 다른 연구 보고서에서 공통적으로 제시한 온실가스 감축 및 탄소중립 관련 정책과 더불어 국토계획에 탄소중립 개념이 내재화 되지 못한 이유들에 대해 검토하였다.

이밖에 수원, 충주 등 탄소중립 녹색도시 사업 계획에 적용된 에너지 전환, 탄소 흡수원 확대, 자원순환, 기후변화 적응, 사회전환 프로그램 등과 함께 새만금 스마트 수변도시 탄소중립 마스터플랜 계획에서 제시한 실행 전략들을 검토하였다.

2.3 독일

독일의 탄소발자국 감축과 관련한 정책적 배경 및 법제도, 탄소발자국 감축 도시계획요소, 에너지 전환 절차, 부문별 감축 대책들, 도시계획 과정에서 공공 참여 등에 대해 검토하였다. 독일은 유럽의 프레임워크와 긴밀히 협력하여 기후 보호 목표를 설정하였고, 이러한 목표를 달성하기 위해 수많은 법률안의 통과, 전략 개발, 자금 지원 프로그램 마련 등의 조치가 이루어졌다. 또한 바람직하지 않은 개발에 대응하기 위해 개발 상황을 집중적으로 모니터링하고 있다.

여러 단계로 구성된 독일의 계획 체계와 연방 정부의 기존 전략들은 모두 기후 중립을 달성하기 위한 노력들을 지원한다. 공간계획의 수많은 기본 원칙과 구체적인 목표들은 온실가스 배출 감소를 지원하도록 하고 있다. 또한 시민들은 참여 과정을 통해 도시 및 지방자치단체 수준에서 계획 과정에 영향을 줄 수 있다.

독일의 배출량 통계를 보면 초기에는 소폭 감소했지만 이제는 상당한 감소세를 보이고 있다. 하지만 탄소중립 목표를 달성하는 것은 여전히 큰 도전 과제이다.

2.4 탄소발자국 감축 핵심 수단

탄소발자국 감축을 위한 핵심 수단 목록 도출을 위해 이론적 배경과 한국과 독일의 탄소발자국 감축 계획요소, 정책 연구 및 사례 검토 외에도 유엔의 기후변화 대응을 위한 170가지 행동과 녹색 저탄소 건축 환경을 위한 저감 요소 등의 문헌을 참고하였다.

연구진의 기존 지식에 기반한 문헌 검토의 한계를 보완하고자 대규모 언어 모델(LLM)을 활용하여 탄소발자국 감축 도시계획요소와 정책에 대한 인식유형 및 수용성을 측정하기 위한 25개 진술문 초안을 도출하였다. 진술문 초안 각 항목 선택의 타당성과 국문, 영문, 독문 표현의 적절성 등에 대한 20명의 전문가 의견 수렴 후 수정, 보완 과정을 거쳐 최종 35개 진술문을 도출하였다.

35개 진술문은 탄소발자국 감축 전반, 음식, 주거, 통행, 폐기물, 흡수원, 이슈 등 7개 부문별 5개 항목으로 구성하고, 개별 항목들은 계획/설계, 정책/프로그램/사업, 행동/이니셔티브 등 3가지 범주로 구분하여 각 부문별로 해당 범주를 모두 포함하도록 하였다<그림 2 진술문 참조>.

그림 2 한국과 독일의 인식 유형별 응답 비율 및 주요 진술문 비교

국가				한국(KR)					독일(DE)			
유형	#	진술문	#	KR1	KR2	KR3	KR4	KR5	DE1	DE2	DE3	DE4
비율				21%	8%	29%	10%	22%	5%	9%	33%	47%
전반	1	개인이 음식, 주거, 교통, 상품 및 서비스 소비를 줄이기 위해 노력해야 한다.	1			D(+2)					D*(+5)	
	2	도시 거주자의 탄소발자국을 줄이기 위한 도시계획(설계)가 필요하다.	2				D*(+5)					
	3	정부와 지자체가 탄소발자국을 줄이기 위한 정책, 프로그램 및 사업을 추진해야 한다.	3						D*(+5)		D(0)	
	4	기업이 생산 과정에서 탄소발자국을 줄이기 위한 조치를 취해야 한다.	4									D*(−4)
	5	나는 탄소발자국을 줄이는 연구 및 기술 개발에 대한 투자 및 지원 확대를 지지한다.	5						D*(+3)			
음식	6	나는 지역 농산물(로컬푸드) 직판장 설치 및 이용 확대를 지지한다.	6									
	7	정부와 지자체가 저탄소, 친환경, 유기농 농산물 인증 및 소비를 활성화 해야한다.	7									D(+1)
	8	개인이 육류 및 수입, 포장, 가공된 식품 소비를 줄이기 위해 노력해야 한다.	8							D*(−4)	D(+2)	
	9	기업은 대체식품 개발과 함께 식당과 매장에서 채식 옵션을 확대하는 노력을 해야한다.	9	C(−3)	C(−3)	C(−3)	C(−3)					
	10	나는 도시 농업처럼 도심에서 식품을 생산하고 소비함으로써 운송 거리를 줄이는 계획을 지지한다.	10					D(+1)		D(−3)		
주거	11	나는 기존 건물의 냉난방 에너지 효율성을 높이는 그린리모델링 사업을 지지한다.	11									
	12	나는 건물과 주택에 태양광 패널과 태양열 시스템 같은 재생 에너지원을 설치하는 것을 지지한다.	12		D*(+3)	D*(−4)						
	13	개인이 가정에서 전기, 가스, 수도를 아껴쓰도록 노력해야 한다.	13	D*(−4)		D*(+4)				D*(−3)	D(+3)	
	14	건물 및 공장 지붕에 옥상녹화 또는 태양광 패널 설치를 의무화 한다.	14	(−5)	D*(+3)					D*(+1)		
	15	건물을 새로 지을경우 외부 에너지 공급에 의존하지 않는 제로에너지빌딩 설계를 의무화 한다.	15							D*(+2)		
통행	16	개인이 승용차 대신 버스, 전철, 자전거 등 대중교통망을 이용하려고 노력해야 한다.	16			D*(+4)						
	17	나는 자전거 도로 및 보행자 전용 구역의 확대를 지지한다.	17									
	18	나는 탄소 배출량이 많은 차량의 사용을 제한하는 것을 지지한다.	18							D*(+3)		
	19	나는 도시 내 주거 지역 비율과 인구 밀도를 높이고, 혼합 용도 개발을 통해 도시 확산을 줄이는 계획과 디자인을 지지한다.	19				D*(+3)		C*(−1)		C*(−1)	C*(+1)
	20	나는 전기차 충전 인프라 및 전용 주차면 비중 확대를 지지한다.	20						D(−3)			
폐기물	21	개인이 음식물, 일반쓰레기를 줄이고 재활용, 재사용을 늘리는 노력을 해야한다.	21			D*(+5)					D*(+4)	
	22	정부와 지자체가 매장과 숙박시설 등에서 일회용품 사용을 제한하는 정책을 시행해야 한다.	22					D*(+5)		C*(0)	C*(0)	C*(−2)
	23	나는 일회용품 사용을 제한하고 다회용기 사용을 의무화하는 정책을 지지한다.	23								D*(+3)	
	24	기업이 상품 포장재를 줄이고 재활용 가능한 용기를 만드는 등의 조치를 해야 한다.	24				D(0)					D(−3)
	25	나는 음식물 쓰레기, 가축 분뇨, 하수 슬러지 등 유기성 폐기물로 바이오가스 시설을 짓는 계획을 지지한다.	25			D(−3)			D(−3)			D(+3)
흡수원	26	나는 도시 지역의 녹지 공간과 공원 비중을 늘리는 계획을 지지한다.	26	(+5)	D*(−1)							D*(+5)
	27	기업이 공원녹지 조성, 나무 심기 등 흡수원 확대 프로그램 및 사업에 동참해야 한다.	27						D*(+1)			
	28	나는 기존 녹지에 대한 개발행위를 제한하는 그린벨트 지정 확대를 지지한다.	28									D*(−5)
	29	정부는 기존 산림과 녹지의 탄소흡수량을 높이는 연구 및 기술 개발에 투자와 지원을 늘려야 한다.	29		D*(−4)		D(+4)				D(−4)	
	30	생물다양성을 고려한 녹지 및 생물서식공간 조성 등 생태복원 계획 수립이 필요하다.	30									
이슈	31	탄소발자국을 줄이는 도시계획 수립이나 정책, 프로그램, 사업 절차에서 시민들의 참여를 충분히 보장해야 한다.	31						D(+4)	D*(−1)		
	32	나는 전력을 많이 쓰는 도시에 소형모듈원자로(SMR, Small Modular Reactor)를 설치하는 것을 지지한다.	32	D*(+3)	(−5)	D(−5)	(−5)	(−5)	(−5)	(−5)	(−5)	D*(0)
	33	나는 전기요금을 더 내더라도 석탄화력발전소 운영 중단 등 탈석탄 정책을 지지한다.	33		D*(+5)					D*(+5)		
	34	정부와 지자체는 탄소 발자국을 줄이기 위한 소셜 미디어 캠페인을 확대해야 한다.	34		D*(−4)		D(+1)					D*(+2)
	35	나는 에너지 전환 및 탄소발자국 감축을 위한 전기요금 인상을 지지한다.	35		D(+4)				D*(−4)	D*(+3)		

주: 1) 빨간색 – 가장 동의하는 진술문(+5), 파란색 – 가장 덜 동의하는 진술문(−5), 노란색 C (Consensus) – 다른 유형과 차이를 보이지 않는 진술문, D(Distinguish) – 다른 유형과 구별 짓는 진술문(P〈0.05; *는 유의수준 P〈0.01을 의미), 괄호 안의 숫자는 요인 Q분류 점수.
2) KR1: 전문가 주도, KR2: 정책 순응, KR3: 개인 노력, KR4: 계획 중심, KR5: 정부 역할.
3) DE1: 사업 중심, DE2: 규제 선호, DE3: 개인 노력, DE4: 친환경 개발.
자료: 저자 작성.

3. 탄소발자국 감축 핵심 수단에 대한 인식 유형 및 수용성 측정

3.1 LangChain을 활용한 다국어 번역

탄소발자국 감축 핵심 수단에 대한 인식 유형 및 수용성을 측정하는 진술문에 대하여 한국과 독일 응답자 간에 일관된 이해를 보장하기 위하여 대규모 언어 모델(LLM)을 기반으로 하는 오픈소스 프레임워크인 LangChain을 활용하여 다국어 번역 애플리케이션을 개발하고 정책 관련 설문 조사 질문에 대한 교차 언어 검증을 수행하였다.

LangChain을 활용한 앱에서는 영문으로 작성된 진술문을 ChatGPT3.5, ChatGPT4o, Gemini, Claud3, DeepL 등 LLM을 활용하여 각각 한국어와 독일어로 번역하고, 번역된 문장을 다시 영문으로 역번역하여 그 결과가 원문과 얼마나 일치하는지를 코사인 일치도(Cosine Similarity) 점수로 검증, 가장 적합한 번역 결과를 선택한다.

역번역 검증을 거친 진술문에 대해서는 독일과 한국 원어민 전문가와 일반인 평가를 실시하여 번역된 문장이 원래 개념을 정확하게 표현하는지 확인하였다.

3.2 인식 유형 측정: Q 방법론

탄소발자국 감축 핵심 수단에 대한 인식 유형 측정을 위하여 Q 방법론을 사용하였다. Q방법론은 분석적 계층 프로세스(AHP)와 같은 전문가 주도의 의사결정 기법과 달리 정성적-정량적 혼합 방법론으로 일반 대중의 주관적 견해와 판단 기준을 체계적으로 탐색하는 데 유용하다. 특히, 감축 요인과 부문 간 수용성에 차이가 있는 응답자의 주관적 판단 기준을 파악함으로써 정책 수립 과정에서 고려해야 할 핵심 인식을 구체적으로 도출할 수 있다.

앞서 도출한 35개 진술문에 대해 한국과 독일의 도시계획, 환경, 에너지 관련 분야 전문가와 공무원, 회사원, 일반인 등 각 나라별 20인(총 40인)을 대상으로 대면 또는 온라인으로 강제 할당을 통한 11점 척도 Q분류 조사와 인터뷰를 실시하였다. 수집한 자료는 PQ Method KADE 프로그램을 사용하여 주성분 분석과 베리맥스 회전을 통한 요인 분석을 실시하였다.

분석 결과 한국은 전문가 주도(KR1), 정책 순응(KR2), 개인 노력(KR3), 계획 중심(KR4), 정부 역할(KR5) 등 5개 유형으로, 독일은 사업 중심(DE1), 규제 선호(DE2), 개인 노력(DE3), 친환경 개발(DE4) 등 4개 유형으로 정책수용성 인식 유형을 정의, 해석하고 각 유형별 핵심 특성과 함께 유형별 공통점과 차이점을 분석하였다.

3.3 수용성 측정: 온라인 설문

탄소발자국 감축 핵심 수단에 대한 수용성 측정을 위하여 구조화된 설문지를 작성하고 온라인 설문조사를 실시하였다. 한국과 독일 각 나라의 연령대, 성별 인구구조를 반영한 인구비례할당 표본추출을 통하여 각 나라별 250명, 총 500명의 응답을 받았다.

설문 문항은 탄소발자국 개념에 대한 인지 및 동의 여부, 탄소발자국을 줄이는 실천 사항에 대한 인식 수준 등과 함께 부문별 탄소발자국 감축 핵심 수단에 대해 동의하는 정도 등을 포함하여 7점 리커트 척도로 작성하였다. 또한 각 부문에서 가장 동의/덜 동의하는 진술문을 선택하고, 선택된 진술문들 중에서 다시 우선순위를 매기도록 하여 탄소발자국 감축 핵심 수단 간 수용성의 차이를 확인하였다. 이 외에도 탄소발자국 감축 부문별 소비를 줄이기 위한 활동 실천 정도와 사회적 필요성, 개인적 의지, 현실적 효과성 등을 묻는 항목을 추가하였다.

이밖에 탄소중립 목표에 대한 이해도와 찬성 여부, 에너지 전환 정책에 대한 중요도와 성과, 전환 주체 및 역할 등과 함께 환경의식, 사회의식 등 에너지 전환 관련 인식 및 응답자 특성과 관련한 질문들을 추가로 구성하였다.

4. 주요 결과 및 정책적 시사점

4.1 한국과 독일의 인식 유형 및 수용성

한국과 독일의 인식 유형별 공통점 및 차이점을 탄소 감축 접근 방식과 정부, 기업, 개인의 역할, 재생에너지에 대한 태도, 경제적 부담 감수 여부 등에 따라 분석하였다. 주체별 역할과 개입 수준에 따라 양국이 일부 서로 비슷한 인식을 갖는 유형들도 있지만 인식 유형별로 차이가 나는 경우가 대부분이었다.

설문조사 응답자의 인식 유형별 분류 결과 한국은 개인 노력(KR3, 29.2%), 정부 역할(KR5, 22.0%), 전문가 주도(KR1, 21.2%) 등 다양한 요소가 균형을 이루는 다원적 모델을 보였다. 독일은 친환경 개발(DE4, 46.8%)과 개인 노력(DE3, 33.2%)을 강조하는 유형이 대부분을 차지하였다.

리커트 척도로 측정한 설문 항목들은 t-검정을 통해 한국과 독일 응답자 간 평균의 통계적 차이를 비교하였다. 탄소발자국 개념 인식이나 소비 활동 감축 필요성에 대한 동의 정도는 한국이 더 높았으나 탄소발자국을 줄이는 방법에 대한 인식 수준은 독일이 더 높았다. 부문별 수용성 평균 비교에서는 대부분의 항목에서 양국 간 차이를 보였으나 개인의 음식 소비 줄이기(#8), 주거 부문의 제로 에너지 건축(#15), 개인의 소비 감축(#1)과 폐기물 감축(#21) 노력과 같은 실천적 요소들은 국가 간 큰 의견 차이가 없었다.

부문별 수용성 순위 비교 결과 개인의 탄소발자국 감축(#1) 및 음식 소비 줄이기(#8) 항목에 대해 한국은 가장 덜 동의하는 항목으로 응답한 반면 독일은 가장 동의하는 항목으로 응답하여 대조를 이루었다. 전 부문을 통틀어 가장 동의하는 항목은 한국과 독일 간 차이를 보였는데 한국은 탄소발자국 전반에서 정부의 역할(#3)과 상품 생산 과정에서 기업의 역할(#24)을, 독일은 폐기물(#21)과 가정(#13) 부문에서 개인의 자발적 참여에 대한 수용성이 가장 높게 나타났다. 전기요금 인상(#35)은 양국 모두 가장 덜 동의하는 항목으로 나타났다.

결론적으로 각 유형 간의 인식의 차이는 관련 정책 추진 시 단일한 접근법으로는 한계가 있으며 인식 유형별 특성을 반영한 맞춤형 접근과 소통 전략의 필요성과 함께 기업, 정부, 개인의 역할이 균형을 이루어야 함을 보여준다. 한편 한국과 독일은 탄소 감축에 대한 접근 방식에서 차이를 보이며, 각국의 사회적·문화적 배경이 정책 수용성에 중요한 영향을 미친다는 점이 확인되었다.

4.2 정책 제언

Q 방법론 및 설문 분석 결과를 기반으로 각 나라의 인식 유형별 구성 비율에 따라 중점을 두어야 할 탄소발자국 감축 수단을 세분화하여 정책 방향을 설정할 수 있다. <그림 ES2>에서 한국과 독일의 인식 유형 간 일치된 의견(consensus)을 보이는 항목과 각 유형을 구분 짓는(distinguish, D) 항목들을 중심으로 동의 또는 덜 동의하는 정도를 확인하여 정책적 시사점을 도출하였다.

각 나라에서 유형 간 일치가 나타나는 항목들이 국가 간에 차이를 보이는 점과 각 나라에서 유형 간 차이를 구분 짓는 항목들을 비교해 보면 다음 <표 1>과 같이 정책 수용성과 정부, 기업, 개인의 역할, 환경 보호 접근 방식, 주요 정책 수단, 재정 지원 방식, 사회적 수용성, 지역사회 역할 등에서 차이를 보임과 동시에 경제적 부담이 큰 정책에 대한 저항이 존재한다는 공통점도 확인할 수 있다.

이처럼 한국과 독일의 정책 수용성을 비교한 결과를 바탕으로 탄소발자국 감축을 위한 다섯 가지 중점 추진 항목을 1. 정부 주도의 정책 강화 및 인센티브 제공, 2. 교통 분야의 친환경 전환 가속화, 3. 폐기물 및 순환경제 강화, 4. 탄소 흡수원 확대 및 도시 녹지 정책 강화, 5. 전기요금 인상 관련 정책 신중 접근 등으로 구분하고 각 항목에 상응하는 주요 정책 요소들을 제시하였다 <표 2 참조>.

표 1 국가별 핵심 도시계획요소 및 정책 비교

구분	한국	독일
정책 수용성	정부와 기업의 주도적 개입 선호	개인의 자발적 실천 강조
정부 및 기업의 역할	정부·기업 중심의 정책 추진	시민 및 지방 정부 중심의 정책
개인의 역할	개인의 소비·생활방식 변화에 대한 저항이 큼	개인 실천(음식 소비 감축, 재활용, 에너지 절약 등)을 핵심 요소로 인식
환경 보호 접근 방식	기업 책임 및 정책적 개입 중심	개인 생활습관 변화와 에너지 절약 중심
주요 정책 수단	규제 및 인센티브 병행(기업 혁신 유도)	캠페인, 교육, 인프라 개선을 통한 개인 행동 변화 유도
재정 지원 방식	세제 혜택, 보조금, 기술 개발 지원	보조금 및 세금 인센티브 적극 활용
사회적 수용성	전기요금 인상 등 경제적 부담이 큰 정책에 저항이 큼	경제적 부담이 동반되는 정책에 대한 저항 존재
지역사회 역할	정부·기업 중심 정책이므로 상대적으로 낮음	지역사회 주도 프로젝트 활성화
공통점	경제적 부담이 큰 정책에 대한 저항 존재 경제적 부담을 보완하는 맞춤형 전략필요 (보조금, 세금 혜택, 단계적 요금 인상, 에너지 효율화 정책) 지속가능한 탄소 감축 정책이 요구됨	

자료: 저자 작성.

표 2 수용성을 반영한 탄소발자국 감축 중점 추진 항목 및 주요 정책 요소

중점 추진 항목	진술문 번호	주요 정책 요소
1. 정부 주도의 정책 강화 및 인센티브 제공	3, 29, 31	• 탄소발자국 저감 목표 수립 및 법제화 • 탄소흡수기능 강화 연구 및 기술개발 지원 • 시민 및 기업 참여 확대 정책 추진
2. 교통 분야의 친환경 전환 가속화	16, 18, 20	• 대중교통 및 저탄소 교통수단 확대 • 전기차 및 친환경 차량 전환 지원 • 교통부문 탄소감축 인센티브 제공
3. 폐기물 및 순환경제 강화	22, 24, 25	• 기업의 포장재 및 일회용품 사용 규제 강화 • 유기성 폐기물 활용 확대 • 재활용 및 자원순환 시스템 개선
4. 탄소 흡수원 확대 및 도시 녹지 정책 강화	26, 27, 28	• 도시 녹지 및 탄소 흡수원 확대 • 기업 및 민간의 녹지 조성 참여 유도 • 녹지 보존 및 생태계 복원 정책 강화
5. 전기요금 인상 관련 정책 신중 접근	33, 35	• 전기요금 인상 정책 점진적 추진 • 탈석탄 및 재생에너지 확대 지원 • 경제적 부담완화를 위한 보조금 및 인센티브 확대

자료: 저자 작성.

국내 탄소발자국 감축 정책의 실행력을 높이기 위해 탄소발자국 감축 계획요소 및 정책들을 각 법제도 및 계획 수립에 반영하여, 실효성 있는 탄소중립 정책을 추진할 수 있도록 할 필요가 있다. 이에 <표 3>과 같이 광역(기초)지자체 환경계획 수립 지침 개정, '기후위기 대응을 위한 탄소중립·녹색성장 기본법' 관련 계획 수립 및 탄소중립도시 조성 시 활용, 국토-환경계획 통합관리 및 제5차 국가환경종합계획(2020-2040) 수정(안)에 반영하는 등 탄소발자국 감축 계획요소 및 정책의 국내 법제도 반영 방안을 제시하였다.

표 3 탄소발자국 감축 계획요소 및 정책의 국내 법제도 반영 방안

법제도 반영 항목		진술문 번호	법제도 반영 방안
광역(기초)지자체 환경계획 수립 지침 개정		1, 2, 3	• 부문별 탄소 감축 요소를 반영하여 맞춤형 기후(회복)탄력성 중심 정책 수립 • 주민 참여를 확대할 수 있는 체계 마련
기후위기 대응을 위한 탄소중립·녹색성장 기본법	국가 및 지방 탄소중립 기본계획에 반영	4, 5, 7	• 기업의 탄소 감축 책임 명확화 • 친환경 기술 개발 및 탄소 감축 연구개발(R&D) • 로컬푸드 및 친환경 농산물 소비 촉진 • 단계적 석탄화력발전소 폐지, 전기요금 조정 • 저소득층 지원 및 기업 재생에너지 전환 인센티브
	탄소중립도시 조성 사업 계획에 반영	12, 14, 16, 18, 29, 30, 31	• 건물 및 공장 재생에너지 확대 • 친환경 건축 기준 강화 및 에너지 효율화 설비 도입 • 대중교통 중심 도시 설계 및 고탄소 배출 차량 제한 • 탄소중립도시 공간환경계획 부문별 요소 보완 검토 • 주민 참여 기반 탄소 감축 도시계획 마련
국토계획 및 환경계획의 통합관리 공동훈령에 따른 저탄소 국토 조성에 반영		26, 27, 28	• 탄소 흡수원 확대 및 도시 내 녹지 공간 보존 강화 • 기업의 공원 및 녹지 조성 참여 유도
제5차 국가환경종합계획 수정 반영		33, 35	• 탄소흡수원 확대 및 생물다양성 보존을 고려한 생태복원 계획 반영

자료: 저자 작성.

5. 결론

이 연구는 주민 탄소발자국 감축을 위한 도시계획요소 및 정책 수립, 집행 시 이에 대한 인식 유형 및 수용성을 고려한 이해관계자 식별의 중요성과 함께 정밀한 분석 방법론을 제시하였다는 점에서 학술적, 정책적 의의가 있다.

하지만 이 연구는 한국과 독일만을 대상으로 하여 다른 국가나 문화권으로 일반화하기에는 한계가 있으며, 두 나라의 일부 구성원에 의한 응답 결과만으로 탄소발자국 감축에 대한 범국가적인 인식을 대표하기는 어렵다. 탄소발자국 감축 핵심 수단에 대한 인식 유형과 수용성을 다양한 방법으로 접근하여 분석하였으나, 정책 요소 간 상호작용이나 영향력의 정도에 대한 심층 분석이 부족하다는 점에서 한계도 있다.

향후 연구에서는 다양한 국가를 포함하여 비교 연구를 확대하고 조사 대상을 늘려 일반화의 한계를 보완할 필요가 있다. 또한 탄소발자국 감축 정책의 실효성을 높이기 위해 정책 수용성 요소 간 상호작용 분석 등 심층 분석을 통한 결과를 맞춤형 정책 수립의 근거로 활용하는 후속 연구가 필요하다.

주제어 탄소발자국 감축, 지속가능한 도시계획, 정책 수용성, Q 방법론, 온라인 설문

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- Planning Factors Affecting Carbon Footprints of Residents: Density, Land Use, and Suburbanization. Environment and Planning B: Urban Analytics and City Science (2024)

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Comparative Study on Urban Planning Elements and Policy Acceptability to Reduce Residents' Carbon Footprint

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93530
9 791159 809958
ISBN 979-11-5980-995-8