2050 탄소중립에 대응하는 도시정책 방향 연구

2024년 9월

국토교통부

박 정 혁

국외훈련 개요

1. 훈련국 : 미합중국(United States of America)

2. 훈련기관명 : 조지 워싱턴 대학교

(George Washington University)

3. 훈련분야 : 경제학 석사과정

(Master of Science in Applied Economics)

4. 훈련과제 : 2050 탄소중립에 대응하는 도시정책 방향 연구

5. 훈련기간 : 2022.12.29.~2024.10.28.(22개월)

훈련기관 개요

1. 훈련기관: 조지워싱턴대학교(George Washington University), 컬럼비안 문리과대학(Columbian College of Arts & Sciences), 경제학부(Department of Economics)

2. 소재지: 2121 I St NW, Washington, DC 20052

3. 홈페이지: https://www.gwu.edu

4. 연락처: Department of Economics (202) 994-1000
(FAX) (202) 994-614
(E-mail) econgrad@gwu.edu

5. 연혁

1821년 2월 9일 미국 의회에서 헌장을 받아 워싱턴 D.C. 내에 Columbian College 사립대학으로 설립되었다. 이후 1873년 종합대학으로 승격 후, 1904년 초대 대통령 조지 워싱턴을 기리기 위해 현 교명으로 변경되었다.

6. 조직 및 기능

(단과대학 및 대학원) 컬럼비안 문리과대학, 의학전문대학원, 법학전문대학원, 공과대학, 코코란 예술디자인대학, 엘리엇 국제관계대학, 교육대학원, 경영대학, 공공정책언론대학, 정치경영대학원, 밀켄 보건대학, 전문연구대학원, 트라첸버그 공공정책행정대학원, 간호대학으로 구성되며, 약 90개 학위과정 운영 중

(컬럼비안 문리과대학, CCAS) 컬럼비안 문리과대학은 조지 워싱턴 대학에서 가장 오래되고, 가장 큰 단과대학으로, 약 5,000명의 학부생과 2,500명의 대학원생이 42개의 학과에 재학 중. 행정학, 국제정치학, 응용경제학 등이 각각 우수할 뿐 아니라 학제 간 연구가 활발하다는 평가

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I. Introduction

Climate change has recently caused many ecological, economic, and social problems around the world. Global warming caused by greenhouse gases from fossil fuels has led to large-scale disasters such as floods, heat waves, and droughts, which have caused great damage to life and property. In the United States, interest in climate change has increased significantly due to droughts and large-scale wildfires in the West, storms and floods in the Southeast, and record-breaking heat waves across the country. In Korea, climate change is becoming increasingly serious, as seen in the record-breaking heat waves and tropical nights in 2024, and many citizens are feeling the effects of climate change as flood damage from localized heavy rains and crop damage from high temperatures increase.

As these signals show, it is time for us to take decisive action on climate change. To address climate issues proactively, 195 countries adopted the Paris Agreement (2015) on December 12, at the 21st Conference of the Parties to the UN Framework Convention on Climate Change in Paris, France. The agreement seeks to limit global temperature rise to 2℃ above pre-industrial levels and pursues efforts to limit temperature rise to 1.5℃ above pre-industrial levels, and to move the financial economy toward low-emission and climate-resilient development. Korea entered into force the Paris Agreement on December 3, 2016.

In order to achieve the goals of the Paris Agreement, there is a system that urges each member country to increase greenhouse gas emissions net-zero goals and policy instruments every five years. The UNFCCC requires each country to submit its national climate measures, NDCs (Nationally Determined Contributions), by 2023, and to establish the country's net-zero vision and the Long-Term Strategy (LTS). Now, in the face of the climate change crisis that is being felt by the skin, countries around the world are setting GHG emissions reduction targets according to global reduction goals, while proposing and implementing various GHG emissions reduction measures. According to UNEP (2023), the total number of NDCs reached 149 (counting the EU and 27 Member States as a single party) as of 25 September 2023.

Carbon neutrality can be said to be a global trend and obligation that will bring innovative changes to the world and mankind, such as the industrial revolution, information, or digital revolution. Depending on how we cope with such upheaval, it can be said that the fate of a country, society, and its members is likely to be determined accordingly, and global companies are likely to survive. Therefore, we need to analyze the coping cases of advanced countries to come up with elaborate strategies and boldly implement them.

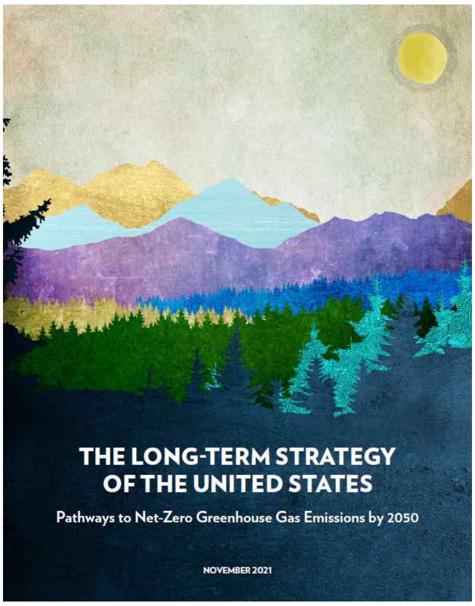

Figure 1. THE LONG-TERM STRATEGY OF THE UNITED STATES (2021)
(source: https://www.whitehouse.gov)

The United States also rejoined the Paris Agreement in 2021, setting a goal of reducing net greenhouse gas emissions by 50-52% by 2030 and achieving net zero emissions by 2050. The United States accordingly established a long-term strategy, 'The Long-Term Strategy of The United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050 (White House, 2021)' in November 2021. In this document, the Biden administration emphasizes that reaching net-zero by 2050 requires action across all sectors of the economy and building a sustainable and resilient economy. The report also argues that this is not only for future generations, but also for the current generation, investing in emerging clean industries will strengthen competitiveness and promote sustainable economic growth. It argues that there are many challenges to achieving carbon neutrality that will require all our ingenuity and dedication, but it must be achieved.

Establishing the concept of carbon neutrality

Before I get into the main topic, I would like to clearly define the concept of carbon neutrality. We often use the terms carbon neutrality and net zero greenhouse gas emissions interchangeably. In the United States, the term 'net-zero' is more commonly used in official government reports, papers, and the media, while in Korea, the term 'carbon neutrality' is often used. Strictly speaking, 'greenhouse gases (GHG)' are a concept that includes 'carbon', and 'carbon' is a concept that includes 'CO2', one of the representative greenhouse gases produced by burning fossil fuels. In addition to carbon dioxide (CO2) and methane (CH4), which contain 'carbon (C)', greenhouse gases include nitrous oxide (N2O), and fluorinated gases (F-gases). According to the U.S. Environmental Protection Agency (EAP, 2023), methane is a powerful greenhouse gas with a global warming potential 25 times greater than carbon dioxide, accounting for about one-third of the current warming caused by human activities. Therefore, in order to respond to the climate crisis, efforts are needed to reduce all GHG emissions in addition to CO_2.

The Paris Agreement (2015) uses the term 'low greenhouse gas emissions' rather than the terms 'carbon neutrality' and 'decarbonization'. The Long-Term Strategy of the United States (2021) uses the terms ‘net-zero GHG emissions’ or ‘net-zero’, ‘zero emissions’ interchangeably, all of which indicate that net greenhouse gas emissions are zero. In addition, this report also uses the term ‘decarbonization’ for the transition to clean energy, and in some parts (p. 54), the term ‘carbon neutrality’ is also used.

In Korea, an organization called ‘the Presidential Commission on Carbon Neutrality and Green Growth (PCGG)’ has been established and is promoting carbon neutrality by 2050. According to this commission (n.d.), carbon neutrality is defined as the concept of reducing net carbon emissions to “zero” so that the total amount of greenhouse gases in the air no longer increases. Reducing the net amount of carbon emissions to "zero" by reducing greenhouse gas (GHG) emissions from human activities (positive factor) and removing GHG emissions through forest sequestration or CCUS (negative factor) is referred to as carbon neutrality (net zero). In addition, the 'Basic Act on Carbon Neutrality and Green Growth for Climate Crisis Response' defines related terms as follows. ‘Carbon neutrality’ refers to a state in which net emissions, which are the amount of greenhouse gases emitted, released, or leaked into the atmosphere, offset by the amount of greenhouse gas absorption, become zero. "Greenhouse gases" refer to gaseous substances in the atmosphere that cause the greenhouse effect by absorbing or re-emitting infrared radiation, such as carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF6), and other substances prescribed by Presidential Decree.

In conclusion, in this paper, I will use carbon dioxide or CO_2 emissions and GHG emissions separately, but as in Korea, I will use 'carbon neutrality' as synonymous with net-zero GHG emissions. In addition, expressions in cited papers or reports will be used as they are, to the extent that there is no misunderstanding.

Why is the role of cities important in carbon neutrality?

According to the International Energy Agency (IEA, 2024a), 39.2% of global CO_2 emissions by sector in 2021 are generated from electricity and heat production, 25.4% from industry, 20.9% from transportation, and 8.3% from buildings. Cities are collective spaces where people live and are the foundations of industry. In Korea, the urbanization rate is as high as 81% in 2021, so it is no exaggeration to say that most energy consumption and greenhouse gas emissions occur in cities. Therefore, it is very important to lead existing city regulation and industrial activation policies and new city or town design policies in a direction that is in line with carbon neutrality.

In addition, while the transition of energy sources through technological development by companies is important in the electricity and heat production and industry sectors, transportation and buildings are sectors closely related to the lives of the people, and thus require multifaceted analysis and detailed policies to change the lives of the people. Therefore, in the land, infrastructure, and transportation sector, analysis and research are needed to promote carbon neutrality at the city level as well as in transportation and buildings.

Research methods and main contents of the this paper

While attending the George Washington University Master's Program in Applied Economics, I took classes in Applied Microeconomics, Probability and Statistics for Economics, Applied Econometrics, and Economics of Supply Chains, and analyzed various policies of the U.S. government to achieve carbon neutrality. In particular, I conducted time series analysis using state-by-state data on various factors affecting CO2 emissions to understand carbon emissions by city characteristics. I also statistically analyzed the incentive effect of the charging station expansion policy among the EV activation policies actively promoted by the Biden administration. In this report, I will include these econometric analysis methodologies, analysis processes, results, and interpretation methods in as much detail as possible so that they can be referred to in future quantitative analysis. In addition, I was able to gain a broad perspective on the research topic through Q&A with various transportation and logistics experts participating in the Economics of Supply Chains and learning through various media.

List of key experts who have spoken in Economics of Supply Chains

Loren Smith, Skyline Policy(transportation policy consulting firm), formerly Deputy Assistant Secretary for Policy at the U.S. Department of Transportation (DOT)

Ben Kochman, Director of Safety from Interstate Natural Gas Association of America (INGAA), formerly Senior Congressional Affairs Officer at the DOT

Omar Vargas, the Vice President and head of Global Public Policy at General Motors (GM)

Ken Leonard, formerly Director of Intelligent Transportation Systems Joint Program Office (ITS JPO) at the DOT

Alexandra Rosen, the Vice President of Advocacy for the American Trucking Associations

Roger Nober, GW Professor of Practice at the Trachtenberg School, formerly Executive Vice President and Chief Legal Officer at BNSF Railway

Bobby Fraser, Director, International Regulatory and Policy of United Airlines

In order to study the training assignment, I conducted research using a combination of research methods that analyzed previous literature and statistical analysis that directly applied econometric research methods. In particular, I reviewed various literature during the research process. I used the school library homepage to search for and reference various papers on statistical analysis methods and analysis of the effectiveness of the US government's policies. Among them, I mainly used papers focusing on cases in the US and major countries, and after 2010 as reference materials.

For data, I mainly referenced official data from international organizations such as the UN, IEA, and OECD, the US federal government such as the Department of the Treasury (USDT), the Department of Transportation (DOT), the Department of Energy (DOE), the US Census Bureau, the Environmental Protection Agency (USEPA), and the Department of Housing and Urban Development (HUD), and the White House. When necessary, I collected data from official websites of state and local governments and US media outlets such as the New York Times and the Washington Post.

In order to find out the direction in which transportation, buildings sectors, and urban policies encompassing them should take to achieve carbon neutrality, I will first investigate the current status of carbon emissions and policy directions in Korea and the United States, and analyze the carbon neutrality policies in the transportation, building, and urban sectors, focusing on the US case. In the transportation sector, I will mainly examine policies to promote the sale of eco-friendly vehicles such as electric and hydrogen cars and find out which policies are the most effective. In the building sector, I will look into ways to encourage efficient use of energy such as zero-energy buildings, as well as ways to change the construction industry to minimize carbon emissions generated during the building construction process. Lastly, I will look into new city concepts such as hydrogen cities that can become the foundation for carbon neutrality in the transportation and building sectors, and I will examine the importance of creating absorption centers in urban areas and excellent overseas cases such as zero-energy towns.

II. GHG Emission Status and Policy Directions

1. Global GHG emissions status

Overall Emissions Trends

According to the UNEP (United Nation Environment Programme) report (2023), global GHG emissions have fluctuated since the 1990s, but they have generally continued to increase except for the recent decline in emissions caused by the COVID-19 pandemic in 2020 (Figure 2). Between 2021 and 2022, GHG emissions increased by 1.2%, setting a new record worth 57.4 gigatonnes of CO2 (GtCO2e), exceeding pre-pandemic 2019 levels. CO2 emissions from fossil fuel burning and other sources accounted for about two-thirds of current GHG emissions, contributing the most to the overall increase. Methane (CH4), nitrous oxide (N2O), and fluorinated gas (F-gas), which currently account for about a quarter of GHG emissions, are also increasing rapidly.

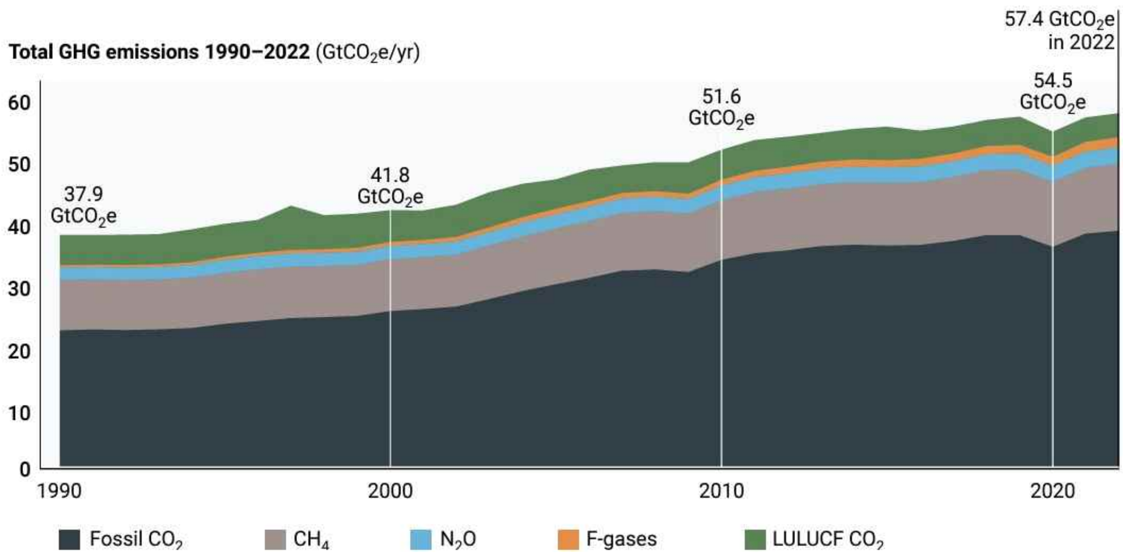

Figure 2. Global total GHG emissions 1990-2022

(source: Emissions Gap Report 2023, UNEP)

Current Status by Country

The UNEP report (2023) finds that most GHG emissions come from a small number of countries. The top five emitters (China, the United States, India, the European Union, and the Russian Federation) accounted for about 60% of greenhouse gas emissions in 2021. Twenty countries (Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, South Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, the United Kingdom, the United States, and the European Union) account for about 76% of global greenhouse gas emissions. The least developed countries, on the other hand, account for about 3.8% of global emissions.

GHG emissions across the G20 also increased by 1.2 percent in 2022. However, while they increased in China, India, Indonesia, and the United States, they showed conflicting patterns among countries, with declines in Brazil, the European Union, and the Russian Federation. GHG emissions per capita also vary considerably from country to country. The global average is 6.5 tons of CO2 equivalent (tCO2e), and the G20 averages 7.9tCO2e as a group. In the U.S. and Russian Federation, emissions are more than double the global average, while India is still below half. Brazil, the European Union, and Indonesia's per capita emissions are similar, slightly below the G20 average.

Emissions by Sectors

GHG emissions can be divided into five major economic sectors: energy supply, industry, agriculture, and LULUCF, transportation, and buildings (UNEP, 2023). LULUCF refers to land use, land use change, and forestry. It represents the impact of human activities on the exchange of CO_2 between the atmosphere and the terrestrial biosphere.

In 2022, energy supply is the largest source of global GHG emissions at 20.9 GtCO2e (36% of the total). This is mainly due to combustion emissions in the power sector (14.8 GtCO2e) and fossil fuel production emissions (6.1 GtCO2e). The energy supply sector has been a symbol of industrialization, contributing the largest contribution to the growth of emissions over the past decades. Currently, it is the sector with the fastest pace of progress in reducing emissions by converting to low-emission fuels and expanding renewable energy sources. Industry is the second largest sector based on direct emissions (14.4 GtCO2e, 25% of the total), followed by agriculture and LULUCF CO2 (10.3 GtCO2e, 18%), transport (8.1 GtCO2e, 14%), and buildings (3.8 GtCO2e, 6.7%). However, reallocating power sector emissions to the final sector based on electricity and heat use (i.e., indirect emissions emphasizing demand perspective) will increase the industrial sector to 34% and the building sector to 16% (Lamb et al. 2021).

CO2 emissions trend

According to IEA (2024a), global energy-related CO_2 emissions grew by 1.1% in 2023, increasing 410 million tonnes (Mt) to reach a new record high of 37.4 billion tonnes (Gt). There was also an increase of 490 million tonnes (1.3%) in 2022, with global CO2 emissions continuing to trend higher except for a significant drop in 2020. In particular, coal emissions account for more than 65% of the increase in 2023, and the side effects of global warming are in the form of a vicious cycle that leads to increased carbon emissions again, with emissions increasing by about 170 million tons due to the decrease in hydroelectric power caused by drought.

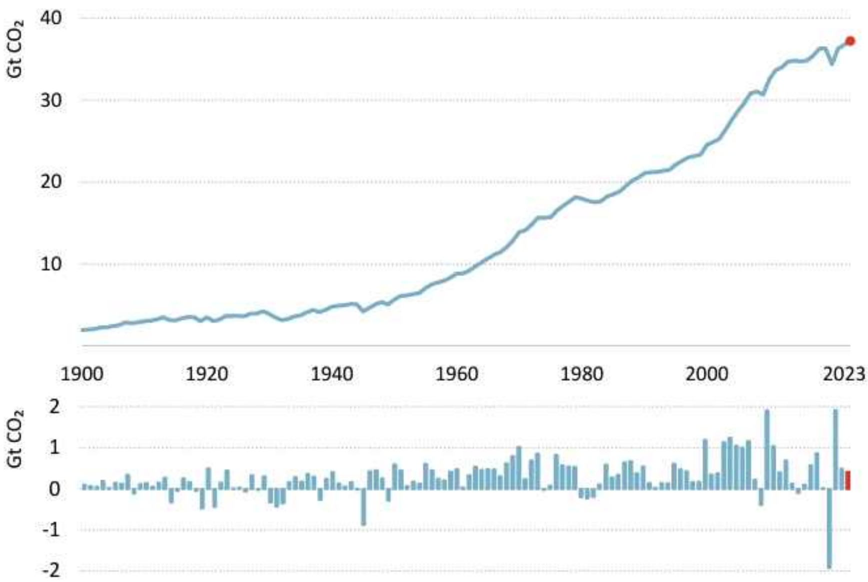

Figure 3. Global energy-related CO_2 emissions and their annual change
(source: https://www.iea.org/reports/co2-emissions-in-2023)

Between 2019 and 2023, total energy-related emissions increased by about 900 million tons. In response, the IEA (2024a) analyzes, "The increase in emissions would have been three times greater without the expansion of five key clean energy technologies: solar PV, wind power, nuclear power, heat pump, and electric vehicle since 2019." Analysts say that emissions are structurally slowing down due to the expansion of clean energy deployment.

Developed economies, represented by the G7, GDP grew by 1.7%, but emissions fell by 4.5%, and coal demand in advanced economies returned to levels around 1900. As for the reduction in advanced economic emissions in 2023, the IEA (2024a) analyzed that it was caused by a combination of structural and cyclical factors, including strong renewable energy deployments, the transition from coal to gas in the United States, weak industrial production in some countries, and mild weather.

On the other hand, China's emissions saw the world's biggest increase of around 565 Mt. in 2023, while India's emissions rose by about 190 Mt. In 2023, climate change has led to a rise in electricity demand and a decrease in hydroelectricity. China continues to add global clean energy, but greenhouse gases have increased significantly due to the use of fossil fuels such as coal. India's per capita emissions are still much lower than the global average.

2. Emissions Status and Policy Direction in the United States

According to the Emissions Database for Global Atmospheric Research (EDGAR, 2023), the U.S. GHG emissions were 6.0 $GtCO_2eq$ as of 2022, down about 15 percent from 7.1 GtCO2eq in 2005. This is about 11.2% of the world's total GHG emissions and the second-largest in the world. The country with the largest emissions is China (15.7 $GtCO_2eq$), accounting for 29.2% of the world's emissions. However, in terms of per capita emissions, China's emissions are 10.95 tCO_2eq, and the world average per capita emissions are 6.76 tCO_2eq, while the United States' emissions per capita are very high at 17.90 tCO_2eq. Among countries with total GHG emissions exceeding 1 $GtCO_2eq$, it ranks second only to Russia (17.99 tCO_2eq) in per capita emissions. Therefore, the United States needs to actively pursue a carbon neutral policy with a strong sense of responsibility for reducing greenhouse gas emissions.

The historical process of establishing the net-zero long-term strategy

The United States joined the Paris Agreement in 2016 during the presidency of Barack Obama, and in accordance with the Paris Agreement, the United States submitted its first LTS (long-term strategy) report to the UNFCCC in 2016, stating that it would reduce greenhouse gas emissions by 80-90% by 2050 compared to 2005 levels. However, President Trump withdrew from the Paris Agreement on November 4, 2019, citing excessive regulation of industry. President Biden announced that he would reverse President Trump's withdrawal from the Paris Agreement as part of his campaign promise, and in January 2021, upon taking office, he issued Executive Order No. 1 to return to the Paris Agreement.

In November 2021, President Biden announced 'The long-term strategy of the U.S. - pathway to net-zero greenhouse gas emissions by 2050', which was further strengthened from the first LTS in 2016. The GHG emissions reduction goals set here are broadly represented by two: a 50-52% reduction from 2005 levels by 2030 and net-zero by 2050.

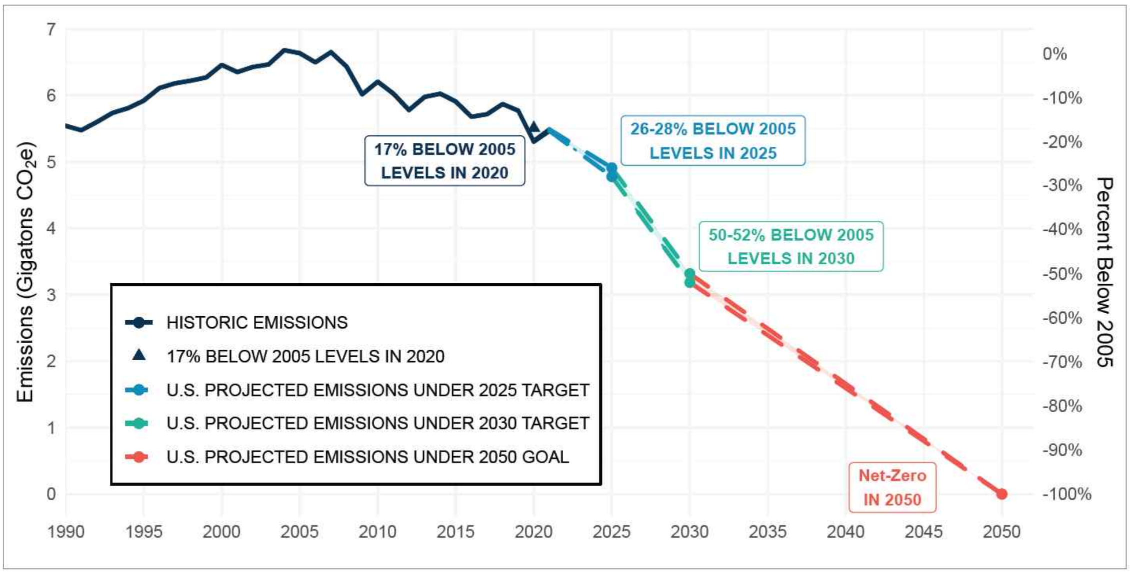

Figure 4. United States historic emissions and 2050 goal for net-zero
(sources: https://www.whitehouse.gov)

Figure 4 shows the historical trajectory of net GHG emissions in the United States from 1990 to 2020, the projected path to the 2030 NDC, which is 50-52% lower than 2005 levels, and the net-zero goal by 2050. The goal of reducing net GHG emissions by 50-52% by 2030 from 2005 levels can be seen as very challenging. It can be interpreted as a will to make this a crucial decade for implementing a series of new policies to accelerate the existing emission reduction trend. The US government has presented rapid expansion of new technologies such as electric vehicles and heat pumps and building infrastructure for core systems such as the national power grid as key means to this end.

Five key transformations to Net-Zero emissions

The U.S. government (2021) outlines five key transformations on the path to achieving net-zero emissions by 2050. First, decarbonize electricity. The U.S. government has set a goal of 100 percent clean electricity by 2035, and the plummeting cost of solar and wind technology, as well as federal and state policies, are accelerating this. Second, electrify end-uses and transition to other clean fuels. Electrify the majority of the economy, from vehicles to buildings and industrial processes, inexpensively and efficiently, and prioritize clean fuels such as carbon-free hydrogen and sustainable bio-fuels in aviation, transportation, and some industrial processes. Third, a strategy to reduce energy waste. This can be achieved through a variety of approaches, including more efficient appliances, energy efficiency improvements in new and existing buildings, and sustainable manufacturing processes. Fourth, reduce methane and other non-CO_2 emissions. Non-CO_2 gases such as methane, hydrofluorocarbons (HFCs), and nitrous oxide (N_2O) are significant contributors to warming, as explained above. Several options have been proposed, including detecting and repairing methane leaks in oil and gas systems, and switching to climate-friendly operating fluids in cooling equipment. Fifth, expanding CO_2 removal. While advanced strategies could bring emissions from energy production close to zero by 2050, non-CO_2 from agriculture is unlikely to be fully decarbonized, so carbon dioxide needs to be removed from the atmosphere. This requires land carbon sinks and engineering strategies.

Emissions status of buildings and transportation sectors in the U.S.

In the United States, transportation sector currently accounts for 29% of total GHG emissions (USEPA, 2021). This makes it the largest source of GHG emissions among sectors such as industry, power generation, transport, and buildings. This is a very high share compared to the global situation where transport only accounted for 14%. This can be attributed to the large land area of the United States, but there is another main reason. While electricity generation is decarbonizing at a relatively fast rate due to the discovery of green energy sources, decarbonization of vehicles and transportation systems is occurring at a slower rate.

Meanwhile, residential and commercial buildings account for more than a third of GHG emissions from the U.S. energy system. About two-thirds of this currently comes from electricity, and the remaining about a third comes from direct combustion of gas, oil, and other fuels for heating, hot water, cooking, and other services. Even when calculated as direct emissions excluding electricity use, commercial buildings account for 6.93% of total GHG emissions, while residential buildings account for 5.77%, for a combined 12.7% (USEPA, 2021). Therefore, the importance of buildings and transportation for carbon neutrality in the United States is very high, and the Biden administration is actively implementing related policies such as expanding electric charging stations to encourage the adoption of electric vehicles.

3. Emissions Status and Policy Direction in Korea

According to EDGAR (2023), Korea's GHG emissions increased by about 25% from 582.5 $MtCO_2eq$ in 2005 to 725.7 $MtCO_2eq$ in 2022. And this is about 1.35% of the world's total GHG emissions and ranks 13th in the world. This is a very high ranking compared to the population, and in terms of per capita emissions, Korea's per capita emissions are very high at 14.01 tCO2eq, compared to the world average of 6.76 tCO2eq. Although per capita emissions are low compared to developed countries with very large territories such as the United States (17.90), Russia (17.99), and Canada (19.79), they are higher than China (10.95), India (2.79), and Japan (9.41). Korea's emissions are expected to be 761.4 $MtCO_2eq$ in 2050 if there is no greenhouse gas reduction strategy in consideration of population, GDP, and industrial structure (PCGG, 2023). Therefore, considering the trend of increasing emissions and per capita emissions, Korea has a very high level of difficulty in net-zero emissions, so it is necessary to preemptively and actively promote a carbon neutral policy.

The Korean Government's Carbon Neutrality Strategy

In December 2020, the Korean government declared its 2050 carbon neutral vision domestically and internationally, and enacted the 'Basic Act on Carbon Neutrality and Green Growth for Climate Crisis Response' in September 2021. In addition, in October 2021, the 2030 NDC (Nationally Determined Contribution) was set to reduce GHG emissions by more than 40% compared to 2018 levels by 2030. The 2030 NDC announced that it has set the goal as an intermediate goal to realize carbon neutrality by 2050, comprehensively considering the purpose of the "Framework Act on Carbon Neutrality and Green Growth (FACNGG)" and international trends.

It will reduce GHG emissions by 40% (291 $MtCO_2eq$) from the 2018 level (727.6 $MtCO_2eq$) to 436.6 $MtCO_2eq$ by 2030. Since Korea's GHG emissions peaked in 2018, the goal of reducing GHG emissions was set using the year as the base year.

The 'carbon neutral green growth national strategy' to achieve the above NDCs and Net-zero goals was finally confirmed by deliberation and resolution of the State Council in April 2023. With the vision of 'carbon neutrality, leap to a global central country', four major strategies and 12 tasks were set.

Four major strategies of the LTS of Korea (PCGG, 2023)

(1) Responsible carbon neutrality that reduces greenhouse gases in a specific and efficient manner
(2) Innovative carbon neutrality and green growth led by the private sector
(3) Carbon neutrality achieved through the empathy and cooperation of all members of society
(4) Active carbon neutrality that adapts to the climate crisis and leads the international community

In addition, the 2023 emissions reduction target is in compliance with the emissions reduction target of the NDCs of October 2020 promised to the international community, but some adjustments were made between and within sectors in consideration of the feasibility of implementation by reduction means. The industrial sector will be relaxed by 3.1%p in consideration of difficulties in securing raw materials and technological prospects, and the insufficient reduction amount will be achieved by expanding the supply of clean energy such as solar and hydrogen in the transition sector and expanding international reductions.

Key policies of building, transportation and urban sectors in Korea

* Summary based on PCGG website data (n.d.)

In Korea, the transportation sector accounted for approximately 14% of GHG emissions in 2018, emitting 98.1 MtCO2eq, which is low compared to the United States' approximately 29%. In this regard, the goal of the NDCs is to significantly reduce emissions from the transportation sector to 61 MtCO2eq, which is about 37.8% lower than 2018 (Figure 5). In addition, the ultimate goal by 2050 is to achieve carbon neutrality in all modes of transportation, including land, sea, and air. To this end, the plan is to convert all vehicles to zero-emission by promoting policies such as expanding the supply of electric and hydrogen vehicles, expanding charging infrastructure, developing lightweight materials and low-carbon fuel technology, and expanding support for early scrapping of old diesel vehicles. In the intermediate stage, the strategy is to strengthen greenhouse gas and fuel efficiency standards for internal combustion engine vehicles based on life cycle assessment, and to strengthen demand management for internal combustion engine vehicles by activating public transportation and bicycles. In addition, Korea plan to promote decarbonization of all transportation by expanding the use of eco-friendly fuels in fields such as railways and aviation and improving low-carbon ship technology.

In Korea, the buildings sector accounted for about 7.6% of GHG emissions in 2018, emitting 52.1 MtCO2eq, which is low compared to the United States' 12.7%. In this regard, the NDCs target is to reduce emissions from the building sector by 35 MtCO2eq, which is about 32.8% compared to 2018 (Figure 5). Since buildings are also a very large consumer of electricity, they can be a key driver of energy savings. In order to achieve carbon neutrality by 2050, the Korean government aims to improve energy efficiency by improving building performance and strengthening requirements. The strategy is to induce a significant reduction in emissions by increasing zero-energy buildings and expanding green remodeling, and to improve energy efficiency by expanding building performance and efficiency assessment management. The plan is to lead carbon neutrality by strengthening energy efficiency and reducing emissions starting with public sector buildings.

ITEM	Sector	2018 emissions	2030 emissions	
			Previous (Oct 2021)	Adjusted (Apr 2023)
Total emissions		727.6	436.6 (40.0%)	436.6 (40.0%)
Emissions	Transition	269.6	149.9 (44.4%)	145.9 (45.9%)
	Industry	260.5	222.6 (14.5%)	230.7 (11.4%)
	Buildings	52.1	35.0 (32.8%)	35.0 (32.8%)
	Transportation	98.1	61.0 (37.8%)	61.0 (37.8%)
	Agriculture, livestock, and fisheries	24.7	18.0 (27.1%)	18.0 (27.1%)
	Waste	17.1	9.1 (46.8%)	9.1 (46.8%)
	Hydrogen	(-)	7.6	8.4
	Fugitive emissions, etc.	5.6	3.9	3.9
Absorption / removal	Carbon sinks	(-41.3)	-26.7	-26.7
	CCUS	(-)	-10.3	-11.2
	International reduction	(-)	-33.5	-37.5

Figure 5. Reduction targets by sector of Korea (unit: $MtCO_2eq$)
(source: PCGG, https://www.2050cnc.go.kr/eng/contents/view?contentsNo=67&menuLevel=2&menuNo=119)

In addition, from an urban perspective, it is important to lay the foundation for decarbonization that encompasses all national spaces, including industry, transportation, and buildings. In order to achieve carbon neutrality across the entire country, Korean government will manage compliance with carbon neutrality values through spatial reorganization, green transportation, green buildings, expansion of carbon sinks, and expansion of renewable energy in national and urban planning, and further strengthen climate change impact assessments in new city development projects. To this end, Korean government plans to strengthen communication between the government and industry, and between the central and local governments, and expands the work performed under the governance system.

4. Statistical Analysis of Factors Affecting Carbon Emissions

It is very meaningful to learn about the various economic factors that affect carbon emissions by region and understand their trends and relationships. I will analyze the correlation between carbon emissions and macroeconomic indicators in the United States using the time series analysis technique I learned in the economic time series analysis class at the George Washington University. As mentioned earlier, I will try to include detailed econometric analysis and interpretation methods so that future readers of this article can refer to econometric analysis methods.

Literature Review

There have been numerous research analyses on the relationship between carbon emissions and macroeconomic indicators including gas prices, personal consumption expenditure, and the Consumer Price Index (CPI). Notably, Nabi et al. (2020) showed that CPI has a positive relationship with carbon emissions through panel data analysis of 98 countries. And Liu et al. (2021) demonstrated that household consumption contributes to more carbon emissions through a case analysis of China. Furthermore, as Mensah et al. (2019)'s study show, the negative relationship between oil prices and carbon emissions can be intuitively predicted. In addition, it is possible to predict relationships such as the positive correlation between gas prices and the inflation rate and the negative correlation between the inflation rate and personal consumption expenditure, and through this analysis.

Sources of Data

Through this paper, I will analyze the four types of time series data.

The first data is the Consumer Price Index (CPI), for All Urban Consumers in the United States (US), which is an index based on 1982-1984=100, monthly, and seasonally adjusted data. The second is Personal Consumption Expenditures (PCE) in US, the unit is Billions of Dollars, it is monthly data, and the data is seasonally adjusted. The third is US Regular All Formulations Gas Price and the unit is Dollars per Gallon. It is monthly data and has not been seasonally adjusted. Seasonality will be identified during the analysis process. All three data above used official data downloaded from FRED (Federal Reserve Economic Data). The last data is Carbon Dioxide Emissions from Energy Consumption in US, sourced from the U.S. Energy Information Administration. This is the total CO2 Emissions emitted from all energy sources such as coal, natural gas, and gasoline. This is monthly data and is not seasonally adjusted. The period of all time-series is monthly data from January 2011 to December 2022, and the total number of observations is 144 each.

Table 1. Summary of the data

	CPI	Gas Prices	PCE	CO2 Emissions
Num.Obs	144	144	144	144
Min.	221.2	1.764	10514	305.2
Median	243.1	2.853	12949	425.7
Mean	248.0	2.954	13286	429.7
Max.	299.0	4.929	17944	532.9

Data Stationary Check

The basic statistical summary and plots are below. Looking at Figure 6, CPI and PCE are trending upward, while gas prices and CO_2 emissions are trending slightly downward. In 2020, all series suffered a sharp decline in common due to COVID-19. Since stationary data satisfies many assumptions of time series forecasting, I checked whether each data is stationary.

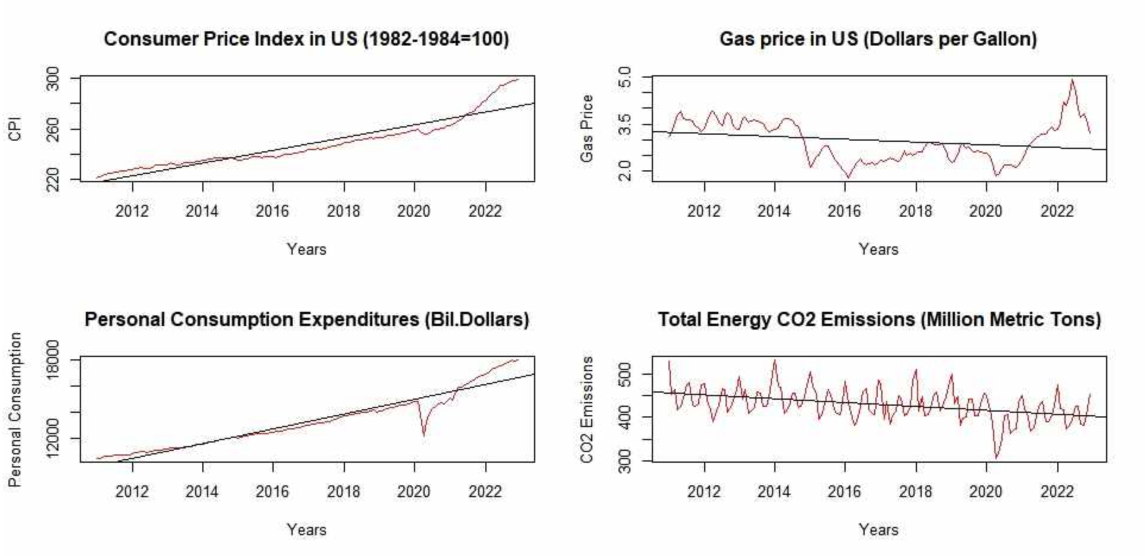

Figure 6. Time Series plots of the data

I analyzed that all time series data are not stationary at the original level and the integration order is I(1). This means that the first difference looks stationary. There is evidence for this conclusion. Each time series does not have a constant mean or variance at the original level, and shocks persist when looking at the ACF. According to the analysis results according to the rule of thumb, taking the first difference for all time series except CO_2 reduces the standard deviation by less than half. And the ADF test results for each time series show that the null hypothesis of nonstationary cannot be rejected at the original level, but the null hypothesis can be rejected as a result of the first difference (except for the 1% level of CO_2). For CO_2, we can conclude that the integration order is I(1) through visual inspection and the internal analysis results of the first difference excluding the seasonal factor.

Variable and Assumption Check

In time series analysis, endogenous variables are variables explained by internal factors and are determined or predicted by data from previous points in time or other endogenous variables. On the other hand, exogenous variables are mainly assumed to change independently and are used as factors that affect prediction. We focused on the correlation between CO_2 emissions and macroeconomic variables such as CPI index, gas price (GAS), and personal consumption expenditure (PCE), and looked for endogenous variables based on CO_2. Basically, according to empirical correlations confirmed in many papers, CPI, GAS, and PCE are all considered endogenous variables in vector autoregressive (VAR) models.

The reason why multicollinearity should not exist in time series analysis is because it greatly affects the accuracy and interpretability of the model. Multicollinearity refers to cases where there is a high correlation between independent variables. This can cause problems such as reduced model interpretability and instability of coefficient estimates in regression analysis or time series modeling. To check for multicollinearity, we checked the VIF and found that the values of CPI and PCE exceeded 30, indicating high multicollinearity. Multicollinearity can have a negative impact on model estimation and lead to coefficient instability, so we set PCE, which is intuitively directly related to CO_2 emissions, as an endogenous variable and CPI as an exogenous variable. There appears to be no multicollinearity between GAS and PCE. See Figure 7.

```
> model_1 <- lm(CO2_train ~ GAS_train + PCE_train + CPI_train, data = data_mat)
> vif_values_1 <- vif(model_1)
> print(vif_values_1)
GAS_train PCE_train CPI_train
 1.310591 33.483985 31.872680
> model_2 <- lm(CO2_train ~ GAS_train + PCE_train, data = data_mat)
> vif_values_2 <- vif(model_2)
> print(vif_values_2)
GAS_train PCE_train
 1.209742  1.209742
```

Figure 7. the results of VIF checking

Criteria for Selecting a Time Series Analysis Model

The VAR model and the VECM model, which are multivariate time series models, are frequently used when analyzing and predicting time series data. These two models have the advantage of simultaneously analyzing multiple time series variables by considering the interaction between variables, but they differ in the situations and characteristics they are applied to, and I will compare them using both models.

The VAR model (Vector Autoregression Model) is a method for modeling the interaction between multiple time series variables that affect each other. Here, VAR(*) means the case where the lag is *. In other words, it indicates that the values of each variable from two points in time ago affect the current point in time, and the VAR(2) model makes predictions using only information from two points in the past (e.g. t-1, t-2) of each variable. In the VAR model, all variables are treated as endogenous variables and are suitable for non-seasonal data.

The VECM (Vector Error Correction Model) is an error correction model used when dealing with non-stationary time series data, and is an extended form of the VAR model that reflects the cointegration relationship. VECM expresses the long-term equilibrium state between variables with co-integration relationships, and for this purpose, it is necessary to check the co-integration relationship between variables.

Co-integration is a statistical property that describes the long-term equilibrium relationship between two or more non-stationary time series variables. Two series are co-integrated when their orders of integration are the same, their orders are greater than zero, and their linear combination produces a series with a lower order of integration.

Figure 8 shows the Johansen test results to diagnose co-integration. At r=0 and r≤1, the null hypothesis is rejected, at r≤3 it is not rejected at the critical level, and at r≤2 the critical value is rejected only in some confidence intervals. Therefore, according to Johansen test results, there is at least one co-integration, and there is a high possibility of two co-integration.

```
######################
# Johansen-Procedure #
######################

Test type: maximal eigenvalue statistic (lambda max) , with linear trend

Eigenvalues (lambda):
[1] 0.47047394 0.26552932 0.12140655 0.02129833

Values of teststatistic and critical values of test:

          test 10pct  5pct  1pct
r <= 3 |  3.06  6.50  8.18 11.65
r <= 2 | 18.38 12.91 14.90 19.19
r <= 1 | 43.82 18.90 21.07 25.75
r = 0  | 90.28 24.78 27.14 32.14

Eigenvectors, normalised to first column:
(These are the cointegration relations)

             CPI.l2       GAS.l2       PCE.l2      CO2.l2
CPI.l2  1.000000000   1.00000000  1.000000000  1.00000000
GAS.l2 -7.116552472 -11.08334950 -2.022793205 22.76784170
PCE.l2 -0.009183985  -0.01469183 -0.008506612 -0.01527246
CO2.l2  0.185817075  -0.12054147  0.011433757  0.08111683

Weights W:
(This is the loading matrix)

             CPI.l2       GAS.l2        PCE.l2        CO2.l2
CPI.d -0.0001763767 -0.005470947  0.0238167261 -0.0036464125
GAS.d  0.0087777593  0.002540034 -0.0000269544 -0.0009586387
PCE.d -0.1882170611  5.555664700 22.6963783718 -0.3256300484
CO2.d -3.0457970903  1.300662656 -0.4401034487 -0.0073994273
```

Figure 8. The result of Johansen test

Carbon Emission Forecast Results through Time Series Analysis

As previously set, in addition to the VAR(2) model with gasoline prices (GAS) and PCE as endogenous variables and CPI as exogenous variables for CO_2 forecasting, two more models were set up. Based on the Johansen test results, a VECM with lag=2 that assumes two co-integrations was set up. In addition, a VAR_exo(2) model with GAS and CPI as exogenous variables was set up to focus on analyzing the relationship between consumer spending and the CO_2 model. Ten forecast periods were analyzed for each model. Figure 9 compares the forecast trends of the three models from March to December 2022. In the case of CO_2, VECM seems to be dominant, and both VECM and VAR predicted a slight increase. When emphasizing only consumer spending (PCE) in the case of VAR_exo(2), the increase effect is low.

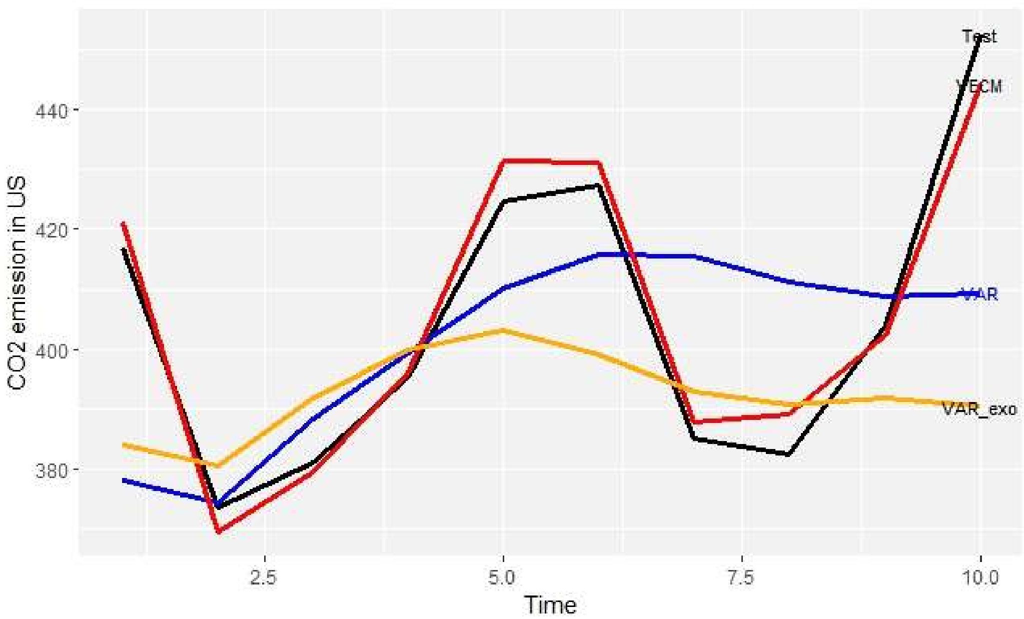

Figure 9. Comparison of forecasts for CO2 (VAR(2) vs VECM(2) vs VAR_exo(2))

Forecast Error Variance Decomposition (FEVD) shows how much of the forecast error in carbon emissions forecasting using a time series model is explained by its own and other variables' variance. For the interpretation of the results, it expresses the percentage of how much of the forecast error variance is due to a specific variable. For example, it can be interpreted that 60% of the forecast error of variable A is explained by its own variable A, 30% by variable B, and 10% by variable C.

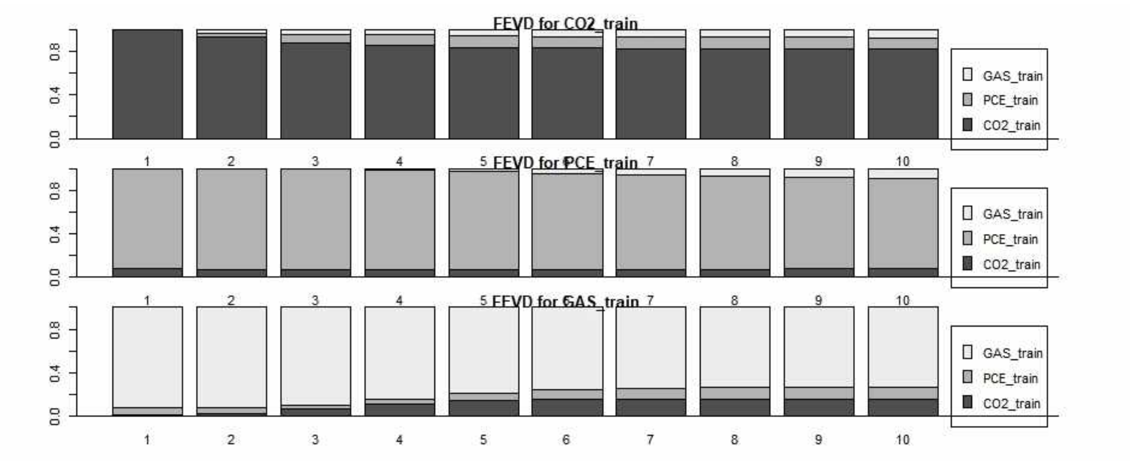

Figure 10. plot of the forecast error variance decomposition

Figure 10 shows the forecast error variance decomposition (FEVD) for each variable in the VAR(2) model. Looking at the results, the impact of each variable itself accounts for the largest proportion. However, as time passes, the influence of other variables is increasing. According to these results, there are no cases in which they do not influence each other at all, so it is judged that there are no variables that can be converted to exogenous variables.

```
> forcast_error$CO2_train
      CO2_train  PCE_train  GAS_train
 [1,] 1.0000000 0.00000000 0.00000000
 [2,] 0.9309329 0.03546838 0.03359873
 [3,] 0.8759196 0.07945409 0.04462635
 [4,] 0.8548058 0.10153805 0.04365619
 [5,] 0.8410381 0.10427025 0.05469164
 [6,] 0.8310226 0.10304010 0.06593734
 [7,] 0.8262302 0.10423803 0.06953176
 [8,] 0.8237654 0.10653462 0.06969998
 [9,] 0.8223951 0.10795040 0.06965454
[10,] 0.8216375 0.10837637 0.06998615
```

Table 2. The FEVD for CO2

Looking at the FEVD results table for CO_2 emissions (Table 2) among the three variables, we can see that most of the changes in CO2 emissions are caused by impacts from CO2 emissions themselves. However, over time, the variation in CO2 emissions due to personal consumption expenditures (PCE) and GAS prices shocks increases, reaching 17.72% in 10 periods. In particular, personal consumption expenditure has a steady influence of about 10% after the fourth period. Note that a shock to a variable could be said to be exogenous if it did not explain any of the CO2 forecast error variance, but such a variable does not exist.

Conclusion

The results of this time series analysis give us the following implications. The time-series changes in CO_2 emissions are significantly affected by the temporal path of CO_2 emissions, consumer spending, consumer price index, and oil prices. PCE has a positive effect on CO_2 emissions, which is consistent with our intuition about the correlation between variables that as consumer spending increases, CO_2 emissions from energy consumption and product production will increase. In addition, it is analyzed that CO_2 emissions increase when gasoline prices decrease. If gasoline demand decreases due to the promotion of carbon neutrality and this leads to a decrease in gasoline prices, it can become a threat factor leading to an increase in carbon emissions.

III. Carbon neutrality in the transportation sector

1. Overview of the U.S. Transportation Carbon Neutrality Policy

As a reminder, the transportation sector is the largest source of greenhouse gas emissions in the United States, accounting for one-third of all emissions. The U.S. government has designated the transportation sector as a key sector for carbon neutrality, and in January 2023, the Department of Energy, the Department of Transportation, the Environmental Protection Agency, and the Department of Housing and Urban Development jointly released the 'The U.S. National Blueprint for Transportation Decarbonization'. This blueprint outlines the strategies and goals needed to transition to a sustainable transportation system by 2050.

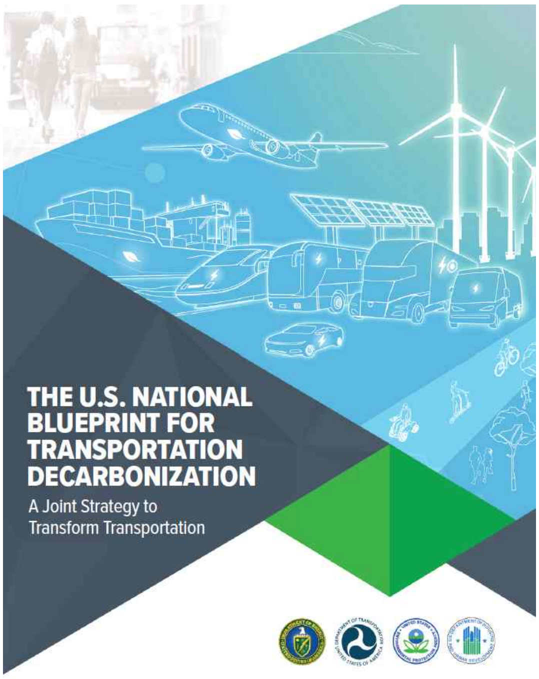

Figure 12. The U.S. National Blueprint for Transportation Decarbonization

The Blueprint for Transportation (2023) outlines three key strategies. First, improve convenience by implementing system-level and design solutions. This is a strategy that improves convenience by supporting regional design and land use planning, which will be discussed in detail in the fifth chapter, Urban and Regional Carbon Neutrality Strategies. Second, improve efficiency through mode switching and more efficient vehicles. Expand affordable, accessible, efficient, and reliable options such as mass transit and rail, and improve the efficiency of all vehicles. The logic is that reducing energy consumption when traveling, such as through mass transit, will save money, enhance national security, and reduce GHG emissions. Third, shift to clean options by deploying zero-emission vehicles and fuels. Switch to zero-emission vehicles and clean fuels for cars, commercial trucks, public transit, boats, and airplanes. This will prevent air pollution and eliminate GHG emissions from transportation.

The first of these three strategies is covered in the fifth chapter, and this chapter will discuss in detail U.S. policies for the transition to zero-emission vehicles and their effectiveness. I will also look at ways to encourage people to use affordable and convenient mass transit.

2. Switching to Eco-friendly vehicle

2.1. Promoting EV sales by expanding charging stations in U.S.

Since the inauguration of the Joe Biden administration in the United States, the most important transportation policy has been to promote sales of electric vehicles (EVs; including battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs)) and to expand the number of EV charging stations to support them. On June 27, 2023, the White House explained in a press release titled "The Biden-Harris Administration is Driving Forward on Convenient, Reliable, Made-in-America National Network of Electric Vehicle Chargers" that public and private investments to achieve the Biden administration's goal of expanding 500,000 public EV chargers are on track. In addition, it explained that since President Biden took office, EV sales have tripled and the number of public charging ports has increased by more than 40%, and as a result, there are now more than 3 million EVs on the road and more than 140,000 public chargers across the United States (Figure 12).

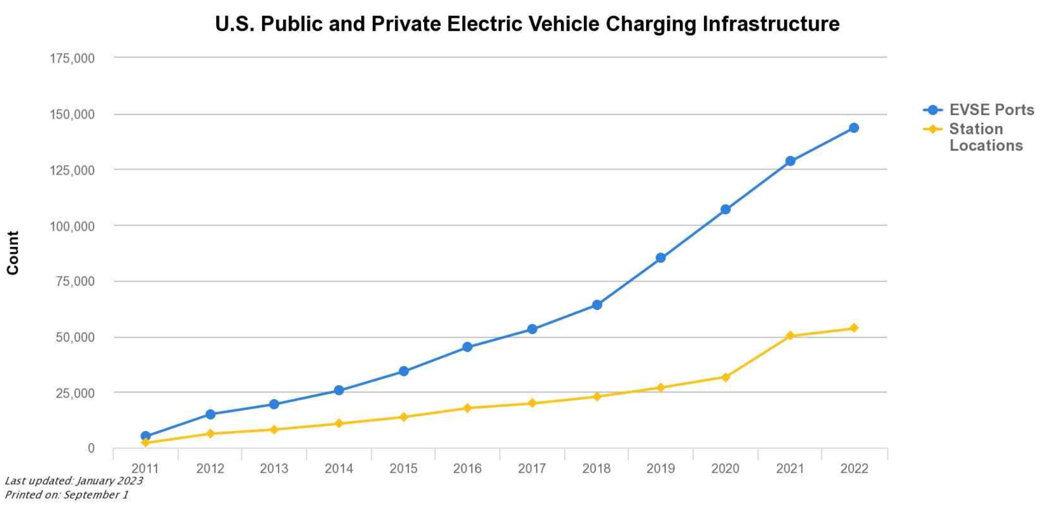

Figure 13. Number of EVSE ports and charging stations in the United States
(source: Alternative Fuels Data Center, https://afdc.energy.gov/data/10964)

The Biden administration has set a goal of eliminating carbon-emitting transportation vehicles from the market by 2050 to achieve carbon neutrality in the transportation sector, and has been continuously pursuing various policies to promote electric vehicle sales since the beginning of its term. In particular, it set a goal of increasing the share of EV sales in the U.S. to 50% by 2030, implemented the Inflation Reduction Act, which provides subsidies (tax credits) of up to $7,500 for electric vehicle purchases, and announced the 'Electric Vehicle Charging Action Plan' in December of the same year along with the passage of the so-called 'Bipartisan Infrastructure Deal' in November 2021 to expand the number of public electric vehicle chargers, which was a pledge made before taking office. In June 2022, it proposed a 'New Standard for Electric Vehicle Charging Networks' to create standards that allow the public and private sectors to actively participate in installing charging stations. In addition, of the $7.5 billion (approximately KRW 9.9 trillion) budget allocated for the installation of electric vehicle charging stations in 2022, approximately $900 million (approximately KRW 1.2 trillion) in 2023 was invested in the installation of EV charging stations on highways, and the conversion of vehicles purchased by public organizations such as the United States Postal Service (USPS) to electric vehicles was also promoted.

Study to Expand U.S. Charging Network by 2030

According to a White House press release in June, the National Renewable Energy Laboratory released the results of "the 2030 National Charging Network study," an analysis quantifying the estimated number, type, and location of chargers needed across the United States to support rapidly growing electric vehicle adoption, prepared in collaboration with the Joint Office of Energy and Transportation (Joint Office) and the U.S. Department of Energy (DOE) Vehicle Technology Office (VTO). The study considered the impact of regional variations in electric vehicle adoption, climate, travel patterns, housing types, and charging preferences. The study found that the nation will need a network of 1.2 million public chargers by 2030 to meet rapidly growing demand for electric vehicles. Of those 1.2 million charging ports, approximately 1 million will be low-cost chargers that can meet a variety of everyday needs with Level 2 charging, while the remainder will be DC fast chargers that are critical for driving confidence and long-distance travel.

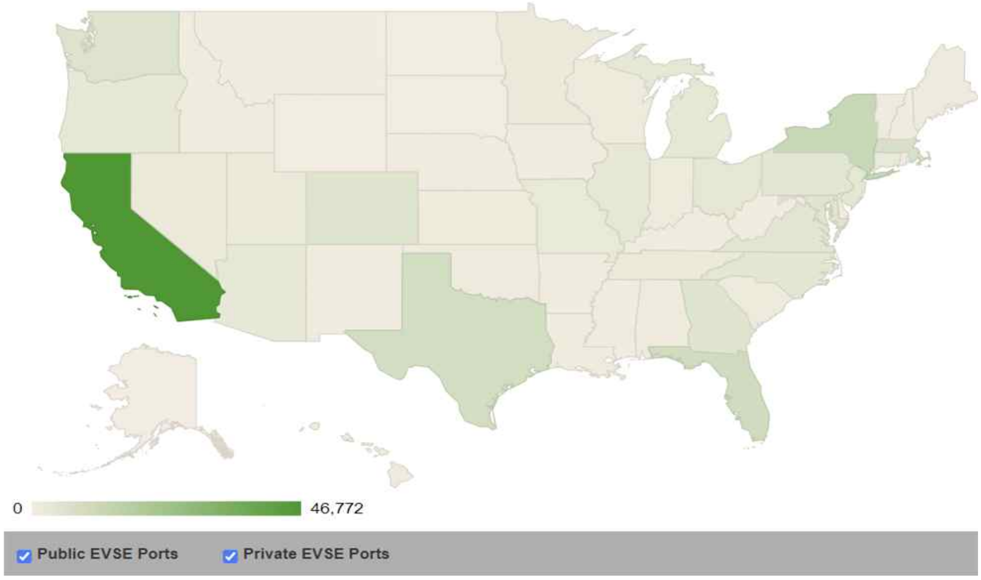

Figure 14. Electric Vehicle Supply Equipment (EVSE) Port by State in U.S.
(source: Alternative Fuels Data Center, https://afdc.energy.gov/data/10366)

The White House estimates that building this public charging network will require cumulative public and private capital investment of $31 billion to $55 billion, and could save consumers hundreds of billions of dollars in reduced fuel and maintenance costs. It also explains that President Biden's Invest in America agenda, growing demand for electric vehicles, and investments from private companies, the public sector, and electric utilities have already committed nearly $24 billion to public charging infrastructure by 2030.

One of the flagship programs for electric vehicle charging is the National Electric Vehicle Infrastructure Program (NEVI), a $5 billion initiative to build a nationwide network of fast electric vehicle chargers along major highways. All 50 states, the District of Columbia, and Puerto Rico are participating in the NEVI program, and over 75,000 miles of the national highway system will be electrified in the first two years alone. The U.S. government has also set new national standards for federally supported electric vehicle chargers, including NEVI-supported chargers. The minimum standard sets a baseline to ensure that national electric vehicle charging networks are interoperable across multiple charging companies with similar payment systems, pricing information and charging speeds, while allowing flexibility to offer other connector types, such as the North American Charging Standard (NACS) developed by Tesla, in addition to the Combined Charging System (CCS) connector used by most automakers, for example.

Limitations and Voices of Concerns

According to the IEA (2024b), EVs (BEVs or PHEVs) will account for 10% of vehicle sales in the United States in 2023. This is a very low figure compared to the global average of 18% and the fact that 38% of new car sales in China EVs. Along with the low market share, a plan to somewhat retreat from the carbon neutral policy was recently announced. On March 20, 2024, the United States announced a final plan that somewhat slowed down the pace of eco-friendly vehicle introduction that was originally planned. The USEPA (2024b) announced a new regulation to increase the proportion of electric vehicles (including hybrids) among passenger vehicles sold to 56% by 2032. The initial target was ‘67% by 2030’, but the target date has been delayed and the proportion has been lowered. Since EVs require less manpower than internal combustion engines to produce, the existing auto industry unions have been strongly opposed to the policy of rapidly increasing EVs.

The Biden administration has stated that it will try to lead the national leadership race for EVs with many competitors through the “Made in America” policy and that investments in electric vehicle charging will create good-paying jobs in local communities across the country. However, some have pointed out that the “Made in America” policy could have a negative impact on the expansion of chargers. Since electric vehicle charging stations must use more than 55% of American construction materials and parts to be eligible for support, it will take a considerable amount of time to replace many of the parts in existing chargers, which are foreign-made, and there are concerns that the cost of building charging stations will increase due to the price of raw materials.

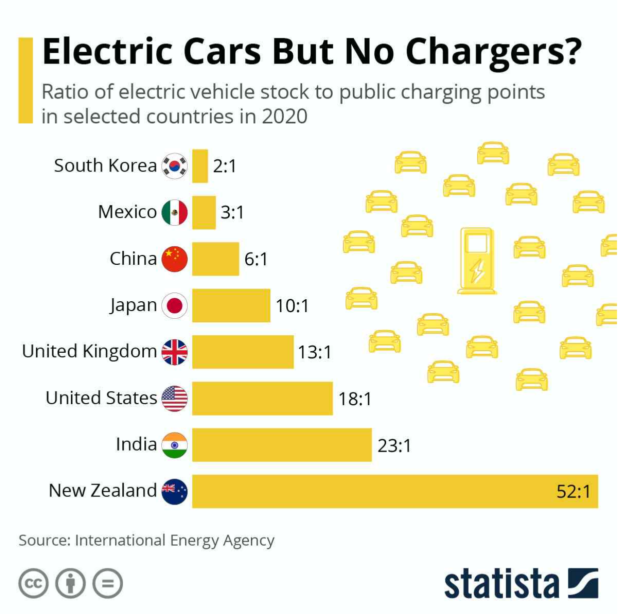

Figure 15. Ratio of electric vehicles to public charging ports by country
(source: https://www.statista.com/chart/26325/ratio-electric-vehicles-to-public-charging-points)

In addition, some have pointed out that the speed of expansion of charging infrastructure is not keeping up with the speed of electric vehicle proliferation. S&P Global Mobility (2023) forecasted that in order to meet the charging demand due to the increase in EVs in the United States, the number of charging stations must increase fourfold within two years and eightfold by 2030. According to data from the International

Energy Agency (IEA), the ratio of EVs to charging ports in the United States is currently at a very poor level of 18:1 in 2020 (Figure 15).

In addition, political uncertainty is also pointed out. In a video speech posted on his campaign website on July 20, 2023, Trump said, "If we fail to block Biden's electric vehicle promotion plan, the American auto industry will perish," and "If I return to the White House, I will end Biden's policies on my first day on the job.“

2.2. Policy effectiveness and focus strategy selection

Why should governments encourage people to adopt electric vehicles?

The activation of EV not only brings environmental benefits such as reduced carbon emissions and improved air quality, but also economic benefits such as job creation, reduced dependence on foreign oil and promotion the growth of the green vehicle market. For this reason, the federal government encourage people to adopt EVs through various policies, and at the state government level, bold policies were being introduced such as making regulations that do not allow carbon emissions for all new cars after 2035 in California (Davenport et al., 2022). California Governor Gavin Newsom announced in August, 2022 that all new vehicles sold by 2035 must be zero-emission. California is the largest auto market in the U.S., and more than a dozen other states have followed suit, bringing the cap to about a third of the U.S. auto market. Interim goals have also been set to require 35 percent of new passenger vehicles sold to be zero-emission by 2026 and 68 percent by 2030.

I will find out which policies are effective in encouraging people to adopt EV. In many studies analyzing EV sales, including research by Jenn et al. (2018), the policies to promote EV had been proven to have an incentive effect. Then, which policies are effective to promote EV, financial incentives, or non-monetary supports? And which policy should the government focus more on? In order to effectively encourage EV adoption, the government should continue to promote financial incentive policies such as tax benefits and strive to implement non-monetary policies such as securing EV chargers and HOV lane access, and the state and federal governments should properly distribute their roles for these.

EV Adoption Status and Factors Influencing EV Adoption

To conduct an accurate analysis, it is necessary to establish a conceptual understanding of EVs. According to the U.S. Department of Energy (n.d.), all electric vehicles, including Battery Electric Vehicle (BEV), Plug-in Hybrid Electric Vehicle (PHEV), and Hybrid Electric Vehicle (HEV), utilize electricity to operate. Furthermore, BEV and PHEV, excluding HEV, are referred to as Plug-in Electric Vehicle (PEV). As of December 2022, the total number of PEV registrations in the United States stands at 3,454,700 units. Among the states, California leads with 1,264,700 registrations, accounting for approximately 37% of all PEVs. Florida follows with 213,800 registrations, and Texas with 191,800 registrations. This can be attributed to California's population and economic size, as well as its bold state-level incentives and regulatory. Conversely, states like North Dakota and Wyoming have fewer than 2,000 PEV registrations. What factors primarily contributed to the varying PEV registrations across states?

Many previous studies have analyzed that such different EV sales by state are the result of financial incentive and non-monetary support policies for EV (Jenn at al., 2018; Narassimhan, & Johnson, 2018). As for financial factors, price incentive factors such as purchase subsidies, tax discounts, and highway toll reductions are representative, and there are also operating cost factors such as electricity cost and macroeconomic factors such as interest rates and fuel energy cost. Non-monetary factors include infrastructure aspects such as the increase in charging stations, free parking, HOVs lane access (Langbroek et al., 2016), institutional aspects such as government plans and regulation, cognitive aspects such as awareness of carbon neutrality and recognition of EV information. In addition, there are also technological factors such as improving EV performance and securing EV safety.

Since there are limitations in analyzing all the factors that affect the adoption of PEVs in this paper, it is necessary to discuss a more effective policy structure by distinguishing between financial support and non-monetary support and analyzing representative incentive policies among them.

Effects of Financial Incentive Policies on EV adoption

Financial incentive policies for EV include income tax credit, rebates, and sales tax waiver for the purchase of vehicles, as well as maintenance subsidies for operating vehicles. Among them, tax reduction benefits for PEV purchases are the most representative policy that has a high correlation with PEV adoption.

First, looking into the effect of tax benefits, Jenn at al. (2018) argued that a rebate or tax credit had a statistically significant effect of approximately 2.6% per $1,000 on average (p.349). In addition, Narassimhan & Johnson (2018) analyzed that within tax incentives, rebates had more impact on PEVs adoption than tax credits or sales tax waiver, indicating that incentives closer to the point of sale are more effective. This is consistent with the results of significantly higher PEVs market share in countries such as Sweden, where point-of-sale VAT exemption is combined with higher VAT on conventional gasoline vehicles (Langbroek et al., 2016). Also, these findings are not limited to developed countries. According to the Colombia case analyzed by Callejas et al. (2022), both sales tax and tariff cuts have an incentive effect.

In addition, in order for financial incentives such as tax benefits and subsidies to work, it is very important for consumers to recognize them. Jenn at al. (2018) argued that higher PEVs incentive effects occurred in states where news articles about government subsidies or price incentives were active. It is consistent with the findings of Dumortier et al. (2015) that the presentation of cost information increases the likelihood of adopting PEVs.

Why is a non-monetary incentive policy for EV necessary?

Policies to install infrastructure for operating PEVs are as important as financial incentives. In particular, the expansion of electric charging stations is a very important factor for consumers to adopt PEVs, but the number of charging stations is still insufficient. There are 53,492 EV charging stations nationwide, and the number of electric vehicle supply equipment (EVSE) ports is 176,000 in US (Department of Energy, 2022). That is just 1 EVSE for every 10 registered EVs. Narassimhan & Johnson (2018) argued that "each additional EVSE port per capita increases PEV purchases per capita by 3%" (p.6). As the number of charging ports increases, the convenience of PEVs increases and the risk of not being able to charge while moving decreases, which will further accelerate the adoption of PEV vehicles.

Other non-monetary incentives include HOV lane access and free parking. Jenn at al. (2018) claimed a 0.04% increase in PEV registrations relative to average vehicle density when HOV lane access was allowed (p.354). To be more specific, they claimed that "in California the average vehicle density is 983 vehicles per HOV lane per hour, resulting in approximately a 46% increase in registrations on average attributable to the HOV access pass" (p.354). Narassimhan & Johnson (2018) also found that HOV lane access has a high correlation with PEV adoption, and that the correlation for BEV is even greater. Also, Langbroek et al. (2016) suggested that other efficient alternatives, such as free parking, exist as an incentive for EV adoption. Overall, it is clear that these various non-monetary supports affect EV adoption no less than financial incentives.

What policies should federal and state governments focus more on?

As analyzed above, both financial incentives and non-monetary support have an incentivizing effect on PEV adoption. However, it is possible to expect counter-arguments that the above analysis results are not equally applicable to other countries or the 50 states in the United States. In fact, it is necessary to promote policies that take into account external factors such as gasoline price level and median income level that affect EV adoption. There is also a need to differentiate between policies that require more focus at the federal and state levels.

First of all, it is necessary to set a future vision for EV activation at the federal government level, and to set a wide range of goals, such as fostering the PEVs industry, inducing energy conversion, and securing electric charging stations. The Biden administration has promised to build a national network of 500,000 charging ports by 2030 (White House, 2023, para. 1) and setting such a country-wide target can lead to a change in people's perceptions. As such, the federal government needs to make more efforts to address the issue of policy promotion that induces changes in people's perception, and efforts to develop electric vehicle-related technologies and secure safety are also needed.

On the other hand, there are policies that require more focus at the state level to account for regional differences. Among the non-monetary incentives, HOV or free parking incentives have little effect in cities where overcrowding is not severe. It would be effective for the state government to secure electric charging station sites by considering regional characteristics and consumer behavior patterns. Policy fine-tuning at the state level is also important, as incentive responses may no longer work differently from the analysis so far as the adoption rate of EVs increases in the future (Jenn et al., 2018, p.354).

I set out to assess effective policies for promoting EVs as an important change to respond to carbon neutrality. As many studies have pointed out, tax rebates are the most effective financial incentives to promote EV adoption, and it is important to inform consumers about these incentives. In addition, as a non-monetary policy, securing electric charging stations is essential and HOV lane access and free parking are also found to have incentive effects. However, since these non-monetary incentives differ according to regional conditions, it is appropriate for the state government to promote them, and systematic role division between the federal and state governments is very important. Despite the limitations of being limited to the US case analysis based on previous studies, this paper provides valuable insights into that government incentive policies should be locally tailored and consumer focused.

2.3. Econometric analysis of influencing factors on EV Adoption in U.S.

The incentive effects of various policies were examined in several literatures in the previous part of the same chapter. As cited earlier, Narassimhan & Johnson (2018) claimed that "each additional EVSE port per capita increases PEV purchases by 3% per capita" (p. 6). Then, to see if this trend is also evident in recent data, I decided to econometric analyze how the addition of EVSE port affects EV adoption using recent data. In addition, I have previously found that lower gasoline prices have a negative effect on CO_2 emissions through time series analysis. This part, I will analyze whether the number of EVSE and gasoline prices affect EV registration and the degree of their influence using the concept of elasticity through econometric multiple regression analysis. I will include detailed econometric analysis and interpretation methods so that readers or referencers can refer to the econometric analysis method.

Why focus on the impact of the number of EVSE and gasoline prices?

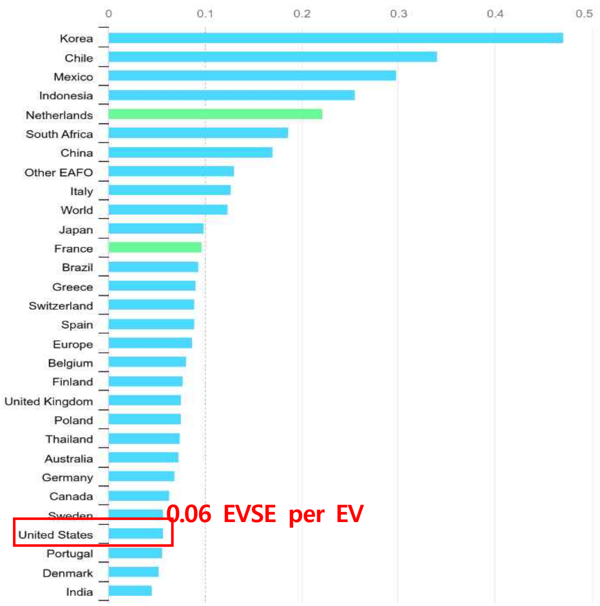

Figure 16. Ratio of EVSE per EV by country, 2020 (Source: IEA)

As I mentioned earlier, President Biden announced in December 2021 a plan to install 500,000 EV chargers by 2030. However, there are still only 176,000 EVSE in the United States. And as shown in Figure 16, the number of EVSE per EV in 2020 is 0.06 in the United States, which is low compared to 0.47 in Korea, 0.30 in Mexico, and 0.17 in

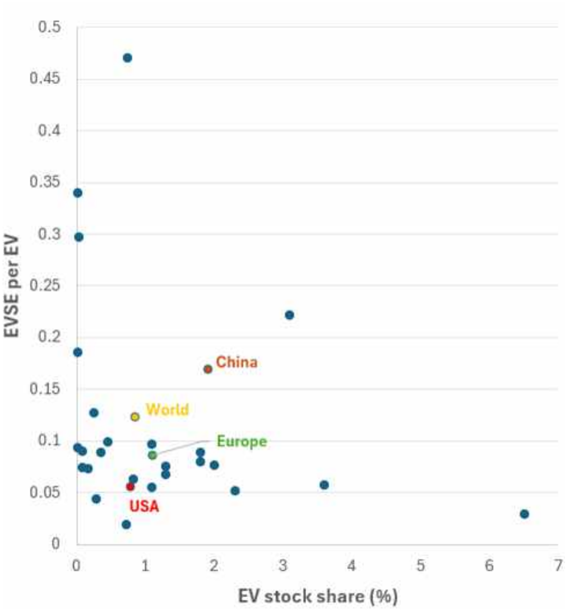

Figure 17. EV stock share and EVSE per EV
(Source: IEA)

China, as well as the world average of 0.12 (IEA, 2021). Looking at Figure 17, it is difficult to see a trend in the relationship between the market share of EV stock among all vehicles and EVSE per EV, but we can see that there is a positive correlation in major regions such as the world, the United States, Europe, and China. Therefore, despite other incentive policies, the reason for the low EV sales share in the U.S. can be attributed to the number of EV chargers. In addition, this quantitative analysis can help us understand whether Korea's policy of expanding charging stations, which is going well, is in the right direction.

And in June 2022, nationwide gasoline prices reached an all-time high, average of $5.02 per gallon (CNN, Jun.2022). A sharp increase in gasoline prices makes people perceive the cost of using gasoline vehicles as high, making EVs more attractive. On the other hand, there are reports that EV sales growth will slow and electric vehicle sales will slump as gasoline prices stabilize in the first quarter of 2024 (Goldman Sachs, 2024). Therefore, the purpose of this article is to find out how these factors affect EV adoption.

Research Question

In this chapter, I focus on three central questions. First, will the expansion of EVSE, as part of the PEV promotion policy, increase the demand for PEV? Second, will the increase in gasoline prices lead to demand for substitutes for gasoline vehicles, ultimately resulting in higher PEV adoption? Finally, how does the effect of rising gasoline prices compare to that of the EVSE expansion?

The answer suggested by the theory is that, first of all, it can be predicted that as the number of EVSE increases, the inconvenience and cost of operating PEV will be reduced, thereby increasing the demand for PEV. Due to the network effect of chargers, convenience will increase exponentially as the number increases, which will have a positive effect on PEV adoption. Additionally, as gasoline prices rise, it can be expected that the cost of gasoline vehicles will rise and demand for EV will increase as a substitute. Although it is possible to predict the direction of the influence to some extent, it is difficult to say for sure the size of the influence, which I will try to find out through actual quantitative analysis in this paper.

Data

The independent variables are the number of EVSE per capita and gasoline prices, and the dependent variable is the number of registered PEV per capita. Here, as a control group, I add personal income and population density variables as explanatory variables. I used atotal of sixdata sets, and all data are US state-level and annual data. The first of these is the annual number of PEV registrations from 2016 to 2022, and I divided this by the state's population data for each year (the second data) to create per capita PEV registration data. The third data is the counts of EVSE from 2015 to 2021, which is also divided by the population to create per-capita data. EVSE is the number of public electric charging outlets at an alternative fuel charging station.

In order to analyze the status of PEV adoption reflecting the expansion of EVSE, the base year of EVSE was analyzed as one year before the introduction of PEV(e.g., relationship analysis between EVSE per capita 2021 and PEV per capita 2022). The source of PEV and EVSE data is the Alternative Fuels Data Center of the U.S. Department of Energy, and that of the population is Census. The fourth is the average annual price of motor gasoline (dollars per million Btu) from 2016 to 2022, sourced from U.S. Energy Information Administration (EIA). One Btu (British thermal unit) is the amount of heat required to raise the temperature of one pound of liquid water by 1°F at the temperature at which water is most dense (about 39°F). So, for motor gasoline, 1 gallon = 120,214 Btu. And the fifth data is personal income per capita from 2016 to 2022, sourced from the Bureau of Economic Analysis. The sixth and final data is population densityfrom 2016 to 2022, sourced from the U.S. Census Bureau.

I will analyze these data using coding in R, a statistical program. The basic distribution of each data can be seen in Figure from 18 to 20. The number of PEV registrations per 1000 people and the counts of EVSE per 1000 people are gradually increasing every year. As of 2022, California has the highest number of PEV registrations per 1,000 people, at about 32.4, compared with the national average of 10.4. Hawaii, Oregon, and Vermont followed. Most states recorded the highest growth in PEV registrations in 2022. The second plot is the number of EVSE per 1,000 people, with Vermont, District of Columbia, and California having the highest numbers. Gasoline price distribution shows a similar trend across the states but is particularly high in Hawaii (green) and California (orange). Due to COVID-19, gasoline prices in all states were unusually low compared to the trend in 2020.

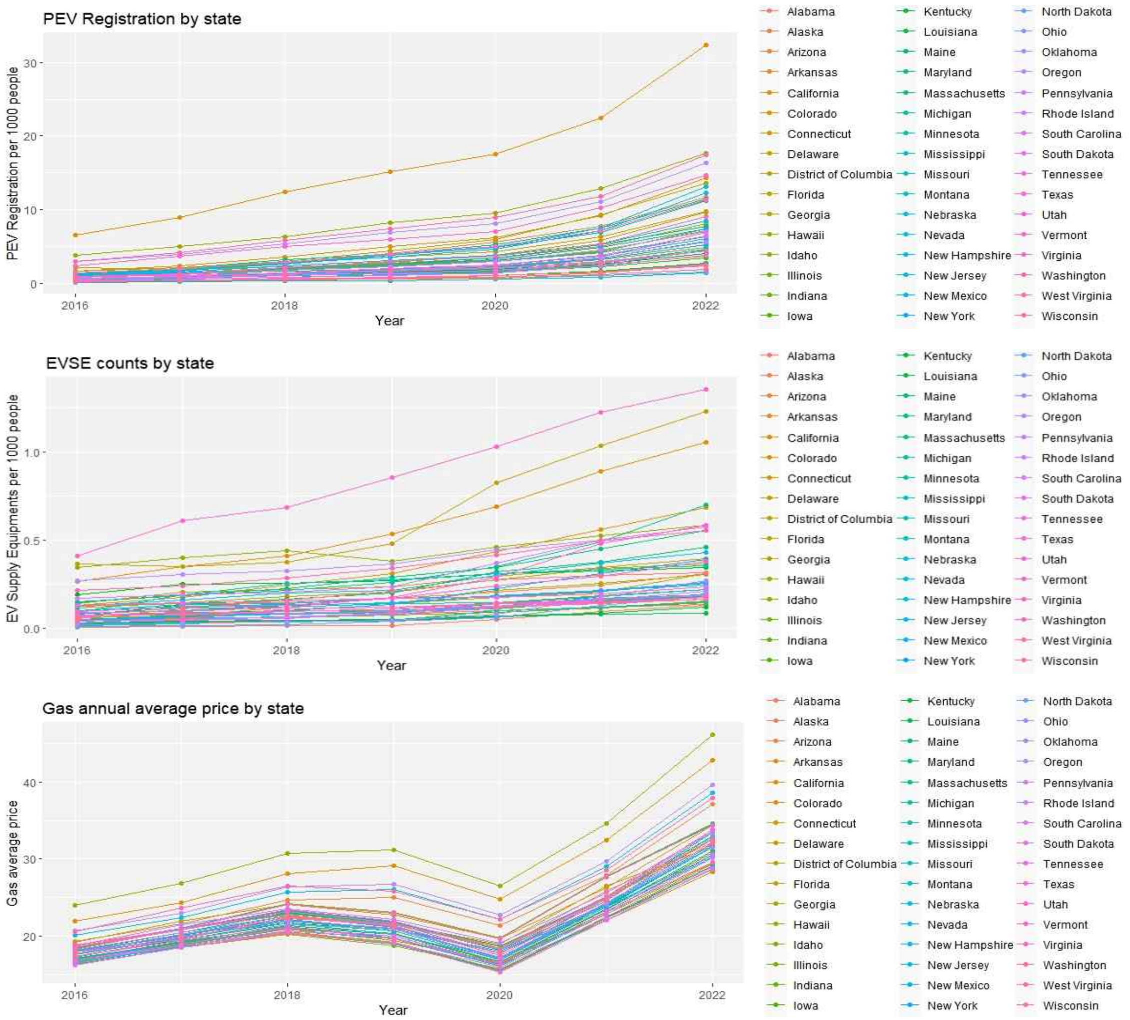

Figure 18. 19. 20. Data Distribution Plots (PEV, EVSE, Gas price)

Summary statistics for variables are included in Table 3. The total number of observations for each variable is 357 with 7 years of data from fifty-one states. To prevent the coefficients of each variable from becoming too large or too small in the analysis, PEV and EVSE were converted to data per 1,000 people, and personal income was also analyzed in units of 1,000 dollars and population density in units of 1,000 people. As mentioned in the introduction, the EVSE per PEV ratio is about 0.06, and the minimum and maximum values of both PEV and EVSE per capita can be seen to be more than three hundred times different.

Table 3. Summary Statistics (Variables)

Variable	Number	Mean	Median	Min	Max	Standard Deviation
PEV per one thousand people	357	3.33	1.97	0.10	32.39	3.77
EVSE per one thousand people	357	0.206	0.145	0.004	1.357	0.197
Gasoline Price (dollars per million Btu)	357	22.78	21.34	15.37	46.14	5.43
Personal Income per capita (one thousand dollars)	357	55.36	53.91	35.64	97.46	10.55
Population Density (one thousand people per mile^2)	357	0.42	0.108	0.0013	11.57	1.56

Econometrical specification

I used multiple linear regression analysis as the most appropriate analysis method to analyze the relationship between a single dependent variable and multiple independent variables. The first and second models are level models. And the first model includes personal income variables and state population density as control group. On the other hand, the second model is a model without a control group. To improve data normality and analysis accuracy, I added Model 3 and Model 4 by performing logarithmic transformation on key variables and analyzed the goodness of fit by comparing them with the level models. 'log(x)' denotes the natural logarithm throughout this paper.

(1) Model 1: $PEV_t = \beta_0 + \beta_1 \cdot EVSE_{t-1} + \beta_2 \cdot Gas_t + \beta_3 \cdot PI_t + \beta_4 \cdot Density_t + \varepsilon_t$

(2) Model 2: $PEV_t = \beta_0 + \beta_1 \cdot EVSE_{t-1} + \beta_2 \cdot Gas_t + \varepsilon_t$

(3) Model 3: $log(PEV_t) = \beta_0 + \beta_1 \cdot EVSE_{t-1} + \beta_2 \cdot log(Gas_t) + \beta_3 \cdot log(PI_t) + \beta_4 \cdot log(Density_t) + \varepsilon_t$

(4) Model 4: $log(PEV_t) = \beta_0 + \beta_1 \cdot log(EVSE_{t-1}) + \beta_2 \cdot log(Gas_t) + \varepsilon_t$

* ***PEV***: PEV registration per one thousand people by U.S. State
EVSE: the count of EVSE per one thousand people by U.S. State
Gas: Average annual price of motor gasoline by U.S. state (unit: dollars per million Btu)
PI: Personal Income per capita by U.S. state (unit: one thousand dollars)
Density: Population Density by U.S. state (unit: one thousand people per square mile)

The null hypothesis of this analysis is as follows:

$$(5)\ H_0: \beta_1 = \beta_2\ (= \beta_3 = \beta_4) = 0,$$

which means that there is no relationship between all independent variables and PEV registration. And the alternative hypothesis is as follows:

$$(6)\ H_1: \beta_1 > 0 \text{ or } \beta_2 > 0 \text{ (or } \beta_3 \neq 0 \text{ or } \beta_4 \neq 0),$$

which means that at least one independent variable affects PEV registration. Since EVSE and gasoline prices are expected to have a positive effect on PEV adoption, the corresponding sign can be established as an alternative hypothesis in equation (6).

Results

I use a multiple regression model with the level model in equation (1) as a first approach to hypothesis testing. Table 4 shows the results of this test. The absolute t-statistics of all coefficients are high, and the P-values are small, so they are statistically significant even at the 1% level, and the null hypothesis can be rejected. In particular, the R-squared value is large at 0.77, and it was analyzed that independent variables can explain about 77% of the volatility of PEV adoption. In addition to EVSE and gasoline prices, personal income and population density in the control group were also analyzed as significant, and the estimates of each coefficient were all positive, except for population density. EVSE can be considered significant with a remarkably high t-value of 18.11, and its coefficient is 11.45, which means that one additional EVSE per 1,000 people yields PEV per 1,000 people increases by about eleven or more. Gas is also statistically significant, with a t value exceeding ten. Interpreting the coefficient of 0.228, a $10 per million Btu increase in gasoline prices, or about $1.2 per gallon, is associated with an increase in PEV adoption of approximately two units per 1,000 people. Additionally, an increase in average personal income is also interpreted to have a positive effect on PEV adoption.

Table 4. Analysis Results of Model (1) & (2)

Dependent Variables: *PEV*

Independent Variables	(1)	(2)
EVSE	11.448*** (0.632)	11.438*** (0.583)
Gas	0.228*** (0.022)	0.279*** (0.021)
PI	0.059*** (0.013)	
Density	-0.438*** (0.074)	
Constant	-7.286*** (0.642)	-5.383*** (0.450)
R-squared	0.7704	0.7447
Adjusted R-squared	0.7678	0.7432
No. observations	357	357

Standard errors are reported in parentheses.
*, **, *** indicate significance at the 90%, 95%, and 99% level, respectively.

However, the negative coefficient for Density is different from the general expectation that the greater the population density, the higher the adoption of PEVs. As a result of analyzing the cause, the District of

Columbia recorded a population density exceeding 10 from 2016 to 2022, which is considered an outlier when compared to New Jersey, which ranked second, at 1.26 in 2020. Accordingly, there is bias in the analysis, and when estimating excluding the District of Columbia, the Densitycoefficient was positive at 0.51, but not significant. While there is slight change in population density over time, the number of PEV registrations is highly variable, so it is judged difficult to significantly estimate changes in population density.

Therefore, the second model estimates only EVSE and Gas as independent variables, excluding the control group including Density, whose estimation is questionable. The results of this are also shown in Table 5. The t statistics of all coefficients are large, and the P-values are small, so they are statistically significant even at the 1% level, and the null hypothesis can be rejected. Compared to the first model, the t-statistics of both EVSE and Gas increased, and the coefficient of Gas increased slightly. The standard errors of the two variables are also almost similar. The R-squared value decreased by about 0.025 compared to the first model, slightly lowering the explanatory power.

As mentioned earlier, the third and fourth models were log-transformed and estimated according to equations (3) and (4). Table 5 shows the estimation results of the third and fourth model. Looking at the third model, both the R-squared value and the adjusted R-squared value increased by more than 0.05 compared to the first model. It is analyzed that independent variables could explain approximately 82.5% of the variation in PEV registrations. Compared to the first model, the standard error became significantly smaller for EVSE and Density but increased for Gas and PI. When performing a two-tailed test at the 1% level, all variables have sufficiently large t statistics and sufficiently small P-values to be significant and the null hypothesis that there is no relationship between independent and dependent variables can be rejected. However, in the case of log(Density), the t statistics cannot be considered significant when performing a one-tailed test at 1% level, so it cannot be certain that it has a positive impact. The coefficient of log(EVSE) is 0.636, which means that a 1% increase in EVSE per 1000 people is associated with an increase of approximately 0.6% in PEV per 1000 people. This could be good evidence proving the economic effect of the EVSE expansion policy mentioned in the introduction. Interpreting the log(Gas) coefficient of 1.426, a 1% increase in gasoline prices is associated with an approximately 1.4% increase in PEV adoption per 1,000 people. This can be interpreted as the cross-elasticity of PEV adoption with respect to gasoline changes asked in the research question.

Table 5. Analysis Results of Model (3) & (4)

Dependent Variables: log(*PEV*)		
Independent Variables	(3)	(4)
log*(EVSE)*	0.636*** (0.034)	0.771*** (0.031)
log*(Gas)*	1.426*** (0.132)	1.594*** (0.126)
log*(PI)*	1.061*** (0.171)	
log*(Density)*	0.042* (0.017)	
Constant	-6.624*** (0.690)	-2.734*** (0.422)
R-squared	0.8245	0.7955
Adjusted R-squared	0.8225	0.7943
No. observations	357	357

*, **, *** indicate significance at the 90%, 95%, and 99% level, respectively.

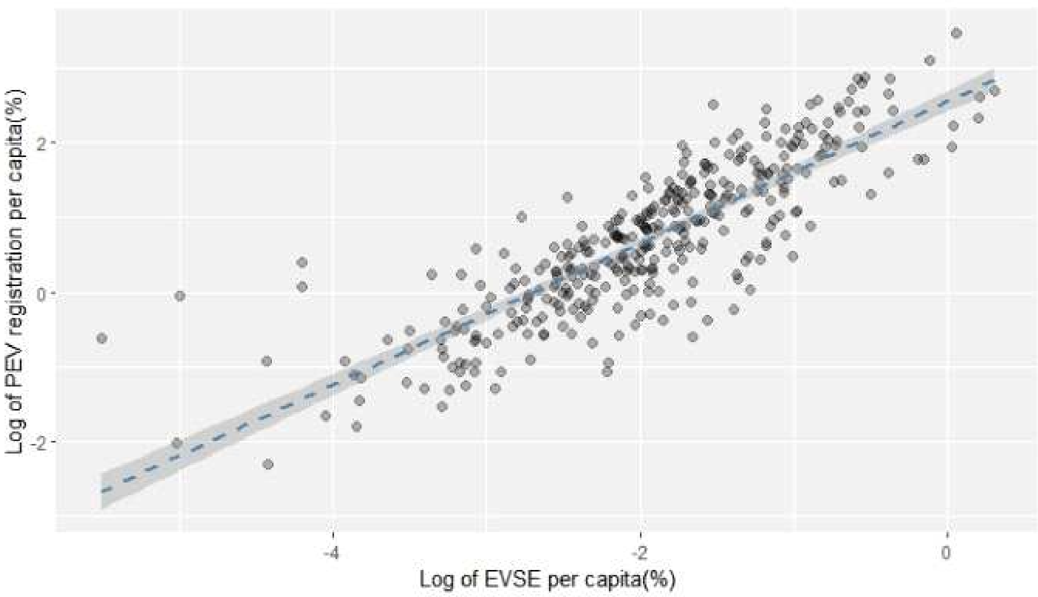

Figure 21. log(EVSE)-log(PEV) plot

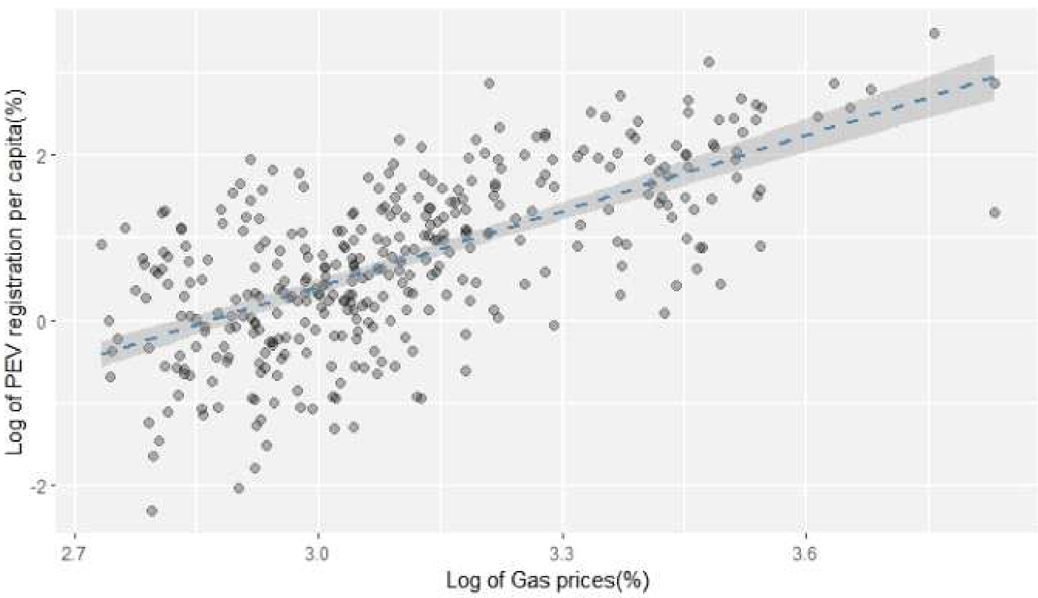

Figure 22. log(Gas)-log(PEV) plot

In addition, as shown in Figures 21 and 22, both log(EVSE)-log(PEV) and log(Gas)-log(PEV) show positive correlation, and the respective correlation coefficients are 0.84 and 0.65, which are relatively close to 1.

In the fourth model, *log(PI)* and *log(Density)* are estimated excluding the control group. Compared to the second model without log transformation, both the R-squared value and the adjusted R-squared value increased by more than 0.05. The t-values of all coefficients are large, and the P-values are small, so they are statistically significant even at the 1% level, allowing the null hypothesis to be rejected. Compared to the second model, the t-value of *EVSE* increased, but the t-value of *Gas* became smaller. The standard error decreased to one-tenth of the level of *EVSE*, while it increased for *Gas*. Compared to the third model, the R-squared value decreased by approximately 0.029, slightly lowering the explanatory power.

Table 6. Regression Results from Model (1) to Model (4)

Dependent Variables	(1) *PEV*	(2) *PEV*	(3) log*(PEV)*	(4) log*(PEV)*
Independent Variables				
EVSE	11.448*** (0.632)	11.438*** (0.583)		
log(*EVSE*)			0.636*** (0.034)	0.771*** (0.031)
Gas	0.228*** (0.022)	0.279*** (0.021)		
log(*Gas*)			1.426*** (0.132)	1.594*** (0.126)
PI	0.059*** (0.013)			
log(*PI*)			1.061*** (0.171)	
Density	-0.438*** (0.074)			
log(*Density*)			0.042* (0.017)	
Constant	-7.286*** (0.642)	-5.383*** (0.450)	-6.624*** (0.690)	-2.734*** (0.422)
R-squared	0.7704	0.7447	0.8245	0.7955
Adjusted R-squared	0.7678	0.7432	0.8225	0.7943
No. observations	357	357	357	357
p-value	<2.2e-16	<2.2e-16	<2.2e-16	<2.2e-16

The results of comparing the estimation results of the four models are shown in Table 6. In terms of goodness of fit, the third model, which has the largest R-squared value and adjusted R-squared and a significantly reduced standard error of EVSE, is judged to be the most stable model. The advantage of logarithm transformation is that it can increase the linearity and normality of the model and reduce unit differences. In addition, since it is useful in explaining the percentage change in the dependent variable according to the change in the independent variable, I will consider the third model with log transformation as the best model and analyze whether there is a crucial violation of the OLS assumption.

Testing for OLS Assumptions

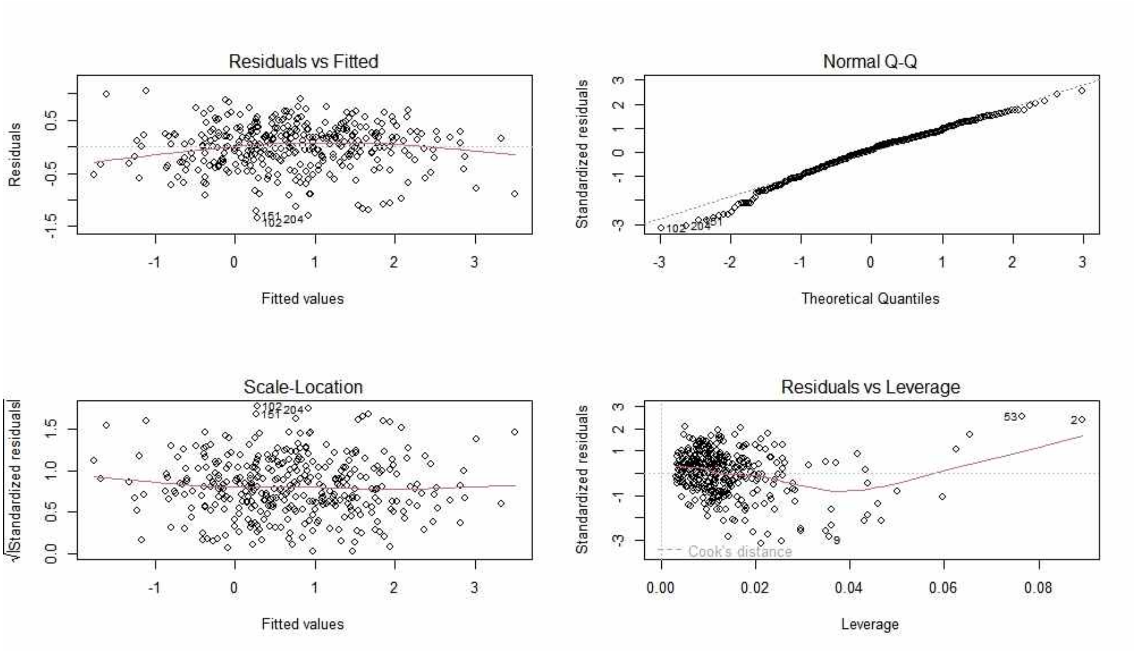

Figure 23. Regression Diagnostics (from R)

To check whether the assumptions of the linear regression model were satisfied, I performed a diagnostic test based on the third model. First, the diagnostic results through graphs are shown in the four plots in Figure 23.

Looking at the relationship between the residuals and fitted values in the first plot, the distribution is generally not significantly distorted, but is slightly curved, which suggests a violation of linearity. Looking at the second QQ plot, there are quite a few outliers that are far from normal. Looking at the fourth plot, as a result of the cook's distance test, there were no outlier data outside the cook's distance.

As a result of evaluating the VIF value, the values for all variables were less than 10, so there was no multicollinearity, and the independent variables could be considered independent. Durbin-Watson test results DW=1.7594, which satisfied the independence assumption as there was no autocorrelation. Additionally, as a result of the NCV test, the p-value is over 0.05, which means that heteroskedasticity cannot be assumed. Therefore, there is no need to consider heteroscedasticity in this model and there appears to be no need to use robust standard errors. The Shapiro-Wilk test results show that the p-value is so small that the null hypothesis can be rejected, which means that the residuals in the data are not normally distributed.

Summarizing all test results, I interpret that there are no problems with multicollinearity, heteroskedasticity, or autocorrelation, but the assumptions for linearity and normality of the model are not satisfied.

Conclusion

In conclusion, through various models, I analyzed that both the increase in EVSE per capita and the increase in gasoline prices have a significant and positive impact on PEV adoption. The high R-squared value of the analytical model shows that the selected variables are good predictors of EV adoption rate. This is consistent with the intuition based on economic theory that PEV operating costs decrease due to an increase in EV chargers and that the likelihood of adopting PEV as a replacement for gasoline vehicles increases as gasoline prices rise. And this has various implications for policymakers and others.

First of all, the relationship between EVSE and PEV has a two-sided network structure in which the value of PEV increases as the count of EVSE increases, and the value of EVSE increases as the number of PEV increases. In order to promote PEV adoption by increasing this network effect, it is necessary to increase EVSE through government policy to function as a priming force. Therefore, the direction of the Biden administration's policy and Korean government policy of expanding EV chargers can be judged to be correct. When promoting such a policy, the speed of implementation can be adjusted by considering the elasticity suggested in this paper that if EVSE per 1,000 people increases by 1%from a year ago, PEV per 1,000 people increases by about 0.6%.

Second, I find that when gasoline prices rise, there is a larger-than-expected stimulating effect on PEV adoption. A high cross-elasticity was derived, with a 1% increase in gasoline prices leading to an increase of approximately 1.4% in PEV registrations per 1,000 population. Although it is an extreme measure that does not take other conditions into account, it can be expected to be effective to increase the adoption of PEV by increasing taxes on gasoline and using this budget to expand EVSE and provide incentives for PEV purchases.

However, this analysis also has limitations. First, several factors other than personal income or population density, which were set as the control group, will affect the adoption of PEV. In particular, financial factors such as tax credit and subsidies, or technological advances such as electric battery development and performance improvement, may be bigger factors. Moreover, the introduction of bold policies, such as California's implementation of a regulation banning carbon emissions for all new vehicles after 2035 (New York Times, August 2022), will go beyond the results of our analysis. Second, there are internal validity limitations related to the appropriateness of the OLS model in this paper. Through a diagnostic test for the assumptions of linear regression analysis, it was revealed that several assumptions were satisfied, but the linearity and normality of the residuals could not be said to be clearly satisfied, which may compromise the reliability of the linear relationship analysis. I tried to improve this through log transformation, but there were limitations. Third, there may also be a reverse causal relationship between per capita EVSE and PEV adoption. It is difficult to determine causality because as more people drive PEV, the demand for EVSE also increases. Lastly, because I analyzed data by state in the United States through this paper, there are limitations to external validity as it cannot be applied to other countries.

2.4. Distribution of hydrogen cars

Hydrogen cars are environmentally friendly because they emit no exhaust gas at all since hydrogen and oxygen combine in the fuel cell to emit water. They can generally travel 500 to 700km on a single charge, making them suitable for long-distance driving. They also have the advantage of a refueling time of 3 to 5 minutes, which is much faster than the rapid charging of EV. On the other hand, hydrogen charging is difficult to do at home, so the infrastructure for charging stations is more important, but they have the disadvantage that it is more difficult to find charging stations than electric charging stations. Hydrogen charging stations are expensive to build, costing over 2 billion won in Korea, and they must meet strict safety regulations. In addition, they cannot be installed more than 50 meters from apartment complexes and medical facilities, and more than 200 meters from schools, so there are significant restrictions on location selection. Moreover, due to the lack of development in hydrogen production and storage technology, they are not gaining public trust in terms of cost and safety.

Meanwhile, due to these pros and cons, there is an analysis that EVs are suitable for relatively short-distance, small-sized transportation, and hydrogen vehicles are suitable for relatively long-distance, large-sized transportation. Based on this, the Korean government announced a strategy to build a lineup of EV in ultra-small electric vehicles, small trucks, passenger cars, and SUVs, and hydrogen vehicles in passenger cars, SUVs, large trucks, and buses by 2030 (Future Automobile Industry Development Strategy of Korea, 2019). Therefore, it is necessary to continuously examine the direction of coexistence and development of electric and hydrogen vehicles, and further, the application of the corresponding eco-friendly engine technology to ships, trains, airplanes, and ships.

According to the automobile magazine Car and Dirver (2024), there will be only about 17,000 hydrogen fuel cell vehicles in the United States in 2024, and all of them are in California. California is the only state with a network of retail hydrogen fueling stations to enable the use of automobiles. Although major automakers are focusing on making electric vehicles mainstream by 2030, hydrogen vehicles are still far behind. The only hydrogen-powered cars sold in the United States so far are the Honda ‘Clarity’ Fuel Cell, Hyundai ‘Nexo’ SUV, and Toyota ‘Mirai’. Honda has now discontinued all of its Clarity models and is releasing a new hydrogen-powered model, the CR-V e:FCEV. Hyundai has only sold about 1,600 Nexo SUVs in the United States over the past six years, with the remaining 14,300 being Mirai sedans. The biggest obstacle to hydrogen adoption in the United States is refueling. A decade ago, California was supposed to have 100 hydrogen stations, but fewer than 60 are actually operating. The biggest problem is that not all stations are always online and available to refuel. Many hydrogen drivers have to use some kind of app to map out where to refuel before they set off. Many stations often refuel only two to five cars before going offline for up to 30 minutes to refuel.

In addition, the factors affecting EVs and the incentive effects of charging stations analyzed above are not limited to EVs, but can also be applied to other eco-friendly vehicles such as hydrogen cars. According to Korean government, Korea Automobile Mobility Industry Association (KAMA) and others (Yonhap News, April 7, 2024), the number of hydrogen cars registered in Korea was 34,872 as of March 2024, a 180% increase from March 3 years ago (12,439 units). On the other hand, the number of hydrogen charging stations increased from 69 to 172 during the same period, a mere 149% increase. Accordingly, the number of vehicles per charging station (charging cost) increased from 180 to 203. Korea's goal for expanding hydrogen charging stations is to install 660 by 2030, all within 20 minutes of major cities. This goal will play a very key role in the spread of hydrogen cars due to the network effect of charging stations discussed above.

However, there are many criticisms that although fuel cells do not emit any exhaust gases when running an engine using hydrogen, carbon may be generated when fossil fuels, especially methane, are used in the hydrogen production process, and that the low maximum output and complex structure of the engine have not yet been sufficiently resolved. Therefore, in order for hydrogen cars to become a solution for carbon neutrality, the continuous development and advancement of hydrogen production, storage, and charging technologies should be given top priority.

2.5. Recent Problems

Mineral issues when making batteries

The mineral issue that occurs when producing batteries, a key component of eco-friendly cars, is emerging as an important issue for several reasons. Hydrogen fuel cells require rare materials such as platinum as catalysts, so their production costs are relatively high. Therefore, it is important to find alternative catalysts for them. In particular, the problem is caused by the various metals (lithium, cobalt, nickel, etc.) required in the production process of lithium-ion batteries, which are key components of electric vehicle batteries.

The main reason this is a problem arises from the scarcity of minerals and the instability of the supply chain. According to Furchtgott-Roth (2024), Lithium brines typically contain less than 0.1% lithium, so that entails some 25,000 pounds of brines to get the 25 pounds of pure lithium. Cobalt ore grades average about 0.1%, thus nearly 30,000 pounds of ore. Nickel ore grades average about 1%, thus about 6,000 pounds of ore. Graphite ore is typically 10%, thus about 1,000 pounds per battery. Copper at about 0.6% in the ore, thus about 25,000 pounds of ore per battery. In total then, acquiring just these five elements to produce the 1,000-pound EV battery requires mining about 90,000 pounds of ore. This means that accessing about 90,000 pounds of ore requires digging and moving between 200,000 and over 1,500,000 pounds of earth—a rough average of more than 500,000 pounds per battery.

Metals such as lithium, cobalt and nickel are essential in electric vehicle batteries, but these resources are finite and concentrated in certain countries or regions. For instance, the U.S. produces about 1 percent of the world's lithium, while Australia, Chile, Argentina and China collectively produce over 90 percent. The global demand for lithium is expected to rise from 500,000 metric tons of lithium carbonate equivalent in 2021 to 3 to 4 million metric tons by 2030. Most of the cobalt comes from Congo, Africa, where political instability threatens the stability of the supply chain. This scarcity and regional dependency can lead to price volatility, which could impact the cost of EV battery production.

There are also environmental and ethical concerns: Lithium mining is particularly water-intensive, which could exacerbate water shortages in arid regions. American automakers won't be able to keep up with lithium demand for EV batteries, so they will likely have to source it from South America. South America's "Lithium Triangle," an area covering parts of Chile, Argentina and Bolivia, where more than 75 percent of the world's lithium is found. Lithium mining requires a high volume of water-about 400,000 gallons per ton of lithium. This can deplete the groundwater and lakes, so the land becomes damaged. There is a tension between green technologies intended to slow the effects of climate change - like electric vehicles - and the environmental impacts of creating those technologies.

In addition, cobalt mining causes environmental problems such as ecosystem destruction and deforestation, and especially in the mining process, environmental destruction and child labor exploitation occur. This leads to sustainability issues and may conflict with the logic that EVs should be promoted because they are environmentally friendly. There are also other ethical issues. Most of the domestic critical mineral deposits needed for EV batteries - lithium, cobalt, nickel, copper - are near Native American reservations. Lithium Americas Corp. has faced resistance from both Native American tribes and environmentalists over its proposed lithium mine, Thacker Pass, in Nevada. By some estimates, Thacker Pass could contain the largest hard rock lithium deposit in the U.S.

The long mining period also adds to the difficulty. The time required to locate an economically suitable mineral deposit, acquiring capital, land, mineral rights, and permits, among other requirements, can take years. It can range from 1 month to 11 years, the average is 5 years. The most common types of mining are open pit mining, surface mining, underground mining, and extracting compounds or ions from brines. Therefore, securing a supply chain that predicts this is fraught with many difficulties.

In conclusion, minerals essential for electric vehicle battery production pose scarcity and environmental and ethical issues, and securing transparency in the global supply chain and sustainable technological development are important to address these issues. Industry experts expect demand for EV batteries to spike to tens of millions of units annually in the years ahead. There's an expectation that hundreds of mines will be needed, possibly up to 384 additional graphite, lithium, nickel and cobalt mines by 2035 to supply all those new EVs. Therefore, solving these problems could be another key factor in expanding EVs.

Electric car fire incident in Korea

Recently, as electric vehicle fire incidents have occurred one after another in Korea, the trend of expanding EVs may also slow down. In particular, a large fire that occurred in an underground parking lot of an apartment in Incheon in August 2024 attracted a lot of attention, and as a result, safety issues regarding EVs and charging facilities were highlighted. Accordingly, the Korean government announced electric vehicle fire safety management measures on September 6 of this year. Major countermeasures include strengthening EV safety by early implementation of a battery certification system and mandatory disclosure of battery information, and strengthening the responsibility of manufacturers by expanding corporate liability insurance subscriptions and conducting free EV inspections every year. In particular, efforts are being made to prevent the adoption of EVs from being hindered by public anxiety by actively promoting the BMS (Battery Management System), which detects and warns about the status of electric vehicle batteries in real time.

As such, detailed policy adjustments are necessary as unexpected obstacles may arise in the decarbonization of all vehicles by 2050. In particular, thorough management of batteries, which are the core driving force of eco-friendly vehicles such as EVs and hydrogen vehicles, will be important.

3. Supporting public transportation activation and transportation efficiency

According to DOE et al. (2023), in 2018, public transportation in the United States saved 63 million metric tons of carbon dioxide equivalent. Given the clear carbon emissions savings from public transportation, one of the key strategies of the U.S. government's blueprint for transportation decarbonization (2023) is to improve efficiency by increasing the availability of high-efficiency travel options, while also improving the energy efficiency of all vehicles, especially passenger cars with low occupancy rates.

Figure 24 provides a summary of current emissions from various transportation modes in the United States. For local passenger trips, buses and mass transit rail offer the cleanest options, other than walking or biking. For long-distance passenger trips, multi-occupant buses and cars offer the lowest emissions options, followed by rail and air.

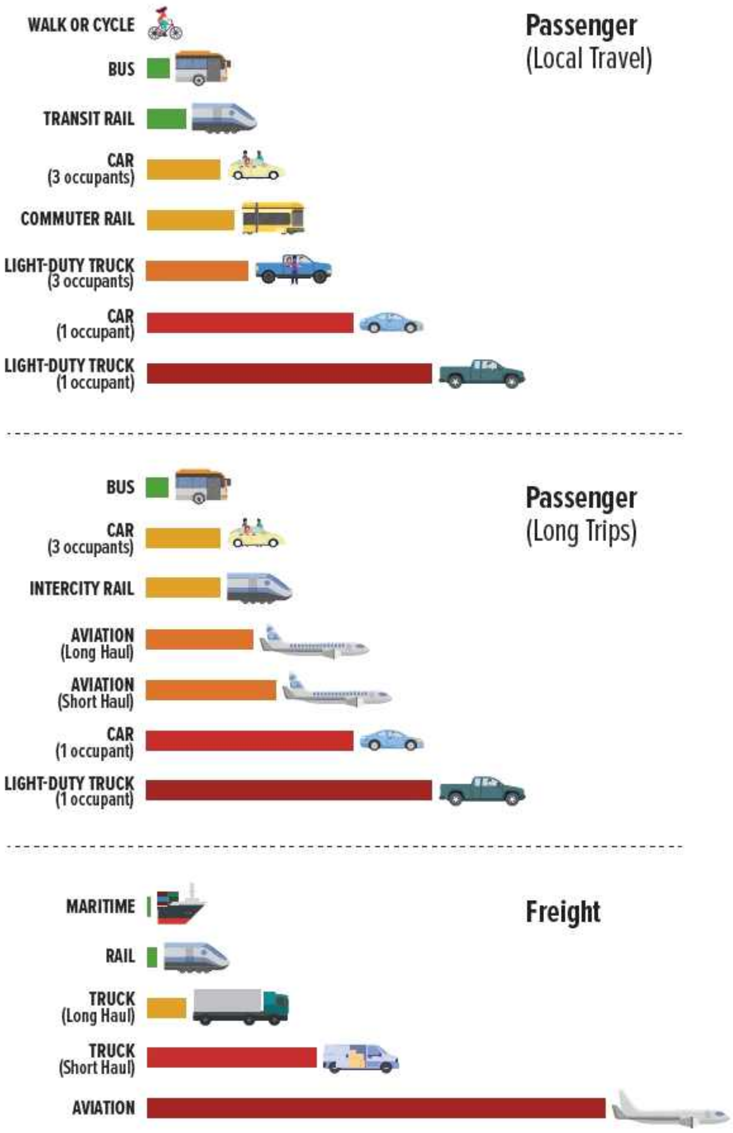

Figure 24 Emissions by mode of transportation
(source: us national blueprint for transportation decarbonization)

For freight, sea and rail offer the cleanest options. In general, transportation options that move more people or larger volumes of goods (e.g., buses, trains, large ships, carpooling) produce lower GHG emissions per mile traveled.

Road freight vehicles, such as trucks and vans, are the largest contributor to freight emissions, and this aspect is a key reason why transportation has become the largest source of GHG emissions in the United States. Using more efficient modes and vehicles is necessary to reduce overall transportation emissions and energy use. New transportation services and infrastructure, such as shared electric scooters and bikes, shared mobility apps, and inter-modal freight terminals, can enable a shift to more efficient modes of transportation and help reduce GHG emissions.

By increasing clean, efficient transportation options and improving vehicle efficiency, we can reduce harmful climate change impacts and air pollution. We can ensure a more affordable transportation system, reduce our dependence on fossil fuels, and improve energy security. The United States is highly dependent on private vehicles. According to Statista's Global Consumer Survey (Richter, 2022), 76% of U.S. commuters use a personal vehicle to travel between home and work. In Germany, 65% of commuters choose a personal car, 26% choose public transportation, and 23% choose a bicycle, while in the Netherlands, 36% of commuters choose a bicycle to work, while 56% choose a car. Meanwhile, in the United States, only 11% of the 5,649 respondents use public transportation, while 10% use a bicycle. Continuing efforts to expand public transportation, intercity rail, and active transportation options and use in the United States will further reduce emissions.

To this end, the US government proposes the following solutions in the Blueprint (DOE et al., 2023): (i) investing more in efficient passenger and freight transportation, such as public transportation, biking, and walking; (ii) providing incentives for less carbon-intensive options and shared-economy travel; (iii) improving transportation system operations, such as automated solutions and multimodal freight transportation; (iv) improving vehicle energy efficiency, such as reducing non-combustion emissions, such as lightweighting and pipeline spills; and (v) supporting innovative business models and solutions, such as the California Integrated Travel Program (Cal-ITP), which connects rail, buses, and more.

IV. Carbon neutrality in the Buildings sector

1. Overview of the U.S. Buildings Carbon Neutrality Policy

Residential and commercial buildings are among the largest sources of carbon dioxide and other greenhouse gas (GHG) emissions in the United States, including indirect emissions from electricity consumption, the building sector accounts for more than a third of total U.S. GHG emissions. Emissions from direct combustion of gas, oil, and other fuels for heating, hot water, cooking, and other services also account for 12.7% of total U.S. GHG emissions (USEPA, 2021). According to DOE & HUD(2024), there are nearly 130 million existing buildings in the United States, with 40 million new homes and 60 billion square feet of commercial floorspace expected to be constructed between now and 2050. Today, most buildings consume large amounts of energy and cause significant climate pollution to meet our basic needs. Buildings account for 74% of U.S. electricity use and building heating and cooling drives peak electricity demand. Additionally, the building is a place where EV charging and solar power generation can take place, and where energy storage devices, heat pumps and more can be integrated with the electrical system. In this context, the buildings sector will play a key role in achieving economywide net-zero emissions by 2050.

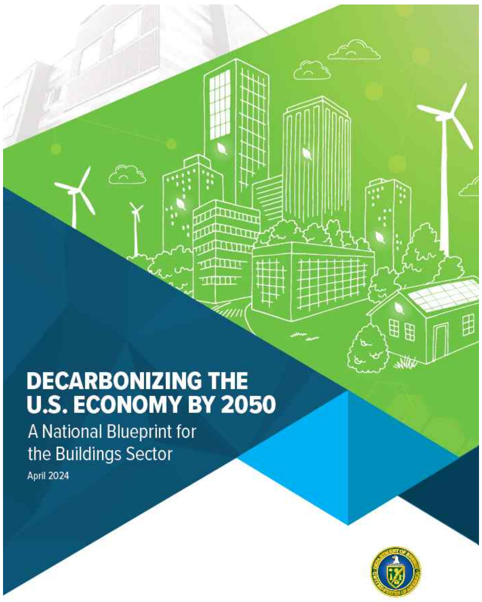

Figure 25. A National Blueprint for the Buildings Sector (source: DOE)

In April 2024, the U.S. Department of Energy, and the Department of Housing and Urban Development jointly released the ‘Decarbonizing the U.S. Economy by 2050: A National Blueprint for the Buildings Sector’ (Figure 25). This Blueprint outlines a strategy to reduce GHG emissions from U.S. buildings 65% by 2035 and 90% by 2050 compared with 2005, while enabling net-zero emissions economy wide. The vision is to achieve our national climate goals through deep and equitable decarbonization of American buildings, and it presents the following four core strategies: (i) Increase building energy efficiency, including reducing on-site energy use intensity in buildings by 35% by 2035 and by 50% by 2050 compared to 2005 levels; (ii) Accelerate on-site emissions reductions, including reducing on-site GHG emissions in buildings by 25% by 2035 and by 75% by 2050 compared to 2005 levels; (iii) Transform the grid edge, including reducing electricity infrastructure costs by tripling demand flexibility potential by 2050 compared to 2020 levels; and (iv) Minimize embodied life cycle emissions, including reducing embodied emissions from building materials and construction by 90% by 2050 compared to 2005 levels.

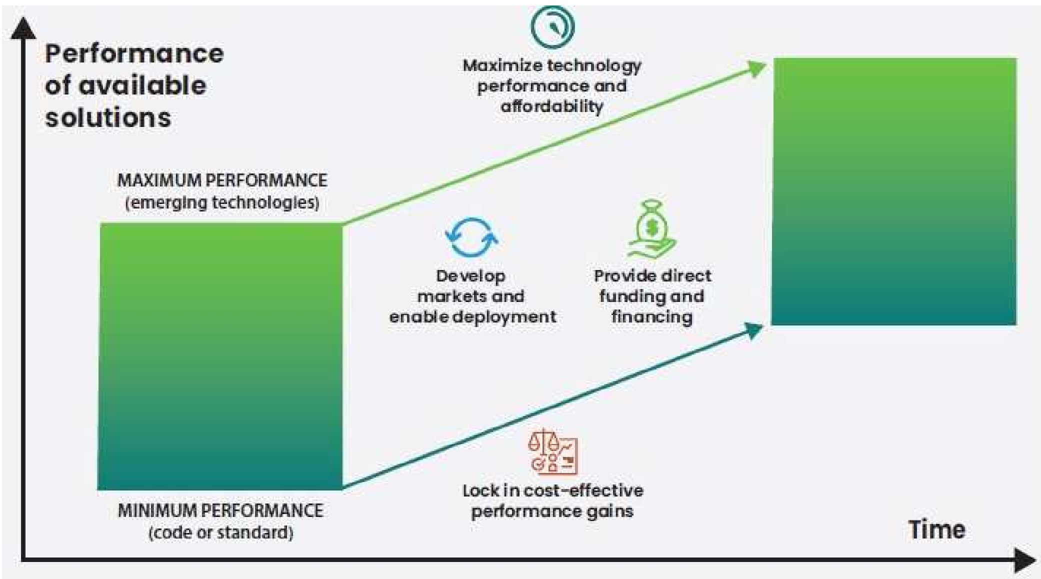

Figure 26. Four types of federal actions accelerating building decarbonization
(Source: DOE & HUD, 2024)

The blueprint outlines four types of federal actions to accelerate and scale building decarbonization (Figure 26): The federal government will pursue technologies that maximize performance and economic viability, including early-stage R&D funding; facilitate market development and deployment of these technologies; and promote financing through tax credits and direct funding; support the development and adoption of building energy codes and state and local regulatory action to drive cost-effective performance improvements nationwide; and accelerate widespread adoption of building solutions, including by leading by example in performance standards and procurement requirements for federally owned or operated buildings.

Looking at these U.S. strategies, the 2050 target is not set as complete carbon neutrality, which is thought to be difficult to achieve in historic buildings and the like. And the plan addresses both operational and whole life cycle emissions, with targets for increasing building energy efficiency, demand flexibility, on-site emissions reduction, and minimizing embodied emissions from building materials and construction.

In the following article, I will first examine the GHG emissions status from the life cycle perspective of a building from its construction to operation and decommissioning, and then examine the factors for reducing carbon emissions in the building construction and operation sectors. In particular, I will explain in detail the areas of minimizing emissions from building materials and construction, and the zero-energy building, which is the ultimate form of increasing the energy efficiency of a building.

2. Life cycle emissions of buildings

According to data from McKinsey & Company (João Ribeirinho, M. et al. 2020), the construction and operation of buildings and infrastructure account for 39% of global carbon emissions. The construction sector is slow to innovate due to complex project-based supply chains, and the carbon footprint of buildings is increasing for a variety of reasons. The Economist (2022) emphasized in an article titled “The Construction Industry Is Still Terribly Climate Unfriendly” that carbon emissions associated with buildings are expected to double by 2050 on the current trajectory, and that changes are needed in the construction industry to address climate change. It also argues that progress in building energy efficiency is stagnating. It points out that between 2016 and 2019, the global annual rate of improvement fell by half, according to Globalabc’s tracker, which measures indicators such as incremental investment in the energy performance of buildings along with the share of renewable energy used.

Construction Industry Supply Chain and Carbon Emissions

It is important to understand the structural causes by analyzing building carbon emissions by life cycle. According to the World Green Building Council (2019), buildings and construction accounted for 39% of global carbon emissions in 2019. Of this, 11% comes from embodied carbon emissions related to materials and construction processes, while building operations account for 28%. Specifically, Figure 29 shows the complex supply chain during the construction phase. Among these, the supply of materials, components, and machinery accounts for approximately 15-35% of building life cycle carbon emissions. In addition, the construction process, which involves general construction companies and multiple

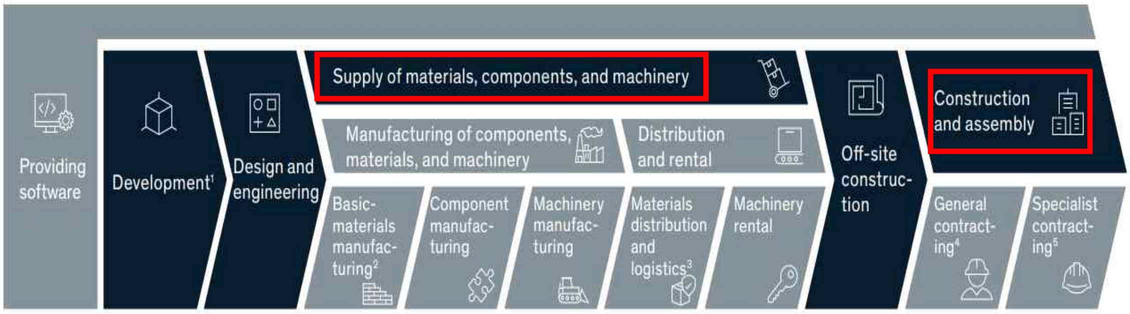

Figure 27. Construction industry supply chain and Embodied Carbon emissions stage
(출처: The next normal in construction. McKinsey & Company (2020))

specialized construction companies, accounts for 2-8% of carbon emissions. Approximately 69% of building life cycle carbon emissions comes from the energy used in subsequent phases, especially in building operations such as heating, cooling, and lighting. Carbon emissions also occur during the decommissioning phase, but this is less significant, at 0-2%. Currently, embodied carbon during the construction phase of a building accounts for a smaller share of global emissions than during the building operation phase. However, this will change as buildings become more energy efficient. In many modern buildings, embodied carbon already accounts for half of total lifetime emissions.

According to Lee (2022), when examining the embodied carbon generated during the construction process by type of construction product, residential and commercial buildings account for about 90% of total carbon emissions, and carbon emissions from the construction of infrastructure facilities such as roads, bridges, and railways account for about 10%. The reason why the carbon emissions of buildings are nine times higher than those of infrastructure is because the carbon emissions of operating buildings are about 940 times higher than those of infrastructure.

In terms of carbon emissions by major construction materials, in the case of building construction, concrete, which uses a lot of cement, accounts for 50-85% of embodied carbon, and steel bars account for about 5%. Carbon emissions also occur from other paints and other materials.

The key factors for carbon reduction that synthesize the carbon emissions status and structural characteristics of the construction industry supply chain are as follows. First, it is important to reduce embodied carbon emitted during the construction phase. In particular, it is important to reduce carbon emissions related to the production of cement and steel bars through technological development and process innovation in the construction material production industry, which is an important supply chain. This is related to the case of carbon-negative concrete. Second, in order to secure quality while reducing carbon emissions during the construction process, it is important to optimize design and construction process management. This is related to the offsite construction case. Third, reducing carbon emissions in the building operation sector is most important. In addition to decarbonizing externally supplied electric energy, it is important to reduce energy consumption through passive houses and zero-energy buildings.

3. Minimizing embodied emissions from building materials and construction

Innovation in Material Production

To reduce embodied carbon emissions during construction, we must first reduce carbon emissions in the construction materials industry. This economic model comes at a huge cost to the planet. Construction consumes nearly all of the world's cement, half of all steel production, and about a quarter of aluminum and plastics, all of which generate enormous amounts of emissions each year.

Cement is the most widely used substance on Earth after water. When mixed with water, it forms concrete, the backbone of buildings, roads, dams, and bridges. While cement itself is environmentally friendly, the process required to make it produces greenhouse gases (Figure 28). According to CBS News (2023), cement production accounts for 8% of global annual emissions. That's twice the amount produced by the aviation industry. If the cement industry were a country, it would be the world's third-largest emitter of carbon dioxide, behind the United States and China. While the cement production process is a manufacturing industry, it is also an industrial sector, but the building industry is almost the only consumer of cement, making it a key player in the transition to decarbonization.

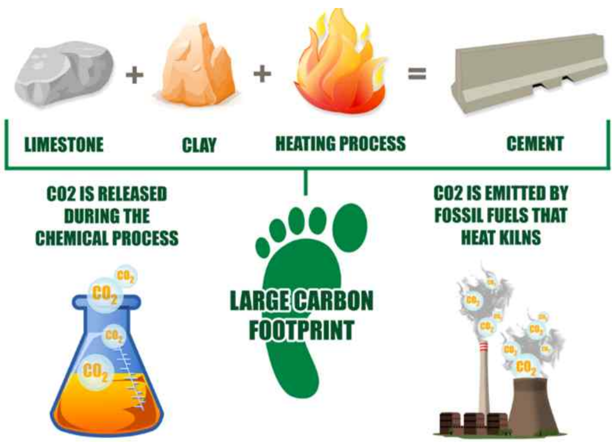

Figure 28. Cement product process
(source: https://www.pcigulfsouth.org)

Since there are likely no other building materials that can replace concrete as a sustainable option, there is a growing movement to explore technologies that can capture and recycle carbon dioxide emissions during the production process. Carbon-negative concrete, also known as carbon capture concrete or CO2 absorbing concrete, is a type of concrete that not only reduces CO2 emissions during production, but also actively absorbs CO2 from the atmosphere during its lifespan.

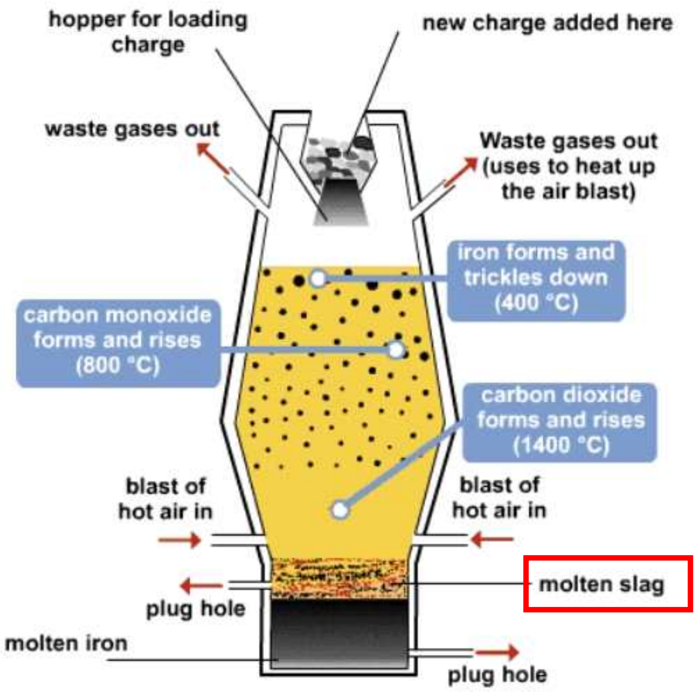

Figure 29. Conceptual diagram of low-carbon concrete production method
(source: https://arijco.com/blast-furnace-slag/)

Low-carbon concrete can reduce carbon emissions by up to 30% by switching fuels from conventional fossil fuels to facilities that utilize waste resources and by switching raw materials from limestone to slag, a byproduct of steel mill blast furnaces (Figure 29).

Another example, a startup profiled by CBS News (2023) is trying to change that. Cody Finke, CEO of Brimstone, a California-based company, and his team in Oakland are developing the world's first carbon-negative cement made from calcium silicate rock. According to Finke, calcium silicate rock is about 200 times more abundant than limestone, which is traditionally used to make cement.

However, the technological development of carbon-negative concrete is not yet commercially viable, and low-carbon concrete has the disadvantage of being more expensive to produce than conventional concrete.

Decarbonization of steel is also important. Lee (2022) points out that it is necessary to increase the proportion of ‘electric furnaces’ with low carbon emissions, and that rebar and shaped steel need to reduce indirect emissions through energy conversion. Of course, this is something that the steel industry should strive for in the industrial sector, which is one of the major sections of carbon neutrality, but since the construction industry is a consumer of half of steel, it can actively demand this decarbonization from its partners and the government can consider a plan to assign this responsibility to construction companies.

Offsite Construction (Prefabrication)

Offsite construction refers to the planning, design, manufacturing and assembly of building elements at a location other than the final installation location to support the rapid and efficient construction of permanent structures. These building elements may be prefabricated at a location other than the final installation location and transported to the site, or prefabricated at the construction site and transported to the final location.

The highest standards for offsite construction suggest that a new building can have a defect-free rate of 95% or more, and construction waste and emissions can be reduced by up to 50% compared to conventional buildings.

Modular construction, which reduces waste by assembling components in a factory and then transporting them to the site, is also gaining attention. According to a forecast from Fortune Business Insights cited by Globe News wire (2021), the global modular and prefabricated home construction market size is expected to grow from USD 41.18 billion in 2022 to USD 54.07 billion in 2026. And the global multifamily modular and prefabricated home construction market size is expected to grow from $41.18 billion in 2022 to $54.07 billion in 2026.

Figure 30. Global Modular and Prefabricated Housing Market
(re-cited from https://swiftlane.com/newsletter-archive/022522-modular-construction/)

According to The Economist (2022), nearly half of new homes in Finland, Norway and Sweden are built in factories. In Changsha, China, a 10-story apartment building was built in 28 hours and 45 minutes using modular construction. Completed in 2017, the 220-bed Holiday Inn Express in Manchester Trafford was built from purpose-built steel containers, complete with factory-built internal fixtures and fittings, all of which were installed before being delivered to site (Figure 31). According to Taylor, Chapman (n.d.), the modules were stacked on top of each other without the need for additional support structures, allowing for rapid on-site installation. Each module also consists of two bedrooms and a hallway area, and all 220 bedrooms were on site within three weeks, ready for external cladding.

Figure 31. Holiday Inn Express in Trafford, Manchester
(source: https://www.chapmantaylor.com/projects/holiday-inn-trafford)

In contrast, the general and special purpose construction industry, which has driven the complex, multi-stage supply chains of the past, could suffer significant declines if not reorganized quickly, due to the inefficiencies of its existing structures and the high carbon emissions.

4. Increase building energy efficiency: Zero energy buildings

Activating Zero Energy Building

A zero energy building is a building that minimizes energy usage by improving insulation and airtightness, reduces energy usage by improving the efficiency of boilers, machinery, and electrical equipment, and ultimately produces renewable energy equivalent to the minimized energy usage. The U.S. Department of Energy (DOE) launched the Zero-Net Energy Commercial Building Initiative (CBI) with the goals of developing new commercial buildings that produce as much energy as they use in 2008 and making these buildings marketable by 2025 (the News, 2008). Recently, the DOE and the U.S. Environmental Protection Agency (EPA) have been suggesting standards for improving the energy efficiency of buildings and actively investing in R&D for ZEB-related technologies. The Energy Star program, which EPA and DOE have been certifying products that reduce energy usage, homes, commercial, and industrial buildings since 1992, also plays a significant role in improving the energy efficiency of buildings.

To create a zero energy building, passive and active technologies can be utilized and renewable energy such as solar energy can be actively utilized. Passive technologies aim to minimize the heating and cooling energy usage of a building. They utilize natural ventilation, natural lighting, airtightness, high-performance windows, external shading, and external insulation (Figure 32). Active technologies minimize energy consumption through high-efficiency equipment. They apply high-efficiency devices and equipment such as high-efficiency boilers, LED lighting, motion-activated lighting, waste heat recovery ventilation devices, and building energy management systems.

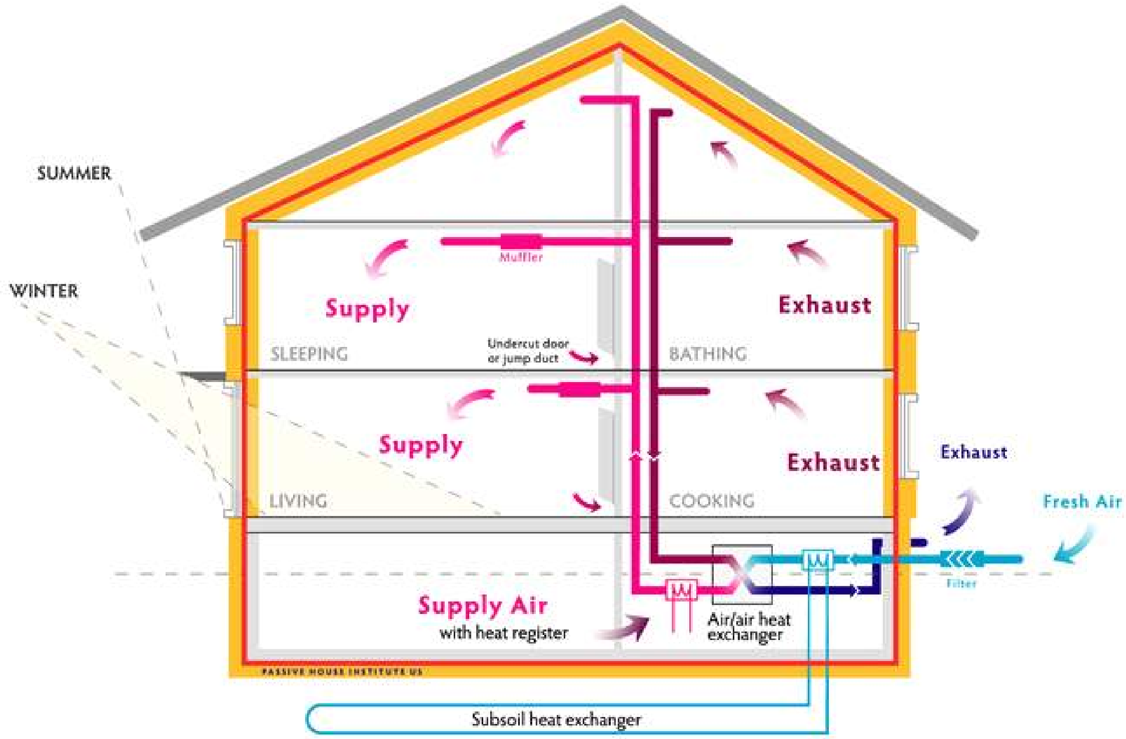

Figure 32. Basics of Pascsive House building design
(source: www.phius.org)

Policy Efforts for Building Energy Efficiency

As previously noted, buildings currently account for 74% of electricity use, and space conditioning drives peak summer and winter demand in many areas, thus increasing grid infrastructure costs. Energy-efficient buildings are therefore essential to ensuring affordable, healthy, comfortable, and resilient indoor environments for occupants, while reducing emissions, energy use, and electricity demand.

More importantly, government efforts are needed to scale up regionally. In the United States, as previously described, the Blueprint for Decarbonizing the Building Sector aims to reduce building energy intensity

(EUI) by 35% by 2035 and 50% by 2050, compared to 2005, through increased energy efficiency in buildings. Key measures to increase energy efficiency include high-performance building envelopes (e.g., high-insulation windows, insulation, air and duct sealing) and passive building design and retrofit approaches, as well as high-performance electrical equipment and appliances (e.g., air and ground source heat pumps, Energy star appliances). Technologies to optimize ventilation rates and heat loads (e.g. energy recovery, demand-controlled ventilation, occupant sensing) are also important.

Specifically, switching to heat pumps for heating and hot water heating inherently increases the efficiency of on-site energy use (Figure 33). Efficient sealing also makes it easier to store thermal energy to preheat or precool a building to survive peak demand periods. This improvement in thermal inertia supports the broader goals of increased building demand flexibility, a modified grid edge in buildings, and 100% clean electricity.

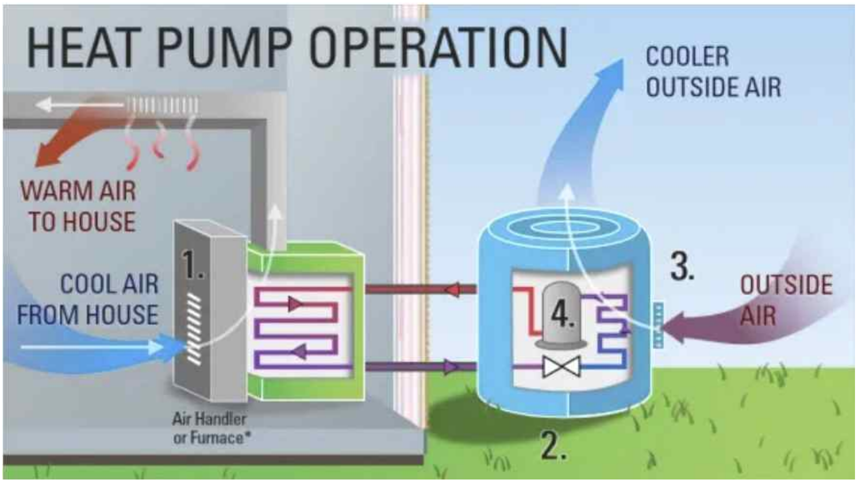

Figure 33. Heat pump operation (in the winter)
(source: EPA, ENERGY STAR Certified Products. https://www.energystar.gov/products/ask-the-experts/how-does-heat-pump-work)

There are also ongoing efforts by the international community, including the United Nations, and major industrialized countries to improve the energy efficiency of buildings (The Economist, 2022). The UN has set several ambitious targets for sustainability in construction. For example, the target reduction in the energy intensity of buildings per square metre will be around 30% by 2030, as defined by the Paris Agreement. The EU has mandated that all new buildings be ‘almost ZEB’ and have an ‘Energy Performance Certificate (EPC)’ from 2021. The UK has passed legislation requiring new homes to produce at least 75% less carbon from 2025. The Italian government has announced it will cover the full cost of green renovations and provide an additional tax credit of up to €100,000 ($104,000) per home. The Netherlands has required a full-life carbon assessment for some large buildings since 2013.

In the US, California imposes carbon intensity limits on certain building materials. The city of Los Angeles aims to have all buildings carbon-free by 2050. New York State supports the Net Zero Housing Program to design low-rise residential buildings with a variety of technologies, such as renewable energy facilities and energy savings, and aims for carbon-free electricity by 2040.

South Korea will require new buildings with 30 or more households to have a 20% energy self-sufficiency rate from 2025 and provide incentives such as a floor area ratio. For existing buildings, a 3% subsidy and tax exemption are provided for green remodeling.

5. Conclusion and Limitations

The supply chain of the construction industry is very complex due to the changing partners for each project, the life cycle divided into planning, design, and operation stages, material production and transportation, and multi-stage construction structure. In addition, innovation toward zero carbon emissions by 2050 is slow due to chronic decline in productivity. However, the demand for eco-friendliness due to climate change is becoming more urgent, and the integration of digital technologies is starting to bring about inevitable changes across the industry.

According to Global Construction Perspectives, the construction market size is expected to continue to grow from $13.7 trillion in 2023 to $16.5 trillion in 2030. In this growing global market, companies that can achieve the eco-friendly goal of reducing embodied carbon emissions through innovation across the supply chain are likely to lead the global market. In addition, the growth potential of operators specializing in designs that meet the increasingly stringent regulations for building operations, such as zero-energy buildings, is very high. Therefore, I believes that it is important for the government to support market-leading construction companies to take the lead in changing the building sector to achieve carbon neutrality.

However, the following limitations should be taken into account when promoting carbon neutrality in the building sector. Energy regulations will continue to reduce the energy intensity of the entire U.S. building stock by improving the energy efficiency of new buildings, but the Building Sector Blueprint (2024) estimates that 75% of the current residential building stock and 51% of the existing commercial stock will remain the same in 2050. Energy regulations generally do not apply to existing buildings or only to large-scale renovation projects.

Moreover, many buildings are not eligible for existing energy efficiency and wind protection programs or related financial incentives due to mold, asbestos, lead paint, or structural problems. According to DOE et al. (2024), nationwide, more than 11 million homes had water leaks through their roofs, basements, walls, windows, or doors last year, and nearly 4 million homes had mold. Therefore, it is necessary to simultaneously pursue measures to solve the basic structural problems of existing buildings and improve energy efficiency, and in this regard, policy support for renovation and expansion, such as green remodeling, is important.

V. Urban and Regional Carbon Neutrality Strategies = Buildings+Transportation+α

1. Carbon neutrality response strategy in the urban sector

The carbon neutrality strategy at the city and regional level is not simply the sum of the carbon neutrality blueprints for the transportation and building sectors discussed above. It should be a macroscopic spatial strategy that serves as the basis for decarbonization of the entire city. The strategies at the city and regional levels should cover key carbon-emitting sectors such as transportation, buildings, industry, and power generation, and create carbon sinks. More demand-friendly policies should be established to ensure the quality of life of local residents.

There has been active research on carbon neutral strategies at the city level recently. According to Seto, K. C. (2023), to achieve deep decarbonization, cities should implement and integrate the following three broad strategies. First, reducing energy and material demand in cities: (i) integrating spatial planning to reduce automobile transportation demand, (ii) improving the efficiency of individual sectors such as buildings, transportation, and wastewater treatment, and (iii) promoting industrial symbiosis to use waste or by-products from one industry as inputs to other industrial processes, thereby eliminating waste and reducing the demand for additional raw materials and associated emissions. Second, transitioning urban energy supply to net zero carbon: (i) electrification of key urban activities such as power grids, mobility, heating and cooking systems, (ii) carbon valorization using captured CO_2 as a chemical feedstock to make consumer products such as plastics, fertilizers and alcohol, (iii) electric vehicles should be an integral part. Third, increasing urban carbon absorption and storage can be achieved through (i) carbonation of cementitious materials, and (ii) carbon sequestration by plants.

In addition to the Seto (2023) paper, when looking at various sources, I think the most important strategies for each section are as follows.

First, in terms of transportation, it is important to induce the use of public transportation and eco-friendly means of transportation such as bicycles and walking through rational city design and regional-level policies. In order to expand the supply of eco-friendly vehicles such as electric and hydrogen cars, it is also important to sufficiently build electric and hydrogen car charging infrastructure around the city. We need urban designs that significantly reduce carbon emissions, such as by securing logistics facilities close to city centers to enable more energy-efficient freight transport or by utilizing inland ports. And it is possible to introduce regional regulation zones that encourage regulation and replacement of old diesel vehicles with high emissions, which are being implemented in Seoul.

In the building sector, it is possible to introduce city regulations that mandate eco-friendly buildings with improved energy efficiency. In addition to new buildings, it is necessary to promote the remodeling of existing buildings to strengthen insulation, install high-efficiency heating and cooling systems, and introduce smart energy management systems. In areas with many aging buildings, it is necessary to adopt a strategy that revitalizes the city while also ensuring energy efficiency by utilizing urban development and remodeling. In particular, when constructing or renovating buildings, as previously emphasized, it is possible to consider introducing policies that allow buildings to produce energy on their own and minimize consumption by applying the zero-energy building standards.

In addition, urban and regional policies can play an important role in expanding the introduction of renewable energy in the power generation sector. Possible options include installing solar panels on roadsides, installing solar panels on building rooftops depending on the climate, or introducing wind power plants to surrounding areas to secure renewable energy. In addition, a smart grid system that can monitor and optimize energy consumption and supply in the city in real time must be established to efficiently manage energy use. In particular, energy can be saved by efficiently promoting the prediction of energy demand for heating and cooling in summer and winter, and storing and utilizing renewable energy, and controlling the energy use of buildings, factories, and transportation systems in real time through IoT technology.

Meanwhile, efficient use of carbon-emitting resources and securing carbon sinks are also areas that must be included in urban policies. Various forms of energy conservation will be possible through urban design that optimizes people's movement and the placement of public infrastructure during urban planning. It is necessary to improve carbon absorption capacity by creating green spaces and forests within the city that reflect the local climate and mandating green rooftops of buildings. It is also important to introduce regulations that take carbon emissions into account when using land in agriculture and other industries.

Finally, regional carbon emission regulations or carbon taxes can be introduced, and the central and local governments can work together to raise public awareness of carbon neutrality through citizen participation, education, and campaigns.

2. Carbon Neutrality Strategies for Cities and Regions in the United States

The direction of city and regional policies for carbon neutrality can also be found in the US National Blueprint for Carbon Neutrality. The first strategy of the Transportation Blueprint (2023) is to improve convenience by implementing system-level and design solutions, which is in the same context as designing cities to respond effectively to carbon neutrality.

Let’s take a closer look at the key policy directions that have great implications in the Blueprint (2023). First, to improve convenience by changing land use planning and transportation system design at the city and regional level. A key strategy is to strategically locate job centers, shopping, schools, entertainment, and essential services near where people live, thereby reducing commuting burdens, improving walking and cycling accessibility, and improving quality of life. More compact cities and towns with a close mix of commercial, residential, and civic uses can reduce the distance between where people live, work, and play, making active transportation and transit more viable and reducing the time people are stuck in traffic.

Reducing transportation emissions also begins with understanding and addressing the factors that influence travel demand and optimizing the number of trips needed to provide reliable access to services and distribute freight to meet the mobility needs of all Americans. Supporting land use strategies and planning practices that enable clean transportation solutions will improve the mobility of people and goods, make it easier for people to access jobs and housing opportunities, community services and entertainment options, and bring other environmental, health, economic, and community benefits.

Second, new technologies must be combined with improved mobility and accessibility to reduce emissions. Telecommuting, the sharing economy, and e-commerce are changing our lives and the way we access goods and services. Mobile applications can more seamlessly integrate multiple travel options—public transportation, e-bike and scooter options, and multimodal freight—on a single platform. Forward-thinking policies and management at the transportation system level are needed to ensure that new technologies improve quality of life and reduce emissions.

Third, prioritize investments in infrastructure modifications and modernization projects that improve existing infrastructure before building new infrastructure, avoiding the need to expand road capacity further. Investing in expanding road capacity increases maintenance costs and creates additional trips, which increases emissions. Additionally, according to DOT (2023), expanding capacity generally has limited or no long-term benefit in reducing congestion. To achieve climate goals by prioritizing repairing and modernizing existing infrastructure, DOT's Federal Highway Administration (FHWA) issued guidance in December 2021 encouraging states and other grantees to prioritize repairing, rehabilitating, and modernizing existing roads and bridges over capacity expansion using newly available resources.

Fourth, states and localities can reform local regulations and zoning policies to increase housing supply in walkable and transit-oriented areas. Local zoning reforms can address the critical need to expand housing supply while simultaneously enabling a wider range of transportation options in communities.

Fifth, reduce travel demand and encourage safe walking and biking through transportation demand management (TDM). This includes strategies such as congestion pricing and parking fees in high-traffic areas, off-hours transit fare discounts, and off-hours product delivery incentives. Smart transportation systems, for example, can help reduce congestion, optimize traffic flow, and improve people's quality of life by allowing them to spend more time with their families rather than being stuck in traffic, all while reducing GHG emissions.

Sixth, we need to address climate change using transit rights-of-way. Specifically, transit agencies can leverage existing land to host critical infrastructure such as electric vehicle charging infrastructure, electric transmission lines, and renewable energy systems with low barriers to approval. For example, over 52,000 acres of vacant roadside land at interstate exits is ideal for solar energy development, providing the potential to generate up to 36 terawatt-hours (tWh) annually, enough energy to power about 10 million passenger EVs.

Finally, strategically planting trees and shrubs is important to sequester carbon and reduce air pollution. Native plants can counteract the heat island effect, capture, filter, and absorb rainfall to protect water quality, and reduce localized flooding. This green infrastructure (trees and planted areas along streets, parking lots, and other paved areas) also beautifies neighborhoods, makes walking and biking more attractive, and manages stormwater runoff more cost-effectively than traditional infrastructure.

3. New city concepts such as Zero-carbon city and Hydrogen Cities

Zero-carbon city and New city concepts

Most cities around the world burn fossil fuels such as coal and oil as their energy source, releasing greenhouse gases into the atmosphere. According to the IEA (2021), as of 2019, cities accounted for two-thirds of all energy consumption and generated 70% of energy-related greenhouse gas emissions. According to HSBC (2019), more than 50% of the world's population currently lives in cities, and this proportion is expected to increase to 70% by 2050 and nearly 80% by 2080.

In this situation, zero-carbon cities, zero-energy towns, and hydrogen cities are being proposed as new alternatives for carbon neutrality. According to Law Insider (2022), a zero-carbon city is a city that generates as much or more carbon-free sustainable energy as it uses, and a city that minimizes carbon emissions by using renewable energy sources in a broad sense. A zero-carbon city is a city that reduces all types of carbon emissions through efficient urban design, electrification, and recycling technologies. Below, I will use cases to examine the characteristics and policy support of a new type of urban concept.

Case of Zero Energy Town

Ro, Christine (Nov 9, 2023) Introduced in Forbes, ‘Bahnstadt’, a town in Heidelberg, Germany, supplies most of its electricity from renewable energy sources. This is a representative zero energy town and a successful example of sustainable urban development. The area is a large-scale eco-friendly urban project that includes both residential and commercial spaces, and the buildings are designed to produce enough energy to be self-sufficient or consume very little energy.

Figure 34. Exterior view of the Bahnstadt building
(source: CNN, 2016, https://www.cnn.com/style/article/heidelberg-green-village/index.html)

All buildings in Bahnstadt are designed to meet the passive house standard. This standard, like the passive house characteristics described above, ensures that comfortable indoor temperatures are maintained with minimal energy consumption. Bahnstadt is the world's largest passive house district, and construction costs were reduced by installing solar panels instead of tents. In addition, high-density insulation, rooftop gardens, and eco-friendly waterways are used to create a total of 216 households living together on five floors, but the energy consumption is very low compared to conventional buildings. According to the city of Heidelberg, Bahnstadt uses at least 80 percent less energy for heating than comparable urban areas. In terms of energy-related CO_2 emissions, it is estimated that the average Bahnstadt resident produces only 6.5 percent of the average Heidelberg resident (Ro, 2023).

Bahnstadt aims to be energy self-sufficient and does not rely on the external power grid, but uses a district heating system in addition to solar energy to provide heat energy. Bahnstadt also aims to reduce dependence on cars and minimize carbon emissions by creating a bicycle- and pedestrian-oriented traffic environment. It is also connected to the center of Heidelberg by rail, making public transportation easy.

However, the unusually hot summer of 2023 has led some residents to install air conditioning due to the heat. This is proof that the designers of Bahnstadt's passive houses underestimated the extent of climate change and that the passive house's heating and cooling system was not perfect. Therefore, rather than blindly copying Bahnstadt's example, it is necessary to supplement it to suit the local climate.

Hydrogen Cities

A hydrogen city is a city that converts the city's energy supply system to hydrogen, making it eco-friendly and more sustainable. This concept aims to achieve carbon neutrality by using hydrogen as the main energy source instead of fossil fuels, through hydrogen production, storage, distribution, and use of hydrogen cars. Hydrogen energy is mainly utilized in various fields such as transportation, heating, and electricity production by introducing hydrogen fuel cells or hydrogen charging stations.

Advancing hydrogen production technology and securing economic feasibility are important. In particular, instead of decomposing fossil fuels such as methane as a hydrogen production method, hydrogen should be decomposed into fuel using renewable energy such as solar, wind, and hydropower. In addition, infrastructure for safely storing hydrogen and quickly distributing it to where it is needed is important. It is also important to actively promote zero carbon emissions from transportation vehicles such as hydrogen cars, buses, and trucks that utilize hydrogen energy, and to expand charging infrastructure (Figure 35). Ultimately, hydrogen energy is also used to supply electricity and heat within the city.

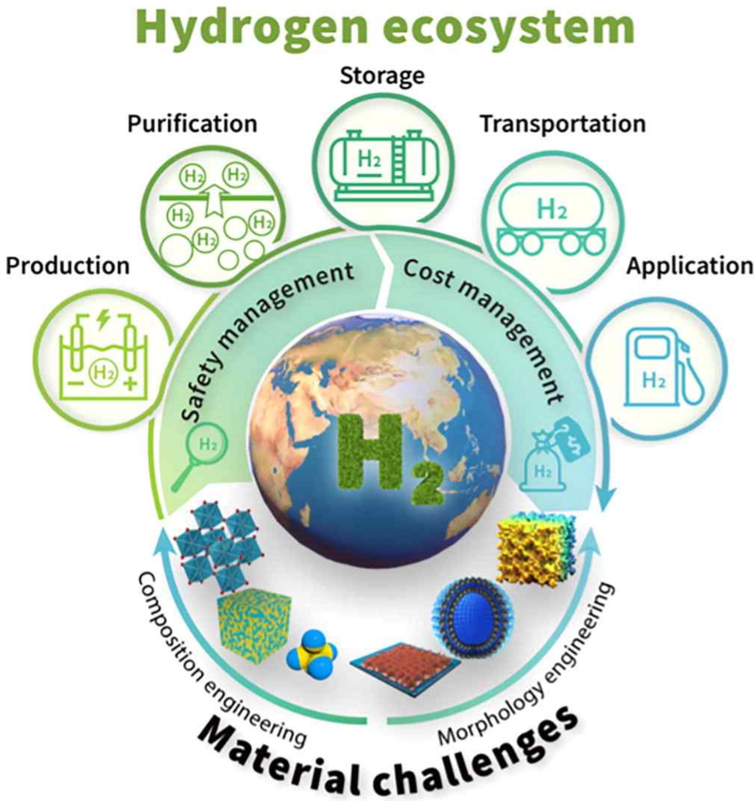

Figure 35. Hydrogen Ecosystem overview
(source: https://www.sciencedirect.com/science/article/abs/pii/S0010854523002618)

Cities such as Heidelberg, which we looked at as an example of a zero-energy town, are operating hydrogen fuel cell buses and expanding green hydrogen production and supply infrastructure. Korea is actively supporting hydrogen cities at the national level in accordance with the roadmap for revitalizing the hydrogen economy. Specifically, Ulsan, Ansan, Jeonju, and Wanju were designated as hydrogen pilot cities in 2020, and hydrogen city projects are being promoted in 12 local governments, including 6 in 2023 and 3 in 2024. The hydrogen city development project is a project to build urban infrastructure such as hydrogen production, transport/storage (pipelines, etc.), and utilization (fuel cells, etc.)

so that hydrogen can be used for housing, work, transportation, and industry, and 20 billion won in national funds will be provided.

In cities, infrastructure is being expanded to use hydrogen as an energy source in various fields such as housing, industry, and transportation. For example, in Ulsan, a hydrogen-based transportation system and a residential complex using hydrogen fuel cells are being developed. Through this, the government aims to supply 2.9 million hydrogen vehicles and install 1,200 hydrogen charging stations nationwide by 2040.

However, there are also negative views that synthetic energy carriers cannot compete with electricity due to high energy losses in the hydrogen economy, as only 20% to 25% of the source energy required for hydrogen synthesized from natural compounds can be recovered for final use by efficient fuel cells, and that producing hydrogen from fossil energy resources involves greenhouse gas emissions (Ulf Bossel, 2006). Therefore, increasing the energy efficiency of hydrogen and producing hydrogen using renewable energy resources will be key to the success of the hydrogen economy and hydrogen cities. On the positive side, some countries are increasingly using renewable energy sources to produce energy and hydrogen. For example, Iceland uses geothermal heat to produce hydrogen, and Denmark uses wind power.

VI. Conclusion

Recently, due to the unprecedented long-term heat wave in Korea, more and more people are feeling the climate change called global warming. In order to prevent rapid climate change, achieving carbon neutrality by 2050 has become an irreversible trend in order to keep the Paris Agreement that each country in the world has resolved to. This article was written to study the direction that urban policies should take to achieve carbon neutrality and share the results as training results. I analyzed carbon neutrality strategies in the transportation and building sectors for the goal of net zero greenhouse gas emissions by 2050 and carbon neutrality policies of cities and regions that encompass these, focusing on cases in the United States. I tried to write the article based on objective data and official government documents as much as possible. In addition, I used econometric analysis techniques that I acquired in my master's degree program in applied economics to examine macroeconomic factors affecting carbon emissions and the incentive effects of expanding charging stations for the adoption of electric vehicles, and I tried to record this in easy-to-understand statistical terms as much as possible.

Key strategies and implications for carbon neutrality in each sector

The key strategies for carbon neutrality in each sector that I derived through this research are as follows. The key strategies for carbon neutrality in the transportation sector are first, switching to efficient transportation, that is, promoting travel using public transportation, and second, switching to zero-emission vehicles such as electric vehicles. In particular, a policy to significantly increase charging stations to promote the adoption of electric vehicles is being implemented, and I concluded that this is effective through various literature and quantitative analyses.

The first key strategy for carbon neutrality in the building sector is increasing building energy efficiency by utilizing passive and active technologies, and the second is reducing embodied carbon emissions through decarbonization of construction materials and innovation in industry. The first key strategy for urban and regional policies for carbon neutrality is that when establishing urban design and land use plans, it is necessary to encourage the use of public transportation and zero-emission vehicles and design freight transportation efficiently. Second, it is important to install infrastructure that maximizes the use of renewable energy and secure absorbers in the city center, such as parks. Third, it is important to induce changes in the lives of local residents through zero-energy building standards that increase the energy efficiency of buildings, carbon emission regulations, and carbon taxes.

The main implications that can be obtained from these core strategies are as follows. First, achieving carbon neutrality is no longer an option but a set goal, and the race to achieve it has already begun. In particular, the development of eco-friendly industries, including the electric vehicle industry and zero-energy buildings, and the speed of technological development will be important critical points that determine national competitiveness. A good example is China, which is leading the growth of the global electric vehicle sales market, which is promoting the so-called ‘electric vehicle boom.’ China sold more than 5 million electric vehicles in 2022, and according to SNE Research (2023), from January to June 2023, China's BYD ranked first and Shanghai Automotive Industry Corporation (SAIC) ranked third in terms of global electric vehicle market sales, surpassing Tesla (second) in the United States, making it the country with the most rapid growth.

In addition, cooperation between government departments, division of roles between central and local governments, and partnerships between the private and public sectors are essential to achieve carbon neutrality. We need to follow the example of the U.S. federal government's comprehensive policy implementation method of breaking down barriers between departments. According to a press release dated December 13, 2021, the White House stated that the Departments of Transportation (DOT) and Energy (DOE) will establish a joint office to leverage the best resources, talent, and experience, including national laboratories from each agency, and that the joint office will ensure that the agencies can work together to implement the EV charging network and other electrification provisions of the bipartisan infrastructure bill. This will provide a "one-stop shop" for states, communities, industry, labor, and consumer groups in a variety of ways and for multiple audiences on EV charging and related topics, and the White House will convene and lead a series of initial stakeholder meetings on topics including partnerships with state and local governments, domestic manufacturing, equity and environmental justice, civil rights, partnerships with tribal communities, and maximizing environmental benefits. Such organic collaboration among numerous stakeholders for each mission is also essential to Korea's carbon neutral policy.

Comparison of Korea and the U.S. and Policy Direction Suggestions

The above study is a strategy derived mainly based on the case of the United States, and it is thought that there is no significant difference in the direction of carbon neutrality policies in the United States and Korea. However, it is most important to adjust the details of the policy considering the differences between the United States and Korea.

First of all, transportation sector emissions account for 29% of total

GHG emissions, the largest sector among all sectors in the U.S. (USEPA, 2021). On the other hand, according to the PCGG (2023), Korea's transportation sector emissions were approximately 14% as of 2018, the third largest sector after the power generation and industrial sectors. Direct emissions excluding indirect emissions due to electricity use in the building sector are 12.7% in the United States (USEPA, 2021) and approximately 7.6% in Korea. Korea has a high urbanization rate of 90.7% (Statistics Korea, 2024), which is higher than the United States' 82.7% (The World Factbook, 2020), and its population density is also very high at 518 (population per km^2) compared to the United States' 35. Therefore, the difference in transportation sector emissions is judged to be due to the fact that Korea has relatively low demand for transportation and movement due to the characteristics of living in small areas, and on the contrary, it can be assumed that carbon emissions in the building sector are higher due to the United States' housing culture centered on single-family homes.

As analyzed above, carbon emissions in the transportation and building sectors are very difficult to reduce due to their conservative nature, so it is difficult to say that reducing carbon emissions in Korea's land, infrastructure, and transportation sectors is less important than in the United States.

Due to these differences, I would like to propose a carbon neutrality policy in the urban sector that Korea should particularly focus on. First, we should boldly promote the spread of domestic electric and hydrogen vehicles. Due to the small size of the country, the network effect of electric vehicle charging stations can be greatly utilized. In fact, as mentioned earlier, according to the data from Stata (2020), Korea recorded the highest ratio of electric vehicles to public charging points in the world at 2:1. On the other hand, the US has only 18:1. Therefore, in the future, we need to make full use of this advantage to expand electric or hydrogen charging stations near the city center, thereby first activating the eco-friendly car market and actively supporting exports overseas.

Second, Korea has chosen new city development as the main method of housing supply, so new city development is very active compared to major advanced countries such as the US. Considering that the US is having difficulties in decarbonizing the building sector due to aging housing, this is an advantage that is advantageous to Korea. Therefore, in the new city design process, it is necessary to design public transportation-friendly and energy-efficient urban transportation and compact cities, and to reflect various factors such as performing as a test bed for new transportation technologies, mandating passive housing technology standards, reflecting new and renewable energy power generation facilities, and promoting resource circulation and recycling to make the newly created new cities carbon-neutral cities.

Third, it is necessary to further strengthen carbon sinks in the city center to compensate for overpopulation and high urbanization rates. It is impossible to reduce all carbon emissions to zero by 2050. Therefore, it is important to reduce net emissions to zero through carbon sinks. Korea, which has a very high urbanization rate, needs to create enough parks and green spaces in the city center to use them as carbon sinks. In this respect, the promotion of Yongsan Park is a very meaningful policy not only in terms of improving the quality of life of Seoul residents, but also in terms of creating a carbon sink in the city center. It is estimated that if Yongsan Park is developed to approximately 3 million m2, the annual CO2 absorption will reach 7,380 tons (Yongsan Park Development Promotion Planning Team, 2010). Yongsan Park should be made into a best practice example of parks in the city center so that it can be benchmarked in many regions.

Finally, It is necessary to promote complementary and convergent development of carbon neutrality and smart technology development by utilizing Korea's advanced information and communication technology (ICT). Along with carbon neutrality, an important global trend is the development of smart technology, also known as the 4th Industrial Revolution. The 4th Industrial Revolution is a technological innovation brought about by the convergence of ICTs, and technologies are being developed to increase industrial efficiency and add convenience to life by utilizing big data analysis, artificial intelligence (AI), and the Internet of Things (IoT). If these smart technologies are utilized, the cost of carbon neutrality can be reduced and more rapid technological development can be promoted. For example, if people's transportation habits and tendencies are analyzed using big data and applied to urban development, the most efficient transportation design for carbon neutrality can be achieved. In addition, if IoT technology is utilized in various facilities where energy is used to detect and manage energy usage, energy savings can be achieved. Another example is when constructing a building, if efficient construction is achieved through design and planning using BIM (Building Information Modeling), carbon emissions can be reduced while also reducing costs. Policymakers therefore need to work with an eye on what policies can accommodate both carbon neutrality and the development of smart technologies.

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