# 탄소중립 추진 과정에서 바람직한 경제·산업 구조 개편전략 연구

**1. Comparative Analysis of GHG Emissions Factors between South Korea and Major European Countries**

**2. Desirable Directions for Energy Transition Policy to Achieving Carbon Neutrality in South Korea : Lessons from Advanced Countries**

**2024 년 6 월**


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# 국외 훈련 개요

1. 훈련국가: 영국

2. 훈련기관명: 엑서터 대학교
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3. 훈련분야: 공공행정

4. 훈련기간: 2022. 8. 31. ~ 2024. 6. 30.

# Comparative Analysis of GHG Emissions Factors between South Korea and Major European Countries

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## 1. Introduction

As global awareness of the severity of the climate change grows, countries worldwide are actively advocating for policies to reduce greenhouse gas (GHG) emissions. Recently, many countries have tried to achieve 'carbon neutrality', whereby they strive to eliminate net carbon emissions from a specific moment onward. Up to now, more than 150 countries have already declared a carbon neutrality goal, although the time of accomplishment or form of declaration differs from country to country (Net Zero Tracker, 2023). In line with these global movements, South Korea is also becoming more proactive in its approach, including setting a goal of achieving carbon neutrality by 2050. To attain this goal, the South Korean government established the 2050 carbon neutrality scenario and enhanced the Nationally Determined Contribution (NDC) by 2030 as an interim goal (Jointly with Relevant Ministries, 2021a; 2021b). In terms of the institutional aspects, the Framework Act on Carbon Neutrality and Green Growth was enacted in 2021 as the legal background and the Carbon Neutrality Commission was established in 2021 as a control tower that oversees related policies.

When examining the global trend more closely, not all countries respond to climate change issues the same way. It varies among countries due to differences in their economic situations, technological advancement, and political environment. Guy, J. et al. (2023) identify four national governance models for climate change response by analysing the policy goals, implementation system, and climate narrative of 21 major emitters: Climate Technocracies, Climate Developmentalists, Carbon Fragmentists and Carbon Centralists (2023, pp. 190-192). Under this classification, South Korea is grouped as Climate Developmentalists along with China, India, and Brazil. The Climate Developmentalists are characterised by their efforts to incorporate climate change responses into broader schemes for state-led development. Their policy narratives primarily centre around fostering economic growth and energy security (Guy, J. et al., 2023, p. 191).

A recent discussion in South Korea shows these characteristics of Climate Developmentalists. For countries like South Korea, which has a manufacturing-driven industrial structure with high energy consumption, the goal of carbon neutrality presents a formidable challenge. In the process of developing concrete implementation strategies, reducing GHG emissions in the manufacturing sector is emerging as a critical priority. There is considerable concern that the rapid implementation of carbon neutrality measures will have a negative impact on the country's industrial competitiveness. Some argue that the rapid restructuring of the industrial sector is nearly impossible to achieve in a short period of time, and that a large amount of GHG emissions is somewhat unavoidable in the current industrial structure. Reflecting these concerns, the South Korean government has recently partially eased the 2030 reduction target for the industrial sector set by the previous administration[1] (Jointly with Relevant Ministries, 2023, p. 21).

Generally, it is widely acknowledged that manufacturing-oriented industries negatively impact GHG emissions levels because of their high energy consumption. **However, it is difficult to definitively answer to what extent an impact this will have.** For example, it is challenging to answer even the simple question, "How much is the share of this industry in the total GHG emissions?". This is because the subcategories of national GHG emissions statistics are not in accordance with the industrial classification system such as ISIC (International Standard Industrial Classification) since the GHG emissions statistics are classified and provided by emission sources such as 1) Energy, 2) Industrial Processes, 3) Agriculture, 4) Land Use, Land Use Change and Forestry (LULUCF), 5) Waste.

**In addition, from a dynamic perspective, it is also unclear whether the country's current industrial structure is a critical factor in accomplishing future emission reduction.** For

[1] In April 2023, the Korean government modified the GHG reduction target by 2030 (compared to 2018 emissions) for the industrial sector from -14.5% to -11.4% while maintaining the overall GHG reduction target (-40% compared to 2018).

example, saying, "Our country's greenhouse gas emissions level is relatively high due to high share of manufacturing" and "Reducing greenhouse gas emissions is demanding in our country due to high share of manufacturing" have different meanings. The former is likely to be true, but the latter may not necessarily be true. However, in many countries, including South Korea, these two are often used interchangeably without clear differentiation.

Given this context, this study focuses on two analyses. **First, the study attempts to produce GHG emissions statistics of industrial sub-sectors for major countries** by using the current GHG emissions statistics and energy consumption statistics. Emission statistics of industrial sub-sectors provide an important basis for further analysis. **Second, the study tries to figure out the degree of impact of various factors, including industrial structures, on the time series changes in GHG emissions.** Through this analysis, the study looks for implications for South Korea's future GHG reduction policies by comparing and analysing the cases of leading advanced European countries that have successfully reduced GHG emissions.

The rest of the study is organized as follows. Chapter 2 introduces prior research on the factors that affect GHG emissions change. Chapter 3 explains the detailed methodology, including the data used. Chapter 4 is the main body of this study, presenting the primary results of analysis and discussions. Finally, Chapter 5 concludes the study and provides brief policy implications.

## 2. Literature Review

With the growing significance of addressing climate change, many studies have been conducted to identify the factors and their contribution to GHG emissions change. In particular, Ang (1994, 1997, 2005) provided the guidelines for the utilization of the LMDI (Logarithmic Mean Divisia Index) methodology through multiple research endeavours. The LMDI approach facilitates the decomposition analysis of factors influencing energy consumption and GHG emissions. These factors are mainly composed of activity effect, structure effect and intensity effect. According to his study, the increase in energy consumption in Canada from 1990 to 2000 was mainly affected by the activity effect, and the structure effect and energy intensity effect acted as factors that reduced energy consumption (Ang, 2005, pp. 867- 869).

Since Ang established the LMDI approach, various applied studies have been conducted based on this, varying the target countries, analysis period, and decomposition factors. Hamilton and Turton (2002) analysed the growth factors in energy-related $CO_2$ emissions for OECD countries over the period 1982-1997. The study mainly focuses on the signatories to the Kyoto Protocol and employs a decomposition formula composed of population, economic growth, energy intensity and the share of fossil fuels. The study shows that across the OECD as a whole, the increase in $CO_2$ emissions is mainly driven by economic growth (both GDP per capita and population growth), offset by declines in energy intensity and the share of fossil fuels. In addition, country-based analysis shows that some countries, such as Japan, have experienced exceptional increases in energy intensity.

Fernandez Gonzalez et al. (2014) analysed changes in $CO_2$ emissions for 27 EU countries from 2001 to 2008 by utilizing the decomposition formula composed of population, GDP per capita, energy intensity, fuel mix and emission factor. The study identifies that for the EU as a whole, $CO_2$ emissions decreased as improvement in energy intensity and fuel mix offset the increasing pressures from population and economic growth, but only 13 out of 27 countries (mostly Western economies) experienced $CO_2$ reductions. The authors assess that despite the EU's common goal of sustainable development, only a few countries appear to have implemented serious efforts in this field. They suggest that Mediterranean and ex-communist members should increase R&D investment in energy-saving technologies, production process improvement, and structural composition changes.

Among these studies, there is a prevailing consensus that the effect caused by economic growth has the most significant influence on the increase in GHG emissions, while improvements in intensity, such as energy consumption per product unit, work to offset this growth effect. By country, major European countries, driven by strong environmental concerns and early action, have successfully achieved both expansion of their economies and reduction of GHG emissions through a decrease in energy and emission intensity. On the other hand, countries experiencing a continuous rise in GHG emissions face relatively more significant challenges in effectively managing the pressure of emission increases from ongoing economic expansion.

Since national GHG emissions statistics do not provide emissions data of individual industrial sectors, most studies on GHG emissions factors have been conducted, excluding the industrial structure effect. Although there have been several studies including the structure effect, they have been conducted mainly on limited sectors such as energy and manufacturing rather than total national GHG emissions.

Mendiluce, M. et al. (2010) analysed changes in energy intensity for Spain and other 15 EU countries over the period 1990-2006 by classifying industry into 16 sub-sectors. Spain's energy intensity increased during the analysis period, unlike the 15 other EU countries. The study identifies that the increase in energy intensity in Spain is mainly due to the rise in the share of transportation and the increase of energy intensity in major industrial sectors such as non-metallic minerals, basic metals and chemicals.

Zhao et al. (2014) analysed the energy consumption of the manufacturing sector for Japan and China during the 1980-2010 period. The study shows that the energy intensity has significantly improved in both countries but for slightly different factors. The structural effect significantly reduced the energy intensity of the Japanese manufacturing industry while having a relatively small influence on Chinese manufacturing. The study also explains the findings in relation to the country's policies, emphasizing that the efficacy of national energy policies holds a significant role in enhancing energy efficiency.

Liu et al. (2015) analysed changes in carbon intensity in China from 1996 to 2012 by dividing the industry into 12 sub-sectors. The study explains that energy intensity improvement is the most significant factor in reducing carbon intensity, whereas the impact of structural changes did not hold substantial importance. Furthermore, the study suggests restructuring the industry around low-carbon sectors and expanding renewable energy use as a policy direction to reduce China's carbon intensity.

Although there are not many, related research has also been conducted on South Korea. Jeong and Kim (2013) analysed the $CO_2$ emissions changes in South Korea's manufacturing industry from 1991 to 2009 by quantifying the contributions from changes in five factors: overall industrial activity (activity effect), industrial activity mix (structure effect), energy intensity effect, energy-mix effect and $CO_2$ emission factors. The sub-sectors of the manufacturing industry for deriving structure effect were composed of nine. The study explains that the structure and energy intensity effects reduced emissions, and the activity and energy mix effects increased emissions in South Korea. Furthermore, by conducting a time series analysis, the study also shows that the factors affecting $CO_2$ emissions exhibited distinct trends before and after the IMF period (1997-1998).

Park and Kim (2013) analysed energy consumption changes in South Korea and Japan during the 1990-2009 period by decomposing the contributions into three factors: activity effect, structure effect, and intensity effect. The study shows that the structure effect and intensity effect played a role in reducing energy consumption in both countries, but to different extents. The intensity effect was greater than the structure effect in South Korea, whereas the structure effect was greater than the intensity effect in Japan.

Park and Shim (2015) analysed GHG emissions change in South Korea from 2004 to 2011 by dividing the industrial sector into 18 sub-sectors. The study shows that even within the same industry, the factors affecting GHG emissions change differ depending on the specific sub-sector, and thus emphasizes the need for differentiated policy responses for specific sub-sectors. In addition, in terms of methodology, they allocated the emissions from power generation to sub-sectors by using the proportion of each sector's electricity consumption. This method is also used in this paper to obtain GHG emissions statistics of industrial sub-sectors.

**Considering the existing studies, this study is significant in two aspects. First, this study aims to analyse and compare the factors that affect GHG emissions in South Korea and advanced European countries.** Most of the research on South Korea's GHG emissions so far has only dealt with South Korea itself. Through comparative analysis with advanced European countries, it is possible to obtain implications for the future policy direction that South Korea should pursue.

**Second, this study attempts industrial sub-sector analysis by using GHG data from the UNFCCC (Greenhouse Gas Inventory) submitted by each country.** Most of the studies that have attempted industrial sub-sector analysis take the method of calculating sectoral emissions by multiplying each energy source's sectoral consumption and emission factor. In contrast, this study tries to allocate national GHG statistics by sector and complements it by using energy consumption statistics. The detailed methodology is described in the following chapter.

# 3. Methodology

### *3.1 Overview and Data*

This study identifies the factors of GHG emissions changes from 1995 to 2020 for four countries: Korea, the UK, Germany, and France. While it would have been desirable to include a broader range of countries for analysis, the limitation of available data and time constraints restricted the number of countries. The analytical work of this study is composed of two parts. The first part is to estimate the country's GHG emissions by the industrial sub-sector. The second part decomposes the GHG emission factors. The following section provides a detailed explanation of each task. Table 1 indicates the primary data used for this work.

First, the 'value added and its components by activity' data from the Organization for Economic Cooperation and Development (OECD) are used to identify the industrial structure of each country. All the data are in constant prices to exclude the price factor, and the base year is 2015. When comparing data between countries, the values are converted from domestic currency into U.S. dollars by using the official exchange rate in 2015. In the case of South Korea, the data from the Korean Statistical Information Service (KOSIS) are also used since the data from the OECD is not sufficiently subdivided by sectors. The GHG inventory data from the United Nations Framework Convention on Climate Change (UNFCCC) is the primary source of national GHG emissions. In the case of the U.K., Germany and France, all detailed values for each subcategory can be obtained from UNFCCC's data. For South Korea, the data from the Ministry of Environment is also used. As South Korea is a Non-Annex I country of the framework, the data reported to the UNFCCC does not contain detailed contents. However, apart from this, South Korea produce and announce detailed GHG emissions statistics based on the same guidelines of UNFCCC[2]. All the energy-related statistics are from the International

[2] IPCC (2006), *Guidelines for National Greenhouse Gas Inventories*

Energy Agency (IEA)'s Energy Balance 2022. Energy consumption data are required to allocate GHG emissions data to industrial sub-sectors and calculate the energy intensity (energy consumption/value added) and the emission intensity (GHG emissions/energy consumption), which are used for decomposition analysis of GHG emissions factors.

**Table 1**
Data sources for analysis

| Data | Sources | Notes |
|---|---|---|
| Value added and its components by activity | OECD.Stat<br><br>Korean Statistical Information Service (KOSIS) | Basic data of industrial structure (2015 constant price) |
| National GHG emissions | UNFCCC GHG Inventory<br><br>Ministry of Environment (South Korea) | Basic data of GHG emissions |
| Final Energy consumption | Energy Balance 2022 (IEA) | Use for allocating indirect GHG emissions by sectors |

### *3.2 Estimation of GHG emissions by sub-sectors*

As stated above, the current subcategories of GHG emissions statistics are not in accordance with the industrial classification system. So, the initial step of estimating GHG emissions by industrial sub-sector is determining the classification standards for detailed industries. Considering the feasibility of aligning the available data, this study classifies industries into 14 sub-sectors, including nine sub-sectors within the manufacturing sector (see Table 2). The work process to obtain GHG emissions statistics by industry is as follows:

First, directly match subcategories that are similar to the International Standard Industrial Classification System (ISIC Rev.4) by referring to the reporting guidelines on GHG emissions.

And then, allocate other subcategories to individual industries by using IEA's sectoral energy consumption statistics. For example, GHG emissions from 'public electricity and heat production' (1.A.1.a of GHG inventories), which accounts for a high proportion of the total GHG emissions, is distributed to the industrial sub-sectors according to each industry's final electricity and heat usage. GHG emissions from activities unrelated to the industrial sectors, such as residential usage, car transportation and waste, are excluded from the allocation. Lastly, other minor GHG emission statistics, such as LULUCF (Land Use, Land-Use Change and Forestry), are also excluded. GHG emissions statistics calculated in this process enable the determination of the amount of emissions produced by a particular industrial sector in different countries. While some variation exists among countries, the sum of the estimated GHG emissions allocated to the sub-sectors covers about 60 to 80 percent of the total GHG emissions of each country and shows almost the same movement to the total emissions (See Fig. 1).

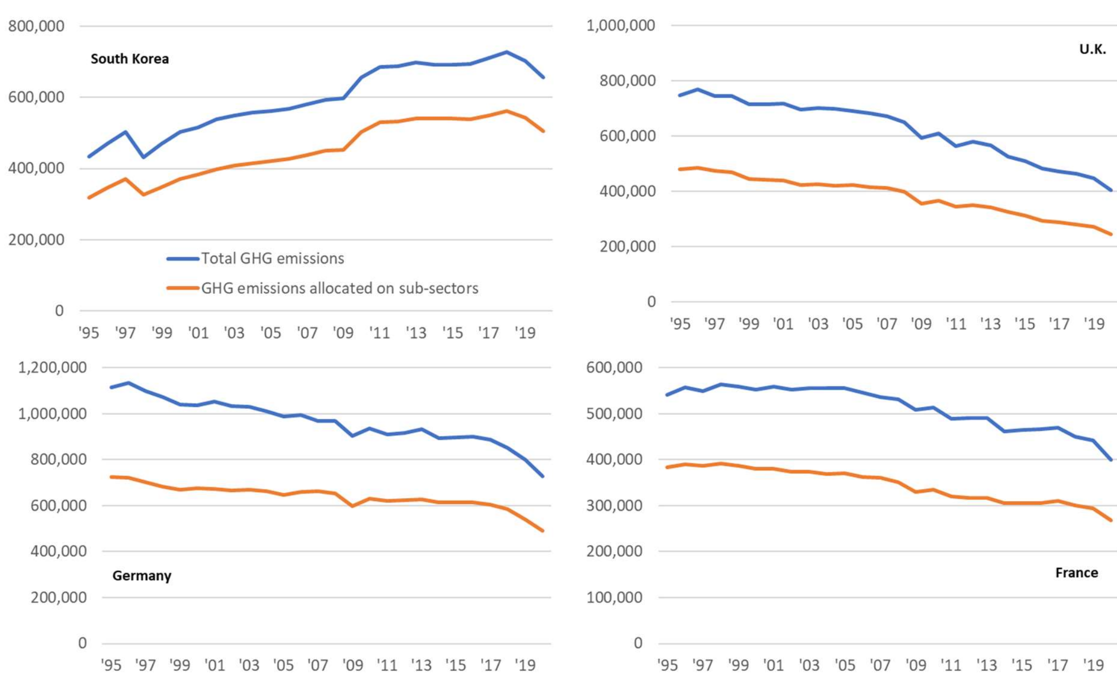


**Fig. 1**. Total GHG emissions and Emissions allocated on sub-sectors (Kt $CO_2$ eq).

**Table 2**
Classification of industrial sub-sectors

| Value added and its components by activity (OECD, ISIC rev4) | | Green House Gases Inventory (UNFCCC) | Energy Balance (IEA) | Final taxonomy |
|---|---|---|---|---|
| **Agriculture, forestry and fishing** | Agriculture, forestry and fishing | 1.A.4.c Agriculture/Forestry/Fishing<br>3. Agriculture | Agriculture/Foestry | **1. Agriculture/Forestry/Fishing** |
| | Forestry and logging | | | |
| | Fishing and aquaculture | | Fishing | |
| **Mining and quarrying** | | 1.A.1.c Manufacture of Solid Fuels and Other Energy Industries<br>1.B.1 Solid Fuels | Mining and Quarrying | **2. Mining and Quarrying** |
| **Manufacturing** | food products, beverages and tobacco products | 1.A.2.e Food Processing, Beverages and Tobacco | Food and Tobacco | **3. Food and Tobacco** |
| | textiles, wearing apparel, leather and related products | 1.A.2.g.vi Textile and Leather | Textile and Leather | **4. Textile and Leather** |
| | wood and paper products: printing | 1.A.2.g.iv Wood and Wood Products<br>1.A.2.d Pulp, Paper and Print | Wood and Wood products<br>Paper, Pulp and Print | **5. Wood and Paper** |
| | coke and refined petroleum products | 1.A.1.b Petroleum Refining | Chemical anc Petro Chemical | **6. Chemical anc Petro Chemical** |
| | chemicals and chemical products | 1.A.2.c Chemicals | | |
| | basic pharmaceutical products and preparations | 2.B Chemical Industry | | |
| | rubber and plastics products | 1.B.2 Oil and Natural Gas and Other Emissions | | |
| | other non-metallic mineral products | 1.A.2.f Non-metallic Minerals<br>2.A Mineral Industry | Non-metalic minerals | **7. Non-metalic minerals** |
| | Manufacture of basic metals | 1.A.2.a Iron and Steel | Iron and Steel | **8. Iron and Steel/Non-ferrous metals** |
| | fabricated metal products, except machinery and equipment | 1.A.2.b Non-Ferrous Metals<br>2.C Metal Industry | Non-ferrous metals | |
| | computer, electronic and optical products | 1.A.2.g.i Machinery | Machinery | **9. Machinary** |
| | electrical equipment | | | |
| | machinery and equipment n.e.c. | | | |
| | transport equipment | 1.A.2.g.ii Transport Equipment | Transport Equipment | **10. Transport Equipment** |
| | Other manufacturing, repair and installation of machinery and equipment | 1.A.2.g.viii other | Other Manufacturing | **11. Other Manufacturing** |
| **Construction** | | 1.A.2.g.v Construction | Construction | **12. Construction** |
| Transportation and storage | | 1.A.3 Transport | Transport | **13. Transport** |
| Wholesale and retail trade, repair of motor vehicles and motorcycles<br>Accommodation and food service activities<br>Information and communication<br>Financial and insurance activities<br>Real estate activities<br>Professional, scientific and technical activities<br>Administrative and support service activities<br>Public administration and defence, compulsory social security<br>Education<br>Human health and social work activities<br>Arts, entertainment and recreation<br>Other service activities<br>Act. of HH as employers, undif. G&S-producing activities of HH for own use | | 1.A.4.a Commercial/Institutional | Commercial and Public Service | **14. Commercial and Public Service** |

* Written by author with reference to Jin, T. et al. (2020)

### *3.3 Decomposition analysis*

This study employs the LMDI (Logarithmic Mean Divisia Index) approach, which is most widely used in the field to identify each factor's contribution to GHG emissions changes. The LMDI approach starts with setting the identity equation of the object to be decomposed. This study decomposes the factors affecting GHG emissions into four factors. The first factor is the activity effect. It means that GHG emissions increase as the production activity of the economy increases. The second factor is the structure effect, which means the GHG emissions change caused by the alteration of each industrial sector's share in total production. The third factor is the energy intensity effect. This means the change in GHG emissions according to the change in energy used to produce a unit of output in specific industrial sectors. The last factor is the emissions intensity effect, which represents the impact of a change in emissions per unit of energy consumption on the total GHG emissions. Thus, the identity equation of this study is formed by multiplying total production ($Q$), production share ($S_i$), energy intensity ($I_i$), and emissions intensity ($U_i$) of the industrial sector, as shown in the formula below.

$$C = \sum_i C_i = \sum_i Q \times \frac{Q_i}{Q} \times \frac{E_i}{Q_i} \times \frac{C_i}{E_i} = \sum Q \; S_i \; I_i \; U_i$$

**Table 3**
Variables used in GHG emissions change analysis

| | |
|---|---|
| $C$ = total national GHG emissions | $C_i$ = GHG emissions of *i* industrial sector |
| $Q$ = total national output | $Q_i$ = output of *i* industrial sector |
| $E_i$ = energy consumption of *i* industrial sector | |

By using this identity equation, the changes in GHG emissions between two specific time points can be decomposed into each effect. The LMDI decomposition analysis includes two methods: additive and multiplicative decomposition. The additive decomposition shows the absolute value of each factor's contribution to the changes in GHG emissions compared to the base year. So, the sum of each effect equals the total GHG emissions change during the whole period. The multiplicative decomposition shows the relative contribution rate of each factor to the change in GHG emissions. So, multiplying the effects of each factor goes to the overall rate of change in GHG emissions. The LMDI formula for each decomposition method is as follows (see Table. 4).

**Table 4**
LMDI formula for decomposing changes in GHG emissions

| | Additive decomposition | Multiplicative decomposition |
|---|---|---|
| Total Effect | $\Delta C_{tot} = C^T - C^0 = \Delta C_{act} + \Delta C_{str} + \Delta C_{int} + \Delta C_{emi}$ | $\Delta D_{tot} = D^T / D^0 = \Delta D_{act} \times \Delta D_{str} \times \Delta D_{int} \times \Delta D_{emi}$ |
| Effect by Factor | $\Delta C_{act} = \sum_i \frac{C_i^T - C_i^0}{\ln C_i^T - \ln C_i^0} \ln(\frac{Q^T}{Q^0})$ | $\Delta D_{act} = \exp\,(\sum_i \frac{(C_i^T - C_i^0)/(\ln C_i^T - \ln C_i^0)}{(C^T - C^0)/(\ln C^T - \ln C^0)} \ln(\frac{Q^T}{Q^0}))$ |
| | $\Delta C_{str} = \sum_i \frac{C_i^T - C_i^0}{\ln C_i^T - \ln C_i^0} \ln(\frac{S_i^T}{S_i^0})$ | $\Delta D_{str} = \exp\,(\sum_i \frac{(C_i^T - C_i^0)/(\ln C_i^T - \ln C_i^0)}{(C^T - C^0)/(\ln C^T - \ln C^0)} \ln(\frac{S_i^T}{S_i^0})$ |
| | $\Delta C_{int} = \sum_i \frac{C_i^T - C_i^0}{\ln C_i^T - \ln C_i^0} \ln(\frac{I_i^T}{I_i^0})$ | $\Delta D_{int} = \exp\,(\sum_i \frac{(C_i^T - C_i^0)/(\ln C_i^T - \ln C_i^0)}{(C^T - C^0)/(\ln C^T - \ln C^0)} \ln(\frac{I_i^T}{I_i^0}))$ |
| | $\Delta C_{emi} = \sum_i \frac{C_i^T - C_i^0}{\ln C_i^T - \ln C_i^0} \ln(\frac{U_i^T}{U_i^0})$ | $\Delta D_{emi} = \exp\,(\sum_i \frac{(C_i^T - C_i^0)/(\ln C_i^T - \ln C_i^0)}{(C^T - C^0)/(\ln C^T - \ln C^0)} \ln(\frac{U_i^T}{U_i^0}))$ |
| | $\Delta C_{act}, \Delta D_{act}$ : Activity effect | $\Delta C_{str}, \Delta D_{str}$ : Structure effect |
| | $\Delta C_{int}, \Delta D_{int}$ : Energy intensity effect | $\Delta C_{emi}, \Delta D_{emi}$ : Emissions intensity effect |

* Written by author with reference to Ang, B.W. (2005)

Table 5 shows the hypothetical analysis results that can be derived through the LMDI formula in Table 4. In the example below, the additive decomposition result indicates that GHG emissions increased by 70,645 Kt $CO_2$eq during the period. The activity effect, energy intensity effect and emission intensity effect accounted for the 52,208 Kt $CO_2$eq, 26,037 Kt $CO_2$eq, and 2,837 Kt $CO_2$eq increase, respectively, whereas the structure effect affected -10,438 Kt $CO_2$eq decrease. The sum of all factors' effects equals the total rise in GHG emissions. The multiplicative decomposition result can be interpreted as follows. Total GHG emissions increased by 29% during the period. The activity effect contributed to an increase of 20.4%, the energy and emissions intensity effect contributed to 9.7% and 1.0%, respectively, while the structure effect contributed to a decrease of 3.6%. Multiplying the effects of each factor equals the total increase rate of GHG emissions.

**Table 5**

Sample Result of LMDI Decomposition Analysis of GHG Emissions (unit: Kt $CO_2$eq)

| | Activity effect ($\Delta C_{act}$ / $\Delta D_{act}$) | Structure effect ($\Delta C_{str}$ / $\Delta D_{str}$) | Energy intensity ($\Delta C_{int}$ / $\Delta D_{int}$) | Emission intensity ($\Delta C_{emi}$ / $\Delta D_{emi}$) | Total effect |
|---|---|---|---|---|---|
| Additive | 52,208 | -10,438 | 26,037 | 2,837 | 70,645 |
| Multiplicative | 1.204 | 0.964 | 1.097 | 1.010 | 1.29 |

## 4. Results and discussion

### *4.1. Overview of trends in GHG emissions*

This section examines the GHG emissions trends and industrial structure of selected countries prior to discussing the analysis result. Fig. 2 shows the trend of the total GHG emissions of selected countries. In 1995, the total GHG emission was highest in Germany, followed by the U.K., France and South Korea. Since then, GHG emissions have steadily decreased since 1996 in the U.K. and Germany, and since 1998 in France. Compared to peak levels, emissions in the U.K. are down by -47.3%, in Germany by 35.7%, and in France by -29.2%. On the other hand, South Korea's GHG emissions continued to rise until 2018, increasing by 67.6% compared to 1995. South Korea's GHG emissions decreased for two consecutive years in 2019 and 2020, but considering the impact of external factors such as COVID-19, additional monitoring is needed to determine whether 2018 is the peak. As a result, the order of GHG emissions by country in 2020 was changed to Germany, Korea, France, and the United Kingdom. In 1995, Germany's GHG emissions were almost three times that of South Korea, but in 2020, there was only a small difference in emissions levels between the two countries.

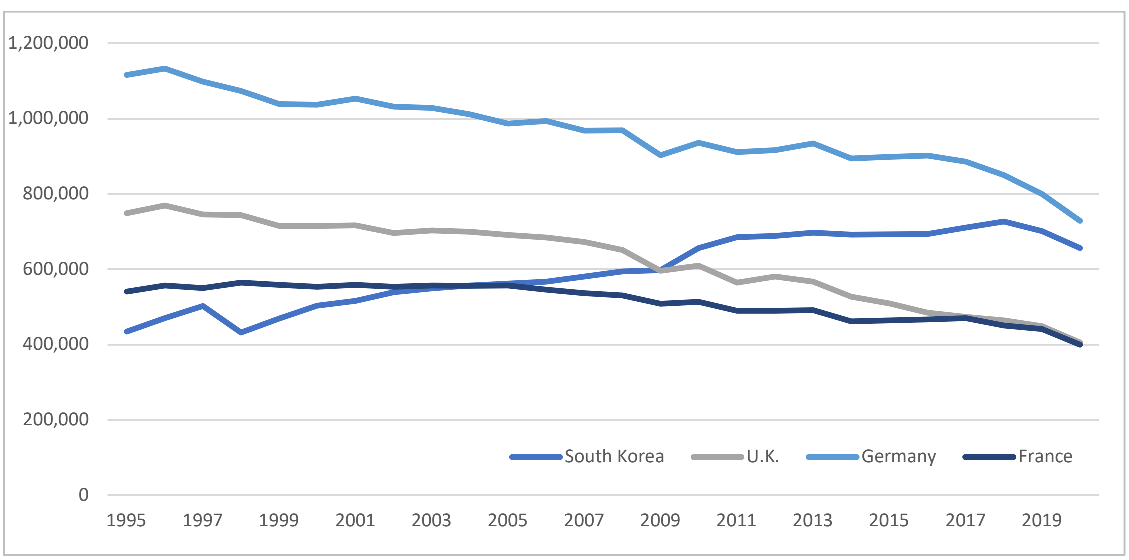


**Fig. 2**. Trends in Total GHG emissions (Kt $CO_2$ eq). *Source*: UNFCCC Greenhouse Gas Inventory

GHG emissions per unit of GDP have steadily decreased throughout the analysis period in all countries, including South Korea (See Fig. 3). This means that the growth rate of GHG emissions is lower than the economic growth rate. In the case of South Korea, emissions per unit of GDP in 2020 was approximately 440 $tCO_2eq$/mil USD, decreased by -44.3% compared to 1995. However, the absolute level is still more than twice that of other major European countries. South Korea's high emissions per unit is affected by various factors, but one of the most important reasons is its industrial structure.

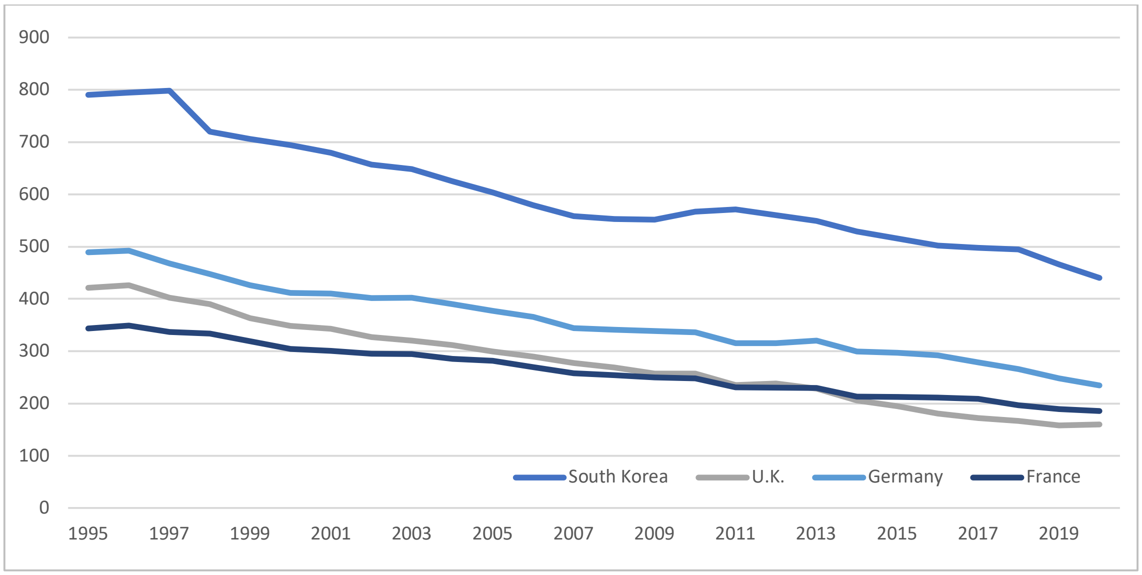


**Fig. 3.** Trends in GHG emissions intensity of GDP ($tCO_2eq$ / mil USD)

Fig. 4 shows the industrial structure of each country in 1995 and 2020. This indicates that a relatively large portion of South Korea's economic output comes from carbon-intensive industries. As of 2020, Korea's manufacturing share is the highest at 28.2% (21.7% in Germany, 11.2% in the U.K., and 11.1% in France). In particular, the percentage of carbon-intensive manufacturing, which includes Chemical and Petrochemical, Iron and Steel/Non-ferrous metal, and Non-metallic minerals, was also the highest at 9.4% (6.8% in Germany, 4.1% in France, and 3.8% in the U.K.). Fig.5 indicates the relation between the share of carbon-intensive manufacturing and emissions per unit of GDP. They show a strong positive correlation, and South Korea is located in the very upper right corner.

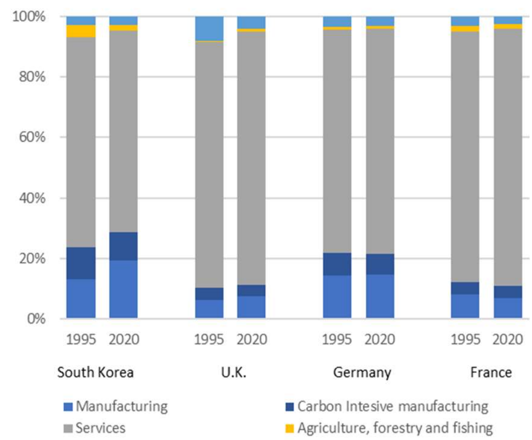


Fig. 4. Value added by sectors (2015 constant price).

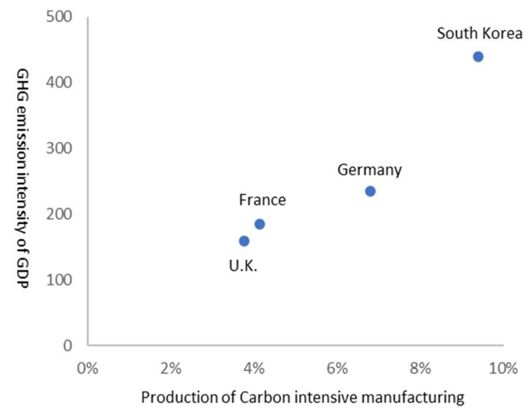


**Fig. 5.** Emissions per unit and manufacturing

Another noteworthy observation concerning industrial composition is that there were no substantial alterations in any country throughout the analysis period. For example, during the analysis period, most countries' manufacturing share in the economy did not change significantly, even in the European countries, which have achieved a substantial amount of GHG emissions reduction. Based on constant price, the U.K.'s manufacturing share has slightly increased from 10.3% in 1995 to 11.2% in 2020, whereas Germany's and France's have slightly decreased, respectively, from 21.9% to 21.7% and 12.3% to 11.1%. It can be interpreted that the GHG emissions reduction of major European countries was attributed to some other factors rather than structural changes, such as a reduction in the share of manufacturing. A more detailed analysis of the factors that affect GHG emissions reduction is covered in the following section.

### *4.2. Country-specific features*

This section examines the GHG emissions statistics calculated by sub-sectors and the results of the decomposition analysis of emissions factors by country in detail.

#### *4.2.1. South Korea*

#### *Trends in GHG emissions by industrial sub-sectors*

Fig. 6 shows the trend of GHG emissions by sub-sector in South Korea. The overall GHG emissions subject to this study increased by 58.6% from 318,262 Kt $CO_2$eq in 1995 to 504,665 Kt $CO_2$eq in 2020. In particular, the Iron and Steel/Non-ferrous metals increased by 99.7%, and the Chemical and Petrochemical industries increased by 96.2% throughout the analysis period, leading the overall emissions increase trend. While emissions increased during the analysis period in most sub-sectors, the exceptions were Non-metallic minerals (-19.6%), Textile and Leather (-63.0%), and Agriculture, forestry and fishing (-2.9%), where emissions decreased.

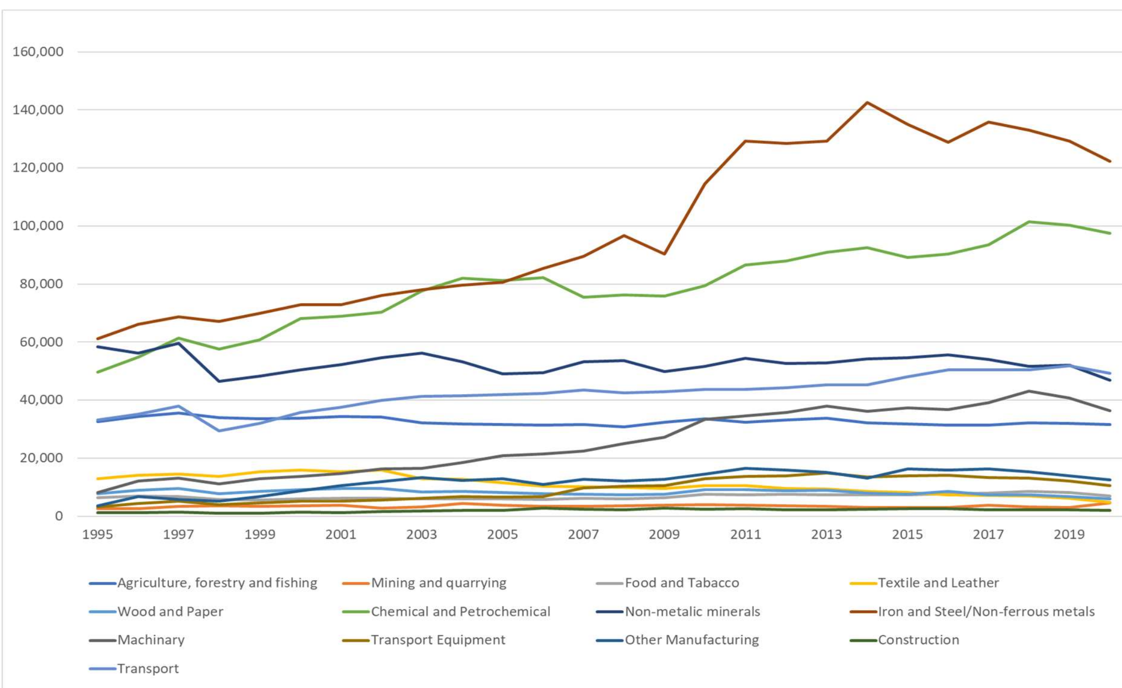


**Fig. 6**. [South Korea] GHG emissions of various industrial sub-sectors.

Fig. 7 shows the composition of GHG emissions by sub-sector in South Korea. As expected, a large amount of emissions comes from manufacturing, which remained in the upper 60% range of total emissions throughout the analysis period. In particular, the share of emissions from the three carbon-intensive industries (the three areas from the bottom of the bar graph) exceeded 50%. Within carbon-incentive sectors, the proportion of Iron and Steel/Non-ferrous metals has increased, accounting for about one-fourth of total emissions as of 2020, and the proportion of Non-metallic minerals continues to decrease. The decline in the proportion of Non-metallic minerals is because the cement industry, a core industry of the sector, has shrunk due to a slowing economic growth since the 1990s. In sectors other than manufacturing, the emissions share of Agriculture, forestry and fishing fell from 10.0% in 1995 to 6.3% in 2020, and the Commercial and public service share increased from 11.7% to 14.5%. Overall, the fact that the share of manufacturing, especially carbon-intensive industries, remains at a high level presents that the industrial structure of South Korea has not rapidly shifted toward the direction of reducing GHG emissions.

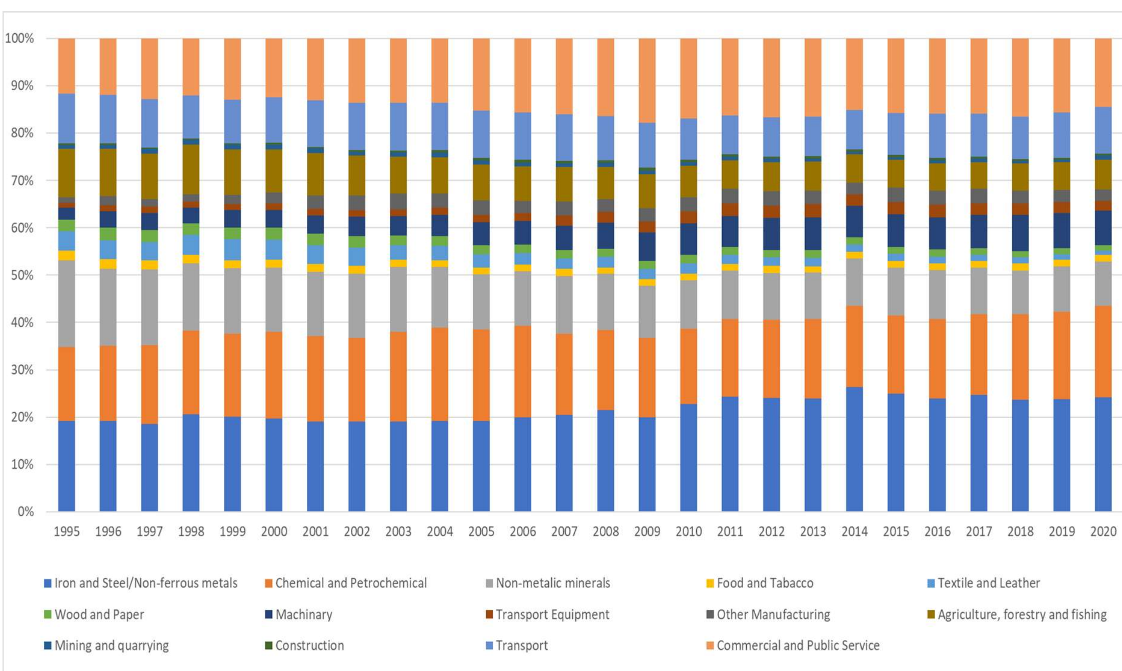


**Fig. 7**. [South Korea] GHG emissions share of various industrial sub-sectors.

### *Energy intensity and Emission intensity by industrial sub-sectors*

By combining sectoral GHG emissions data with the available sectoral value-added and energy consumption data, the energy intensity (energy consumption/value added) and the emission intensity (GHG emissions/energy consumption) can be additionally calculated. This is related to the third and fourth effects of the decomposition analysis, which are addressed in the following sub-section. Fig. 8 shows the trend of energy intensity by sub-sector in South Korea. Energy intensity is the amount of energy consumed to produce a unit of added value, so that high energy intensity means relatively low energy efficiency. Energy intensity generally improves over time through technology development and equipment replacement for energy efficiency increases. Energy intensity is generally higher in the manufacturing sector and lower in the service sector. In the case of South Korea, energy intensity shows a decline (improvement) in most sub-sectors throughout the analysis period. By industrial sub-sectors, Non-metallic minerals has the highest energy intensity, followed by Transport, Iron and Steel/Non-ferrous metal. The energy intensity of Non-metallic minerals fell -53.8% during the analysis period, but is still much higher than that of other manufacturing sub-sectors.

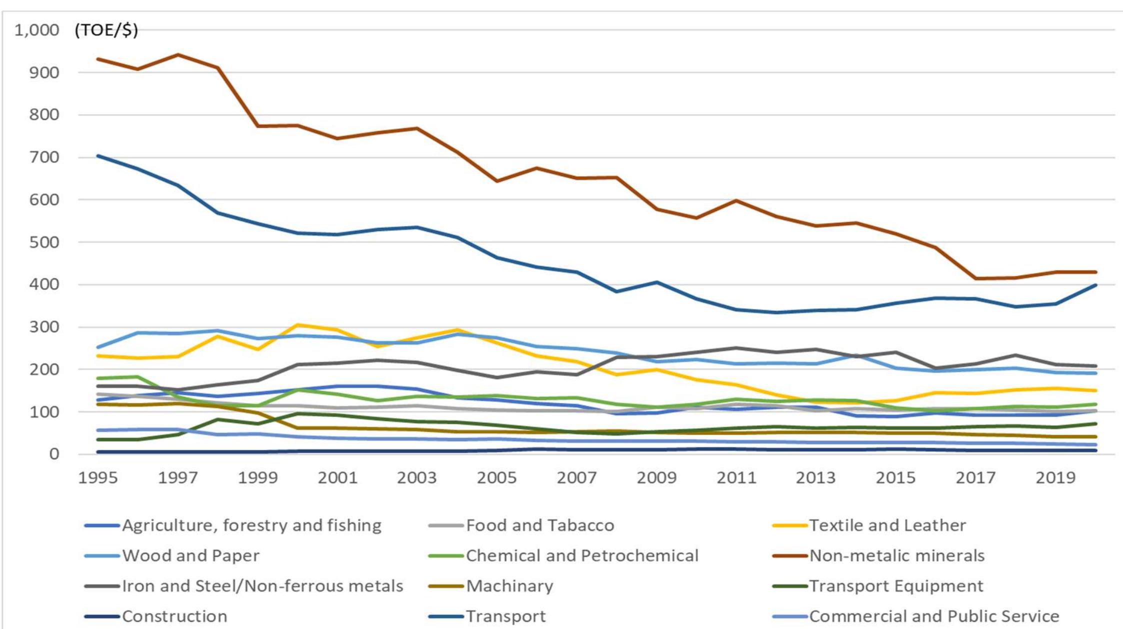


**Fig. 8**. [South Korea] Energy intensity of various industrial sub-sectors.

Meanwhile, the trend in emission intensity is slightly different. Emission intensity refers to the level of GHG emissions compared to energy consumption. It improves when the composition of the energy mix becomes greener or when the emission coefficient of a specific energy source decreases. Fig. 9 shows the trend of emission intensity by sub-sector in South Korea. Unlike energy intensity, which shows an overall trend of improvement, emission intensity has been stagnant in almost all sectors and deteriorating even in some sectors during the analysis period. Emission intensity by industrial sub-sectors is broadly divided into two groups. Carbon-intensive manufacturing and Agriculture, forestry and fishing show high emission intensity, while other remaining sectors show low levels.

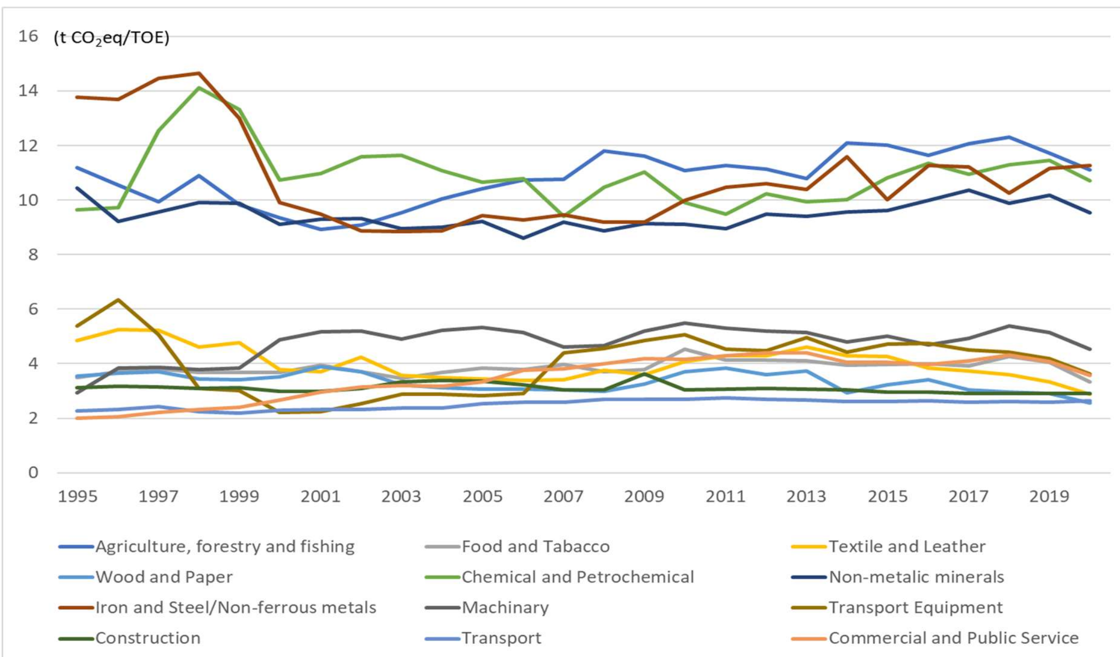


**Fig. 9**. [South Korea] Emission intensity of various industrial sub-sectors.

### *Result of decomposition analysis*

Calculating GHG emissions by sub-sectors makes it possible to analyse the contribution of each factor to the changes in GHG emissions, including aspects of industrial structure change. This sub-section uses the Kaya identity stated in the methodology chapter to decompose the changes in GHG emissions over the analysis period into four factors: activity effect, structure effect, energy intensity effect, and emission intensity effect. As previously stated, the LMDI decomposition analysis includes two methods: additive and multiplicative decomposition. Additive decomposition quantifies the contribution of each factor to the overall change in GHG emissions in absolute terms, while multiplicative decomposition shows this impact in the form of a contribution rate.

Tables 6 and 7 show the additive and multiplicative decomposition analysis results of GHG emission changes in South Korea, respectively. The main results of this data are as follows. The increase in GHG emissions primarily resulted from economic activity growth. Over the period of 1995 to 2020, South Korea's GHG emissions increased by 186 Mt $CO_2$eq (58.6%), and the activity effect contributed to the increase in GHG emissions by 363 Mt $CO_2$eq (145.7%). The structure effect resulting from changes in production share by industrial sub-sectors worked to reduce GHG emissions by 61 Mt $CO_2$eq (-14.0%). This indicates that the South Korean economy has made little progress in shifting toward an industrial structure with lower GHG emissions. The energy intensity effect was the most significant reduction factor contributing to emissions reduction by 148 Mt $CO_2$eq (-30.7%). On the other hand, the emission intensity contributed to a slight increase in emissions by 32 Mt $CO_2$eq (8.2%).

When examining the data broken down into the five-year unit, the activity effect gradually diminishes as the economic growth slows down, and the structure effect and energy intensity effect have continuously contributed to the decrease of emissions since 2000. Considering this trend, it is highly likely that overall GHG emissions will decrease in the future. Moreover, it is evident that enhancing the emission intensity effect is crucial to accelerate emissions reduction alongside the current reduction factors. In that respect, although external factors such as COVID-19 may have played some role, it is encouraging that the emission intensity effect of the latest section improved significantly and shifted to contributing to emissions reduction.

**Table 6**
[South Korea] Result of Additive LMDI Decomposition Analysis of GHG Emissions

| | Activity effect ($\Delta D_{act}$) | Structure effect ($\Delta D_{str}$) | Energy intensity effect ($\Delta D_{int}$) | Emission intensity effect ($\Delta D_{emi}$) | Total |
|---|---|---|---|---|---|
| **1995-2020** | **363,547** | **-60,953** | **-148,139** | **31,947** | **186,402** |
| 1995-2000 | 77,161 | 6,359 | -16,726 | -14,014 | 52,779 |
| 2000-2005 | 91,002 | -11,123 | -56,141 | 25,568 | 25,568 |
| 2005-2010 | 95,381 | -16,551 | -25,820 | 29,294 | 82,304 |
| 2010-2015 | 77,842 | -7,820 | -39,702 | 6,947 | 37,267 |
| 2015-2020 | 53,836 | -49,373 | -28,299 | -11,418 | -35,254 |

**Table 7**
[South Korea] Result of Additive LMDI Decomposition Analysis of GHG Emissions

| | Activity effect ($\Delta D_{act}$) | Structure effect ($\Delta D_{str}$) | Energy intensity effect ($\Delta D_{int}$) | Emission intensity effect ($\Delta D_{emi}$) | Total |
|---|---|---|---|---|---|
| **1995-2020** | **2.4575** | **0.8601** | **0.6932** | **1.0822** | **1.5858** |
| 1995-2000 | 1.2515 | 1.0187 | 0.9525 | 0.9601 | 1.1658 |
| 2000-2005 | 1.2590 | 0.9722 | 0.8676 | 1.0668 | 1.1329 |
| 2005-2010 | 1.2303 | 0.9647 | 0.9454 | 1.0657 | 1.1958 |
| 2010-2015 | 1.1611 | 0.9851 | 0.9266 | 1.0134 | 1.0741 |
| 2015-2020 | 1.1086 | 0.9098 | 0.9472 | 0.9784 | 0.9347 |

Table 8 shows the industrial breakdown of the additive decomposition results of GHG emissions changes from 1995 to 2020. The increase in production (activity effect) in major manufacturing sectors such as Iron and steel/Non-ferrous metals and the Chemical and petrochemical led to a significant portion of the overall increase in GHG emissions. Much of the structure effect came from the shrinking of Agriculture, forestry and fishing sector rather than manufacturing. This implies that expecting further structure effect in the future could be challenging. The energy intensity effect served as a factor in reducing GHG emissions in most industries, except for the Iron and steel/Non-ferrous metals. Lastly, the emission intensity effect has increased significantly in the Chemical and petrochemical, Machinery, and Commercial and public service sectors.

**Table 8**
[South Korea] Result of Additive Decomposition Analysis of Emissions by Sub-sectors (1995-2020)

| | Activity effect ($\Delta C_{act}$) | Structure effect ($\Delta C_{str}$) | Energy intensity effect ($\Delta C_{int}$) | Emission intensity effect ($\Delta C_{emi}$) | Total |
|---|---|---|---|---|---|
| **Total** | **363,547** | **-60,953** | **-148,139** | **31,947** | **186,402** |
| Agriculture/fishing | 29,422 | -22,860 | -7,277 | -232 | -947 |
| Mining&Quarrying | 3,255 | -5,949 | 3,890 | 806 | 2,002 |
| Food and Tobacco | 6,179 | -3,133 | -2,132 | -337 | 576 |
| Textile and Leather | 7,548 | -7,970 | -3,523 | -4,254 | -8,198 |
| Wood and Paper | 6,181 | -3,899 | -1,889 | -2,195 | -1,803 |
| Chemical&Petrochemi | 65,009 | 4,789 | -29,528 | 7,549 | 47,820 |
| Non-metallic min. | 48,021 | -14,143 | -40,518 | -4,775 | -11,414 |
| Iron&Steel/Non-ferrous | 80,835 | -25,786 | 23,596 | -17,634 | 61,010 |
| Machinery | 17,323 | 22,459 | -19,817 | 8,227 | 28,192 |
| Transport Equip. | 5,649 | -575 | 4,562 | -2,438 | 7,198 |
| Other Manu. | 6,530 | -1,853 | -6,014 | 10,181 | 8,844 |
| Construction | 1,473 | -1,242 | 773 | -112 | 892 |
| Transport | 37,225 | -4,535 | -23,005 | 6,458 | 16,143 |
| Commercias&Public | 48,897 | 3,743 | -47,257 | 30,703 | 36,086 |

### 4.2.2. U.K.

#### *Trends in GHG emissions by industrial sub-sectors*

Fig. 10 shows the trend of GHG emissions by sub-sector in the U.K. As seen above, the U.K. has shown the most significant GHG emissions reduction performance among major European countries, and this can also be confirmed in emissions statistics of the industrial sub-sector. The overall GHG emissions subject to this study decreased by almost half (-48.9%) from 480 Mt $CO_2$eq in 1995 to 245 Mt $CO_2$eq in 2020. By industry, GHG emissions decreased in all sub-sectors without exception. In particular, the Chemical and Petrochemical (-70.8%), Iron and Steel/Non-ferrous metals (-68.5%), and Commercial and Public Service (-56.6%) sectors decreased significantly, leading a decline in total emissions.

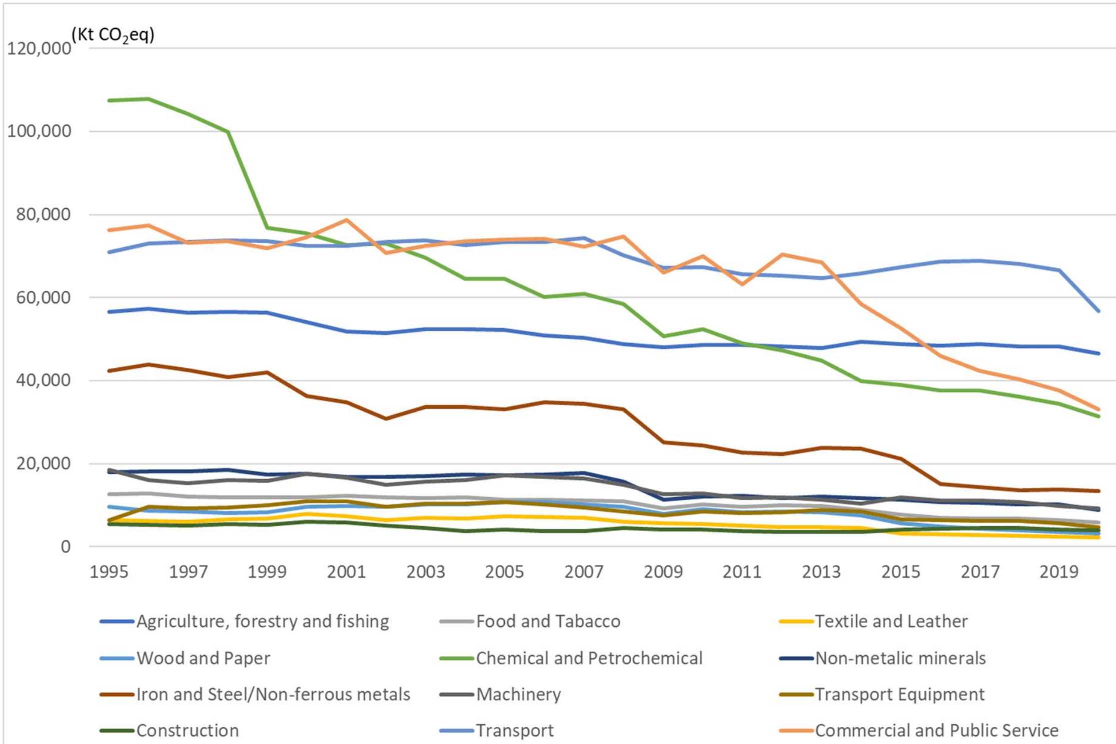


**Fig. 10**. [U.K.] GHG emissions of various industrial sub-sectors.

Fig. 11 shows the composition of GHG emissions by sub-sector in the U.K. What stands out is that the emissions share of the manufacturing sector decreased from 48.9% in 1995 to 35.6% in 2020. As seen above, there was no significant change in the production share of manufacturing in the U.K. Considering that, it can be seen that a relatively large amount of GHG emissions reduction was achieved in the manufacturing sector. In particular, the emissions share of three carbon-intensive manufacturing sectors (the three areas from the bottom of the bar graph) fell significantly from 34.9% in 1995 to 21.8%. Meanwhile, the emissions share of Agriculture, forestry and fishing and Transport sectors expanded from 11.8% to 18.9% and from 14.8% to 23.0%, respectively, from 1995 to 2020. The GHG emissions levels in both sectors decreased during the analysis period, but the amount was relatively small.

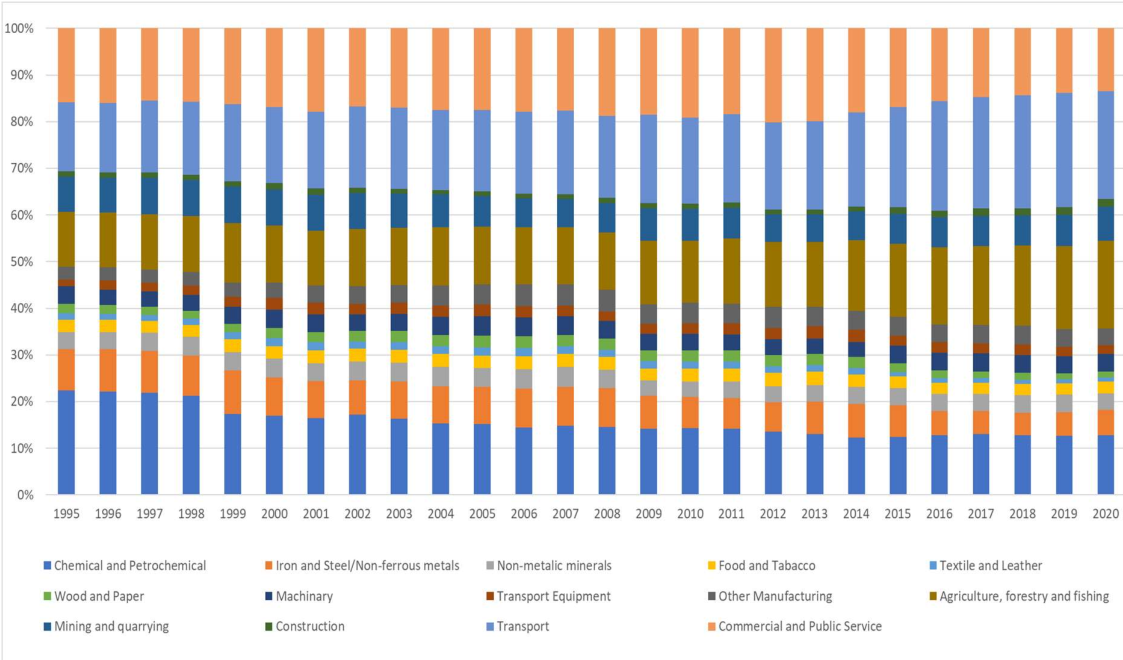


**Fig. 11**. [U.K.] GHG emissions share of various industrial sub-sectors.

### *Energy intensity and Emission intensity by industrial sub-sectors*

Fig. 12 and 13 show trends in energy intensity and emission intensity by sub-sector in the U.K. from 1995 to 2020. The energy intensity fell in all sub-sectors, meaning energy efficiency improved in all industries. By individual sector, industries with high energy intensity levels, such as Iron and Steel/Non-ferrous metals (-70.5%), Chemical and Petrochemical (-59.2%), Textile and Leather (-73.0%), and Wood and Paper (-63.7%) showed a large decline. The emission intensity remained relatively stable in the first half of the analysis period, but it has shown consistent decline trends across all industries since 2010. In the entire analysis period, there was a significant decline in Commercial and Public Services (-53.7%), Chemical and Petrochemical (-51.1%), and Non-metallic minerals (-43.3%). The declines in the Iron and Steel/Non-ferrous metals (-0.4%) and Transport (-2.4%) sectors were relatively small.

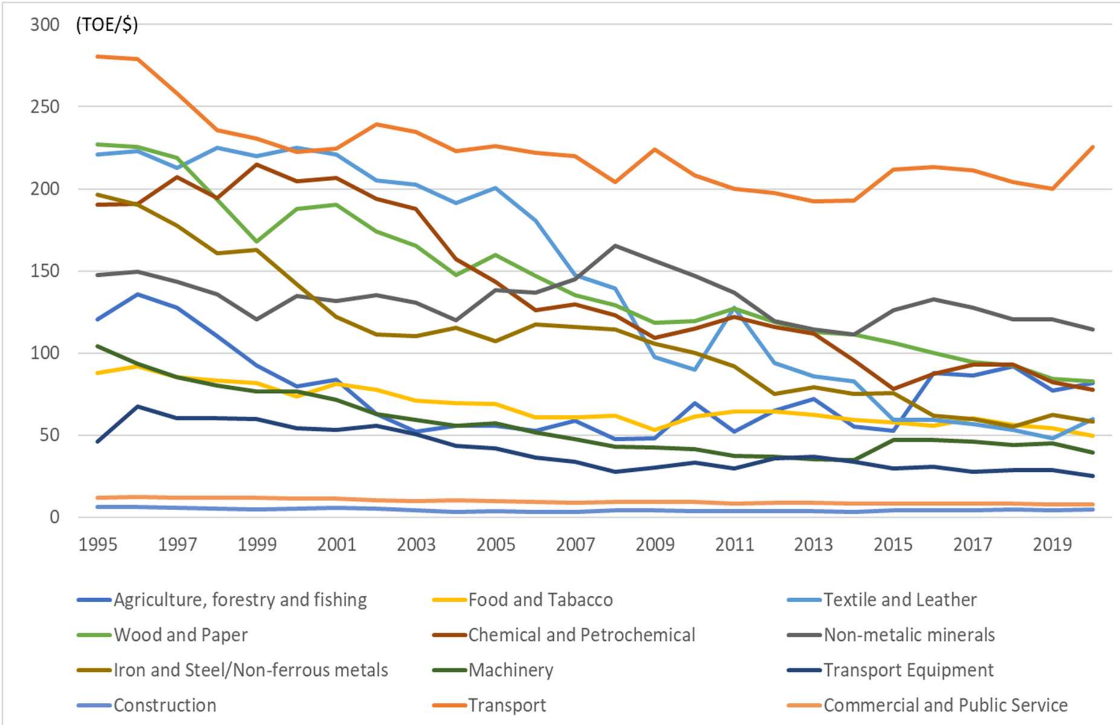


**Fig. 12**. [U.K.] Energy intensity of various industrial sub-sectors.

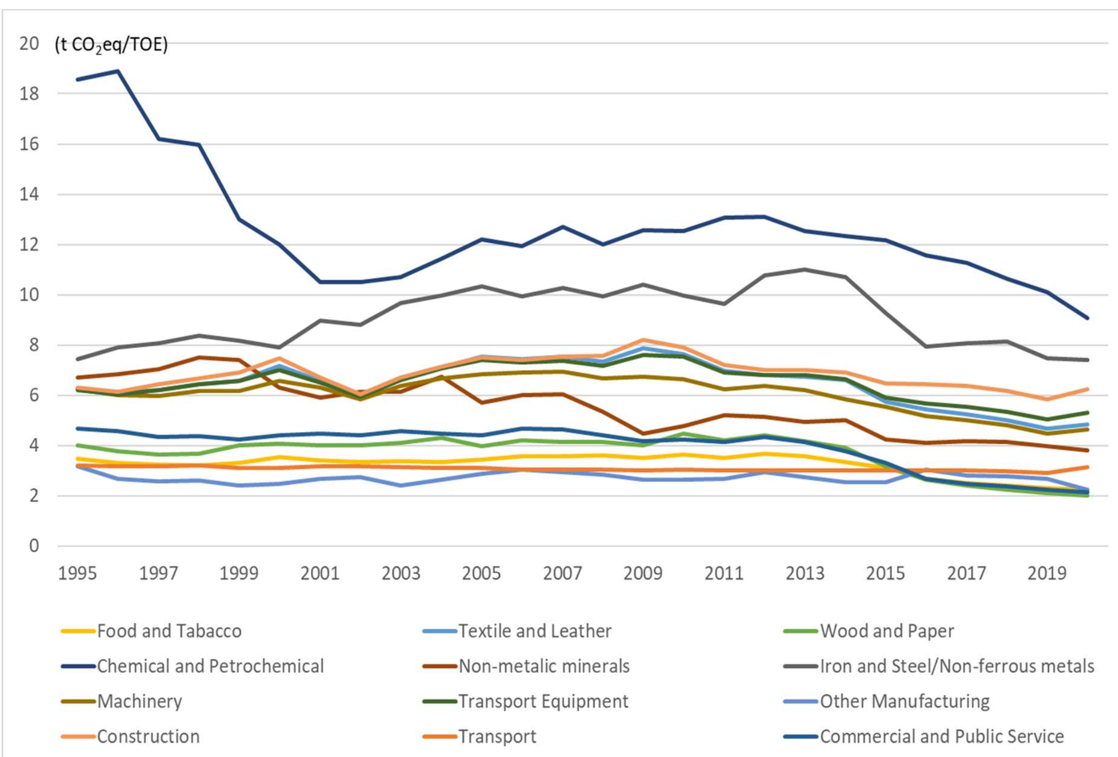


**Fig. 13**. [U.K.] Emission intensity of various industrial sub-sectors.

### *Result of decomposition analysis*

The overall GHG emissions in the U.K. decreased by 234 Mt $CO_2$eq (-48.9%) from 1995 to 2020. Tables 9 and 10 show the additive and multiplicative decomposition analysis results for GHG emission changes in the U.K., respectively. First, the activity effect worked as a factor in increasing GHG emissions by 92 Mt $CO_2$eq (30.1%) through the analysis period. The structure effect acted as a factor in reducing GHG emissions by 36 Mt $CO_2$eq (-9.8%). The energy intensity effect played a significant role in lowering emissions by 137 Mt $CO_2$eq (-32.4%). Lastly, the emissions intensity effect served as the most important reduction factor, decreasing GHG emissions by 152 Mt $CO_2$eq (-35.4%). When examining the data broken down into the five-year unit, the pressure to increase emissions from the activity effect is gradually weakening, and the reduction effects from the energy and emission intensity improvement are expanding. As a result, the scale of GHG emissions reduction is also gradually expanding.

**Table 9**
[U.K.] Result of Additive LMDI Decomposition Analysis of GHG Emissions

| | Activity effect ($\Delta D_{act}$) | Structure effect ($\Delta D_{str}$) | Energy intensity effect ($\Delta D_{int}$) | Emission intensity effect ($\Delta D_{emi}$) | Total |
|---|---|---|---|---|---|
| **1995-2020** | **92,021** | **-36,281** | **-137,021** | **-152,890** | **-234,171** |
| 1995-2000 | 43,461 | 24,939 | -48,685 | -47,613 | -27,898 |
| 2000-2005 | 39,676 | -18,789 | -58,433 | 9,554 | -27,992 |
| 2005-2010 | 6,381 | -29,034 | -17,132 | -16,334 | -56,118 |
| 2010-2015 | 31,720 | -9,230 | -41,457 | -34,289 | -53,253 |
| 2015-2020 | -8,319 | -7,612 | 10,462 | -61,320 | -66,820 |

**Table 10**
[U.K.] Result of Additive LMDI Decomposition Analysis of GHG Emissions

| | Activity effect ($\Delta D_{act}$) | Structure effect ($\Delta D_{str}$) | Energy intensity effect ($\Delta D_{int}$) | Emission intensity effect ($\Delta D_{emi}$) | Total |
|---|---|---|---|---|---|
| **1995-2020** | **1.3007** | **0.9015** | **0.6761** | **0.6461** | **0.5122** |
| 1995-2000 | 1.0988 | 1.0556 | 0.8998 | 0.9019 | 0.9413 |
| 2000-2005 | 1.0961 | 0.9575 | 0.8736 | 1.0223 | 0.9379 |
| 2005-2010 | 1.0164 | 0.9288 | 0.9574 | 0.9593 | 0.8670 |
| 2010-2015 | 1.0982 | 0.9731 | 0.8848 | 0.9037 | 0.8545 |
| 2015-2020 | 0.9705 | 0.9730 | 1.0382 | 0.8020 | 0.7863 |

Table 11 shows the industrial breakdown of the additive decomposition results of GHG emissions changes from 1995 to 2020. In the U.K., all sub-sectors, without exception, contributed to GHG emissions reduction during the analysis period. In particular, the energy and emission intensity effects of two sectors, Commercial and Public Service and Chemical and Petrochemical, are leading the overall emissions reduction.

**Table 11**
[U.K.] Result of Additive Decomposition Analysis of Emissions by Sub-sectors (1995-2020)

| | Activity effect ($\Delta C_{act}$) | Structure effect ($\Delta C_{str}$) | Energy intensity effect ($\Delta C_{int}$) | Emission intensity effect ($\Delta C_{emi}$) | Total |
|---|---|---|---|---|---|
| **Total** | **92,021** | **-36,281** | **-137,021** | **-152,890** | **-234,171** |
| Agriculture/fishing | -13,676 | 11,391 | -20,002 | -15,128 | -10,063 |
| Mining&Quarrying | 6,934 | -43,011 | 45,353 | -27,409 | -18,132 |
| Food and Tobacco | 2,372 | -268 | -5,045 | -3,880 | -6,821 |
| Textile and Leather | 1,061 | 1,014 | -5,218 | -1,022 | -4,165 |
| Wood and Paper | 1,538 | 1,854 | -5,849 | -3,983 | -6,441 |
| Chemical&Petrochemi | 16,446 | 7,013 | -55,367 | -44,118 | -76,027 |
| Non-metallic min. | 3,446 | -1,830 | -3,288 | -7,342 | -9,014 |
| Iron&Steel/Non-ferrous | 6,705 | -4,966 | -30,701 | -95 | -29,057 |
| Machinery | 3,556 | 4,143 | -12,978 | -3,890 | -9,168 |
| Transport Equipment | 1,460 | 1,077 | -3,389 | -836 | -1,688 |
| Other Manufacturing | 2,894 | 629 | -4,648 | -3,757 | -4,881 |
| Construction | 1,266 | -1,331 | -1,333 | -70 | -1,467 |
| Transport | 16,911 | -15,694 | -13,822 | -1,564 | -14,168 |
| Commercial&Public | 13,756 | 3,695 | -20,733 | -39,796 | -43,078 |

### 4.2.3. Germany

#### *Trends in GHG emissions by industrial sub-sectors*

Fig. 14 shows the trend of GHG emissions by sub-sector in Germany. The overall GHG emissions subject to this study decreased by 234 Mt $CO_2$eq (-32.3%) from 724 Mt $CO_2$eq in 1995 to 490 Mt $CO_2$eq in 2020. By industry, GHG emissions decreased in all sub-sectors except for Wood and paper (+19.3%) and Construction (+78.9%). In particular, Mining and quarrying (-82.8%), Transport equipment (-47.4%), Commercial and Public Service (-40.5%), and Chemical and Petrochemical (-40.0%) sectors decreased significantly, leading a decline in total emissions.

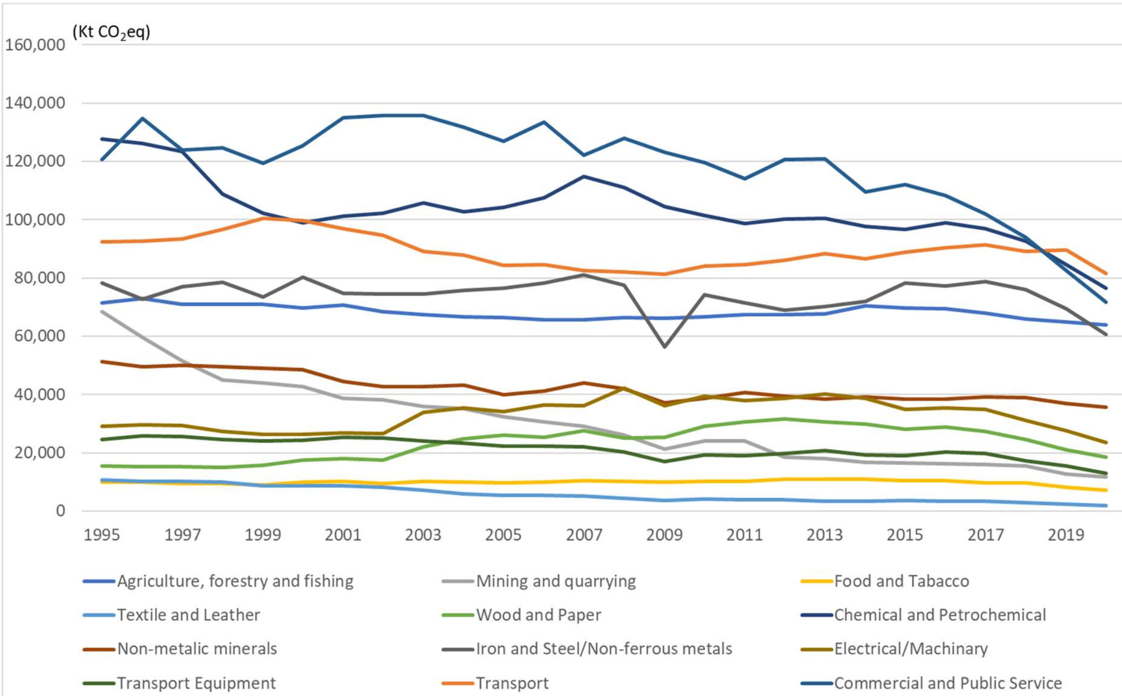


**Fig. 14**. [Germany] GHG emissions of various industrial sub-sectors.

Fig. 15 shows the composition of GHG emissions by sub-sector in Germany. In the case of Germany, the emissions share by industry shows a relatively stable pattern compared to other countries. The emissions share of the overall manufacturing industry was the same at 50.1% in 1995 and 2020, and the emissions share of the three carbon-intensive industries also remained at the around 35% level. In sectors other than manufacturing, the Mining and quarrying sector was an exception, with its emission share significantly decreasing from 9.5% in 1995 to 2.4% in 2020. Other than that, the Agriculture, forestry and fishing, and Transport sectors stand out, with their share of emissions increasing from 9.9% to 13.0% and from 12.7% to 16.6%, respectively.

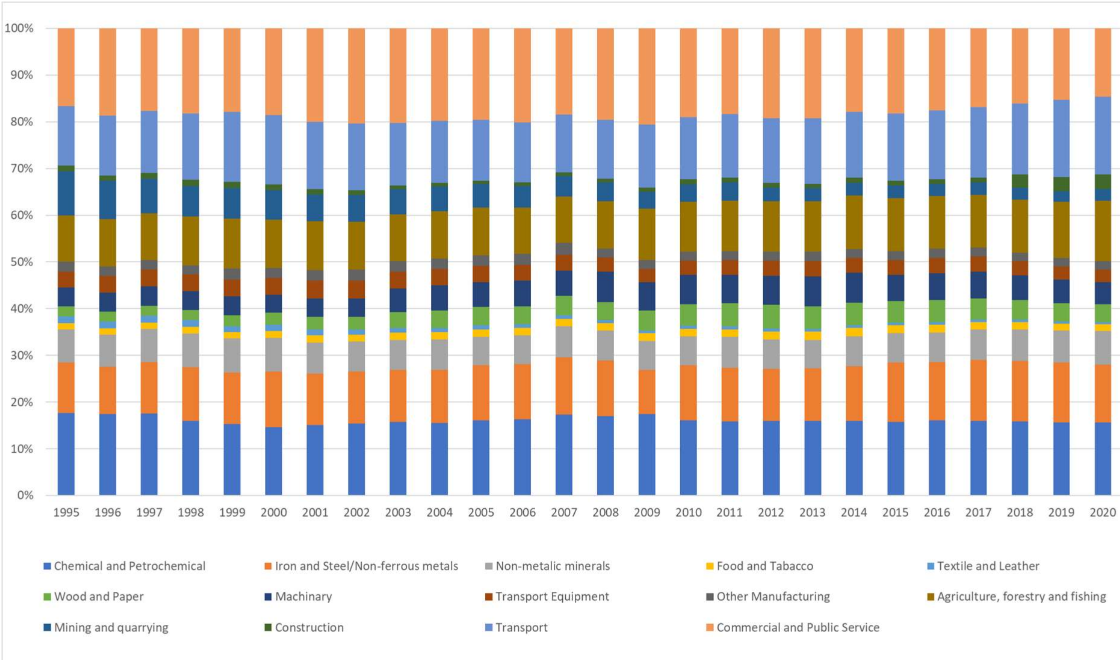


**Fig. 15**. [Germany] GHG emissions share of various industrial sub-sectors.

### *Energy intensity and Emission intensity by industrial sub-sectors*

Fig. 16 and 17 show trends in energy intensity and emission intensity by sub-sector in Germany from 1995 to 2020. The energy intensity demonstrated relatively substantial improvement in the Transport (-36.6%), Iron and Steel/Non-ferrous metals (-31.6%), and Non-metallic minerals (-26.4%) sectors. One notable exception is the energy intensity of Agriculture, forestry and fishing, which has shown a steep rise since 2018, as the sector's energy consumption level has tripled in 2018 compared to the previous year. This increase appears to be linked to changes in statistical standards rather than an actual increase in the sector's energy consumption. Meanwhile, the emission intensity exhibits a more noticeable improvement when compared to its energy intensity, and the pace of improvement has been accelerating since 2015. Among sub-sectors, significant improvements are observed in Chemical and Petrochemical (-49.9%), Machinery (-42.0%), and Transport Equipment (-38.8%) during the analysis period.

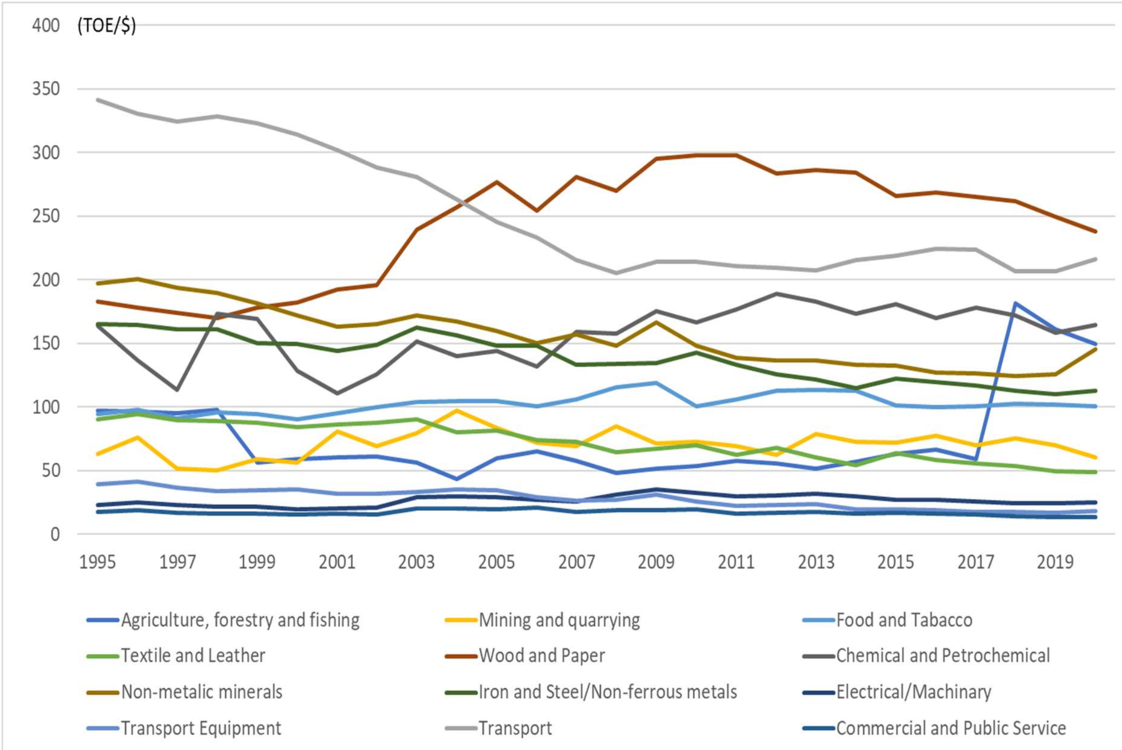


**Fig. 16**. [Germany] Energy intensity of various industrial sub-sectors.

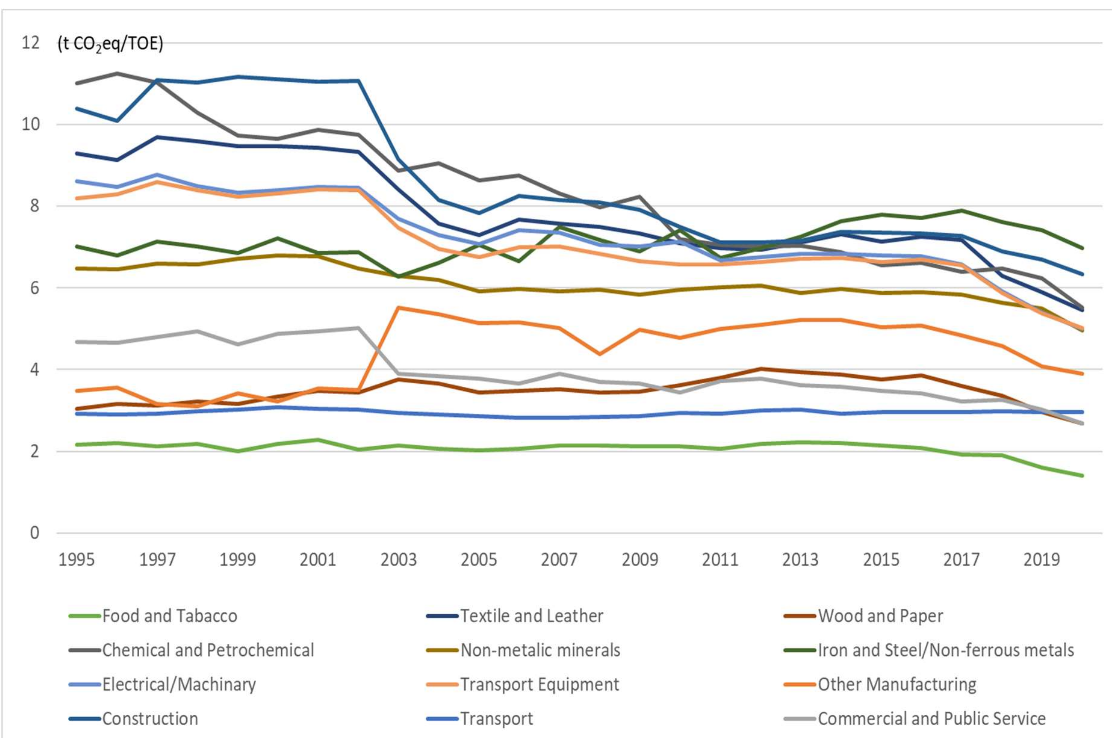


**Fig. 17**. [Germany] Emission intensity of various industrial sub-sectors.

### *Result of decomposition analysis*

The total GHG emissions in Germany decreased by 234 Mt $CO_2$eq (-32.3%) from 1995 to 2020. Tables 12 and 13 show the additive and multiplicative decomposition analysis results for GHG emission changes in Germany, respectively. First, the activity effect increased GHG emissions by 151 Mt $CO_2$eq (28.7%) through the analysis period. The structure effect acted as a factor in reducing GHG emissions by 61 Mt $CO_2$eq (-9.6%). The energy intensity effect lowered GHG emissions by 81 Mt $CO_2$eq (-12.7%). Lastly, the emissions intensity effect was the most important reduction factor, reducing GHG emissions by 243 Mt $CO_2$eq (-33.3%). When examining the data broken down into the five-year unit, the energy intensity effect led the GHG emissions reduction before 2000, and afterwards, the emission intensity effect led the way. The scale of reduction has also increased significantly since 2015.

Overall, Germany has a more noticeable emission intensity effect in reducing GHG emissions than other countries. The rise in the emission intensity effect of Germany can be attributed to the outcomes of energy policies at the national level. Germany enacted the Renewable Energy Act (EEG) in 2000, and since then, they have continuously promoted the voluntary expansion of renewable energy in the private sector by providing government subsidies based on the amount of renewable energy generation (KEEI, 2018, pp. 2-3).

**Table 12**
[Germany] Result of Additive LMDI Decomposition Analysis of GHG Emissions

| | Activity effect ($\Delta D_{act}$) | Structure effect ($\Delta D_{str}$) | Energy intensity effect ($\Delta D_{int}$) | Emission intensity effect ($\Delta D_{emi}$) | Total |
|---|---|---|---|---|---|
| **1995-2020** | **151,636** | **-60,689** | **-81,208** | **-243,443** | **-233,704** |
| 1995-2000 | 58,597 | -27,169 | -115,557 | 34,558 | -49,571 |
| 2000-2005 | 12,433 | -10,599 | 45,055 | -73,589 | -26,701 |
| 2005-2010 | 31,996 | 3,510 | -17,417 | -36,197 | -18,108 |
| 2010-2015 | 49,488 | -21,388 | -30,240 | -12,759 | -14,899 |
| 2015-2020 | 13,080 | -13,591 | 27,411 | -151,324 | -124,424 |

**Table 13**
[Germany] Result of Additive LMDI Decomposition Analysis of GHG Emissions

| | Activity effect ($\Delta D_{act}$) | Structure effect ($\Delta D_{str}$) | Energy intensity effect ($\Delta D_{int}$) | Emission intensity effect ($\Delta D_{emi}$) | Total |
|---|---|---|---|---|---|
| **1995-2020** | **1.2877** | **0.9038** | **0.8734** | **0.6664** | **0.6773** |
| 1995-2000 | 1.0874 | 0.9619 | 0.8476 | 1.0507 | 0.9315 |
| 2000-2005 | 1.0190 | 0.9841 | 1.0705 | 0.8947 | 0.9604 |
| 2005-2010 | 1.0514 | 1.0055 | 0.9731 | 0.9449 | 0.9721 |
| 2010-2015 | 1.0828 | 0.9662 | 0.9526 | 0.9797 | 0.9763 |
| 2015-2020 | 1.0241 | 0.9756 | 1.0511 | 0.7596 | 0.7977 |

Table 14 shows the industrial breakdown of the additive decomposition results of GHG emissions changes in Germany from 1995 to 2020. By industry, the improvement in energy intensity in the Transportation, Iron and Steel/Non-ferrous metals sectors and the improvement in emission intensity in the Commercial and Public Service, Chemical and Petrochemical sectors have significantly impacted overall emissions reduction. The structure effect was mainly observed in the Mining and quarrying sector.

**Table 14**
[Germany] Result of Additive Decomposition Analysis of Emissions by Sub-sectors (1995-2020)

| | Activity effect ($\Delta C_{act}$) | Structure effect ($\Delta C_{str}$) | Energy intensity effect ($\Delta C_{int}$) | Emission intensity effect ($\Delta C_{emi}$) | Total |
|---|---|---|---|---|---|
| **Total** | **151,636** | **-60,689** | **-81,208** | **-243,443** | **-233,704** |
| Agriculture/fishing | 17,327 | -6,057 | 29,359 | -48,202 | -7,574 |
| Mining&Quarrying | 8,264 | -36,819 | -1,231 | -27,008 | -56,794 |
| Food and Tobacco | 2,157 | -1,795 | 548 | -3,700 | -2,791 |
| Textile and Leather | 1,322 | -4,117 | -3,152 | -2,740 | -8,686 |
| Wood and Paper | 4,364 | -3,743 | 4,493 | -2,106 | 3,009 |
| Chemical&Petrochemi | 25,648 | -7,969 | 389 | -69,238 | -51,170 |
| Non-metallic min. | 11,051 | -1,973 | -13,216 | -11,579 | -15,717 |
| Iron&Steel/Non-ferrous | 17,696 | -8,536 | -26,243 | -496 | -17,579 |
| Machinery | 6,731 | 225 | 2,006 | -14,307 | -5,345 |
| Transport Equipment | 4,667 | 6,329 | -13,746 | -8,936 | -11,686 |
| Other Manufacturing | 2,985 | -236 | -10,781 | 1,338 | -6,693 |
| Construction | 3,052 | -6,380 | 16,131 | -5,879 | 6,924 |
| Transport | 22,254 | 5,056 | -39,544 | 1,460 | -10,773 |
| Commercial&Public | 24,118 | 5,325 | -26,223 | -52,050 | -48,830 |

### *4.2.4. France*

#### ***Trends in GHG emissions by industrial sub-sectors***

Fig. 18 shows the trend of GHG emissions by sub-sector in France. The overall GHG emissions subject to this study decreased by 116 Mt $CO_2$eq (-30.2%) from 383 Mt $CO_2$eq in 1995 to 267 Mt $CO_2$eq in 2020. By industry, GHG emissions decreased in all sub-sectors except for Transport Equipment (+1.7%). In particular, emissions in the Textile and Leather (-78.4%), Chemical and Petrochemical (-64.2%), and Electrical/Machinery (-58.9%) sectors decreased significantly, leading a decline in total emissions.

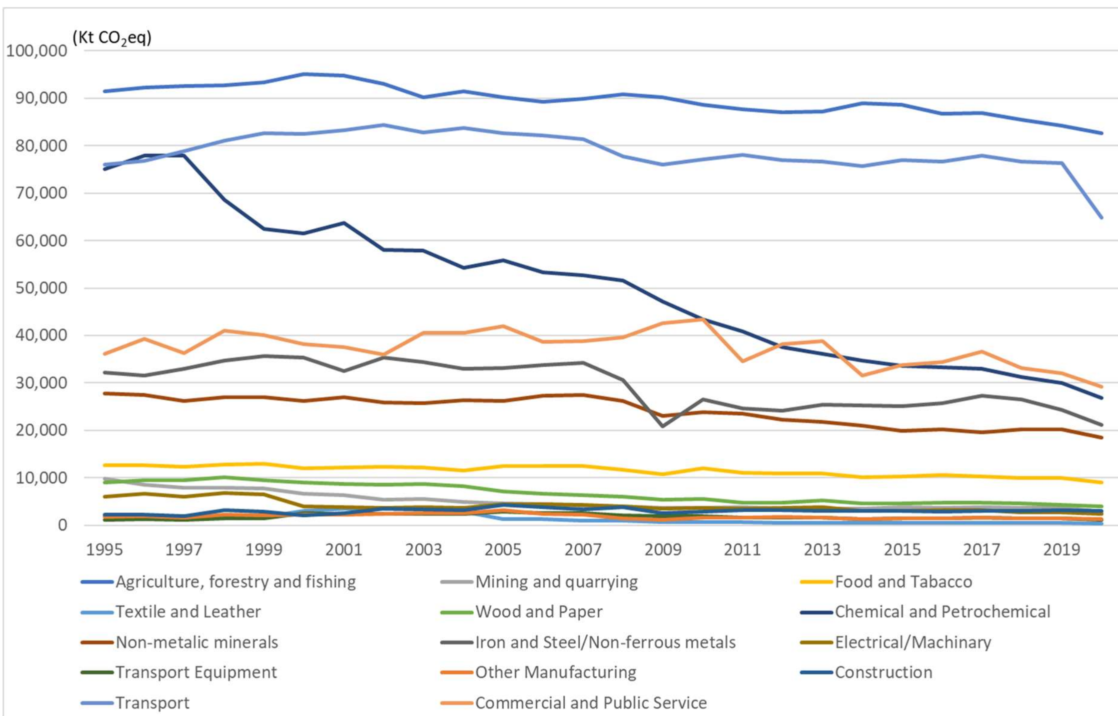


**Fig. 18**. [France] GHG emissions of various industrial sub-sectors.

Fig. 19 shows the composition of GHG emissions by sub-sector in France. In the case of France, the emission share of Agriculture, forestry and fishing is higher than that of other countries. As of 2020, emissions from the agricultural sector are about 83Mt $CO_2$eq, accounting for 30.9% of total emissions. The emissions share of the overall manufacturing industry fell from 43.8% in 1995 to 31.7% in 2020, and the emissions share of the three carbon-intensive industries also fell from 35.2% in 1995 to 24.9% in 2020. Similar to the U.K., considering that there was no significant change in the production share of manufacturing in France, it can be seen that a relatively large amount of GHG emissions reduction was achieved in the manufacturing sector.

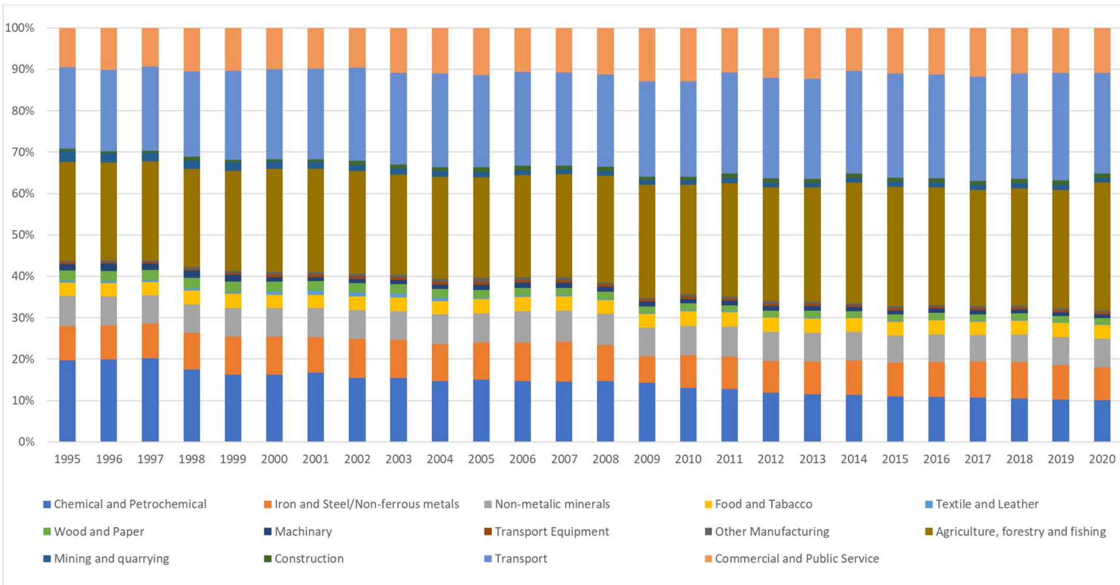


**Fig. 19**. [France] GHG emissions of various industrial sub-sectors.

### *Energy intensity and Emission intensity by industrial sub-sectors*

Fig. 20 and 21 show trends in energy intensity and emission intensity by sub-sector in France from 1995 to 2020. The energy intensity has improved in all sectors except Transport equipment, Food and tobacco and Mining and quarrying. In particular, there was a relatively substantial improvement in the Iron and Steel/Non-ferrous metals (-55.4%), Wood and Paper (-46.5%), and Chemical and Petrochemical (-42.6%) sectors. The emission intensity has improved in all sectors except Iron and Steel/Non-ferrous metals, and showed relatively substantial improvement in the Chemical and Petrochemical (-66.8%), Commercial and public service (-29.2%) and Non-metallic minerals (-28.9%).

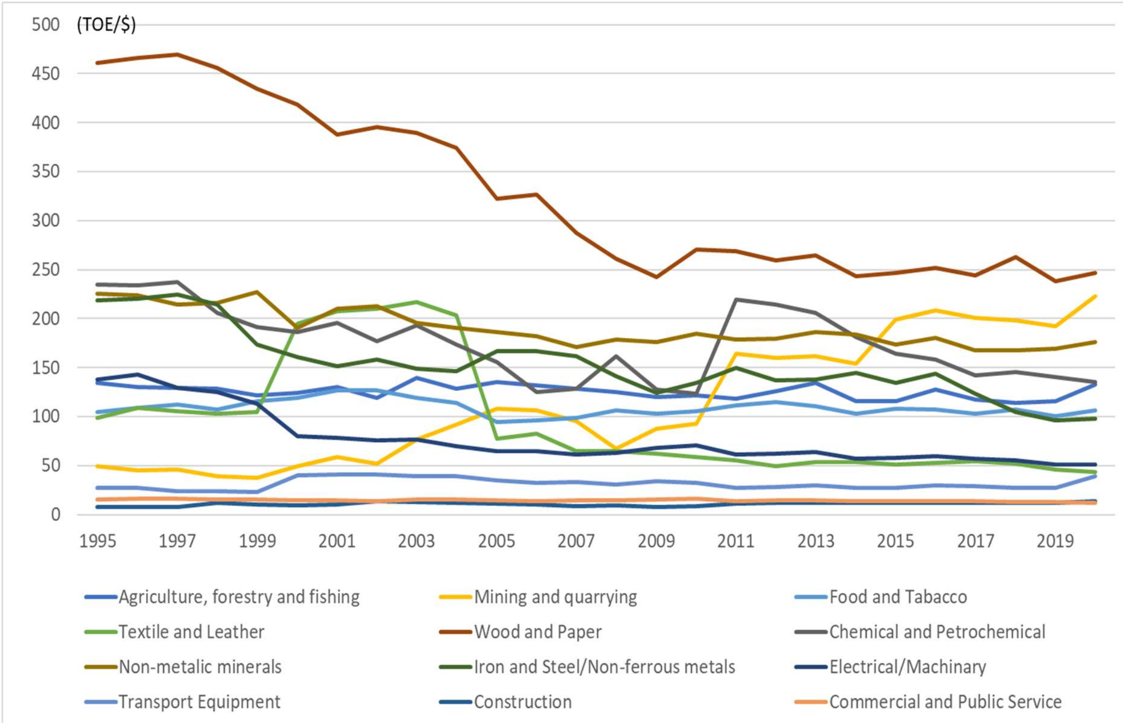


**Fig. 20**. [France] Energy intensity of various industrial sub-sectors.

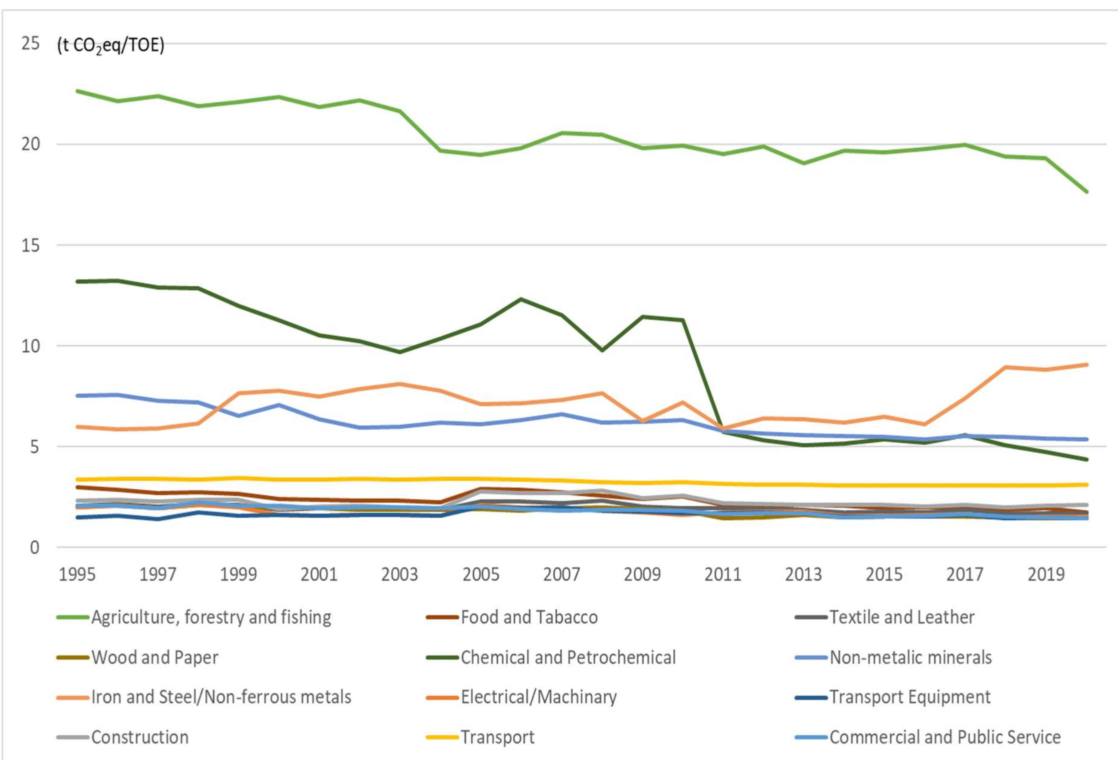


**Fig. 21**. [France] Emission intensity of various industrial sub-sectors.

### *Result of decomposition analysis*

The total GHG emissions in France decreased by 116 Mt $CO_2$eq (-30.2%) from 1995 to 2020. Tables 15 and 16 show the additive and multiplicative decomposition analysis results for GHG emission changes in France, respectively. First, the activity effect increased GHG emissions by 92 Mt $CO_2$eq (33.1%) throughout the analysis period. The structure effect acted as a factor in reducing GHG emissions by 13 Mt $CO_2$eq (-4.1%). The energy intensity effect lowered GHG emissions by 91 Mt $CO_2$eq (-24.5%). Lastly, the emissions intensity effect was the most important reduction factor, reducing GHG emissions by 103 Mt $CO_2$eq (-27.6%). When examining the data broken down into the five-year unit, the energy intensity effect led the GHG emissions reduction before 2000, and afterwards, the emission intensity effect led the way combined with the reduction in the activity effect. Furthermore, it is encouraging that the extent of greenhouse gas reduction is gradually expanding.

**Table 15**
[France] Result of Additive LMDI Decomposition Analysis of GHG Emissions

| | Activity effect ($\Delta D_{act}$) | Structure effect ($\Delta D_{str}$) | Energy intensity effect ($\Delta D_{int}$) | Emission intensity effect ($\Delta D_{emi}$) | Total |
|---|---|---|---|---|---|
| **1995-2020** | **92,103** | **-13,569** | **-90,502** | **-103,817** | **-115,786** |
| 1995-2000 | 49,479 | 17,059 | -59,298 | -9,653 | -2,413 |
| 2000-2005 | 27,662 | -8,622 | -9,809 | -19,720 | -10,488 |
| 2005-2010 | 15,752 | -8,250 | -33,595 | -9,158 | -35,521 |
| 2010-2015 | 16,617 | 562 | 5,021 | -51,286 | -29,085 |
| 2015-2020 | -3,179 | -16,190 | -8,566 | -10,614 | -38,549 |

**Table 16**
[France] Result of Additive LMDI Decomposition Analysis of GHG Emissions

| | Activity effect ($\Delta D_{act}$) | Structure effect ($\Delta D_{str}$) | Energy intensity effect ($\Delta D_{int}$) | Emission intensity effect ($\Delta D_{emi}$) | Total |
|---|---|---|---|---|---|
| **1995-2020** | **1.3313** | **0.9587** | **0.7549** | **0.7243** | **0.6979** |
| 1995-2000 | 1.1383 | 1.0457 | 0.8562 | 0.9751 | 0.9937 |
| 2000-2005 | 1.0764 | 0.9773 | 0.9742 | 0.9488 | 0.9725 |
| 2005-2010 | 1.0457 | 0.9769 | 0.9091 | 0.9743 | 0.9048 |
| 2010-2015 | 1.0532 | 1.0018 | 1.0158 | 0.8521 | 0.9132 |
| 2015-2020 | 0.9890 | 0.9450 | 0.9705 | 0.9636 | 0.8740 |

Table 17 shows the industrial breakdown of the additive decomposition results of GHG emissions changes in France from 1995 to 2020. By industry, the improvement in energy intensity in the Transportation, Iron and Steel/Non-ferrous metals sectors and the improvement in emission intensity in the Commercial and Public Service, Chemical and Petrochemical sectors have significantly impacted overall emissions reduction. While there is some difference in degree, this is similar to the case of Germany examined earlier.

**Table 17**
[France] Result of Additive Decomposition Analysis of GHG Emissions by Sub-sectors (1995-2020)

| | Activity effect ($\Delta C_{act}$) | Structure effect ($\Delta C_{str}$) | Energy intensity effect ($\Delta C_{int}$) | Emission intensity effect ($\Delta C_{emi}$) | Total |
|---|---|---|---|---|---|
| **Total** | **92,103** | **-13,569** | **-90,502** | **-103,817** | **-115,786** |
| Agriculture/fishing | 25,147 | -10,999 | -1,423 | -21,589 | -8,864 |
| Mining&Quarrying | 1,641 | -8,450 | 8,553 | -8,633 | -6,889 |
| Food and Tobacco | 3,096 | -1,212 | 119 | -5,646 | -3,643 |
| Textile and Leather | 281 | -778 | -793 | -198 | -1,487 |
| Wood and Paper | 1,792 | -937 | -3,881 | -2,110 | -5,137 |
| Chemical&Petrochemi | 13,577 | 16,089 | -26,090 | -51,803 | -48,228 |
| Non-metallic min. | 6,585 | -2,528 | -5,589 | -7,770 | -9,301 |
| Iron&Steel/Non-ferrous | 7,593 | -8,223 | -21,21 | 10,870 | -10,975 |
| Machinery | 1,153 | 348 | -3,982 | -1,067 | -3,548 |
| Transport Equipment | 347 | -691 | 416 | -52 | 20 |
| Other Manufacturing | 439 | -67 | -1,863 | 941 | -550 |
| Construction | 747 | -1,086 | 1,408 | -229 | 840 |
| Transport | 20,309 | 3,088 | -29,198 | -5,291 | -11,092 |
| Commercial&Public | 9,396 | 1,876 | -6,964 | -11,240 | -6,932 |

### *4.3. Overall Analysis: With a focus on South Korea's situation*

This sub-section compares the decomposition analysis results of each country and tries to find some implications by focusing on South Korea. Fig. 22 shows the contribution amount of each factor that affected changes in the country's GHG emissions. Overall, South Korea's GHG emissions have increased during the analysis period because other factors did not sufficiently offset the pressure of increasing GHG emissions from economic growth (activity effect). On the other hand, major European countries successfully reduced their emissions by effectively countering the rising emissions pressure from economic growth through energy efficiency and emission intensity improvement. The main characteristics of each effect are as follows.

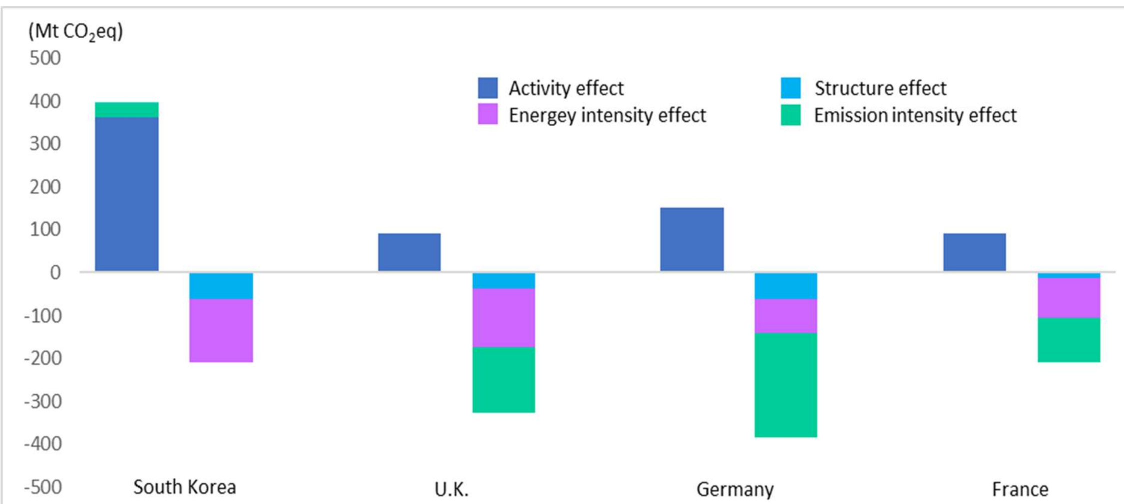


**Fig. 22**. Result of Additive Decomposition Analysis of GHG Emissions factors

The activity effect worked as a factor in increasing GHG emissions in all countries. As expected, it was the largest in South Korea, which is a natural result stemming from each country's stage of economic development. Throughout the analysis period, the South Korean economy grew at an average annual rate of 3.7%, which was comparatively higher than that of the U.K. (1.1%), Germany (1.0%), and France (1.2%). As the South Korean economy has now entered a maturity stage in which economic growth is slowing down, the difference in the contribution of activity effect between countries will gradually diminish in the future.

The structure effect decreased GHG emissions in all countries, though its impact was insignificant. At least under the classification criteria used in this study, it can be affirmed that the industrial structure change is not a major driver for GHG emissions reduction. In particular, based on the sectoral analysis addressed earlier, a significant portion of the structure effect was caused by the decline of primary industries, such as Agriculture in South Korea and Mining in Europe. Considering that such a reduction in the primary industry is unlikely to be continued, there is a possibility that the level of structure effect will further decrease in the future.

The energy intensity effect contributed to significant reductions in GHG emissions in all countries. It is noteworthy that the energy intensity effect strongly contributed to emissions reduction in South Korea as in major European countries. However, as shown in Fig. 23, South Korea's energy intensity levels still remain relatively high compared to other major countries despite its rapid improvement. Generally, a multiplicity of factors, such as industrial structure, level of technology, energy cost and related policies, can influence energy intensity (Kim et al., 2020, p. 198). South Korea's high energy intensity level primarily stems from its economic structure with a high share of energy-intensive sectors. On top of that, when examining energy intensity on a sectoral basis, it was noticed that South Korea's energy intensity is higher than that of other major countries, even in the same sectors (see Fig. 24). This implies that there is still substantial potential for improvement in South Korea's energy intensity, excluding industrial structure aspect. Improving energy intensity will continue to be an important means of reducing GHG emissions.

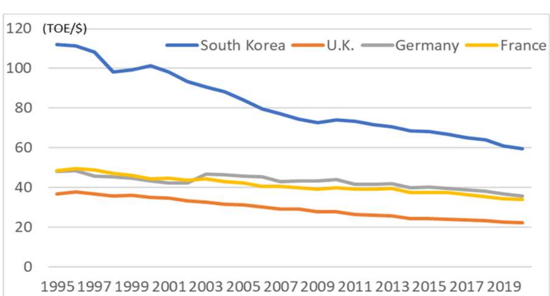


**Fig. 23**. Trends in Energy intensity of Total Economy

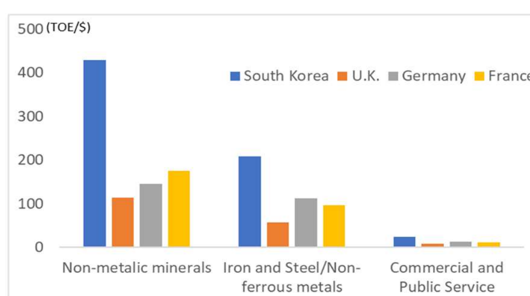


**Fig. 24**. Energy intensity by sectors (2020)

Lastly, the emission intensity effect shows the most noticeable difference between South Korea and major European countries. While the emission intensity effect was the primary driver for reducing GHG emissions in major European countries, it acted as a factor that slightly increased GHG emissions in South Korea. The reason for these different results can be seen in the trend of changes in each country's energy mix. Fig. 25 shows the trend in the share of fossil fuel electricity generation by country. It is a bit surprising that the fossil fuel share of the U.K. and Germany was higher than that of South Korea in 2000. Since then, the U.K. and Germany have actively implemented strong energy policies at the national level, resulting in a substantial decrease in the fossil fuel share to 40% in 2020. In contrast, in South Korea, the proportion of fossil fuel-based electricity generation has rather increased in 2020 compared to 2000. In the case of France, the proportion of fossil fuel electricity generation is significantly low throughout all time periods due to the country's exceptional reliance on nuclear power generation, which exceeds 70%.

This pattern can also be seen in the proportion of renewable energy. In South Korea, the share of renewable energy in final energy consumption is 3.36% in 2020, which is merely a quarter of that of other countries. Notably, the U.K.'s renewable energy share was nearly on par with South Korea's in 2000, and then it has been increasing significantly since the mid-2000s (see Fig. 26).

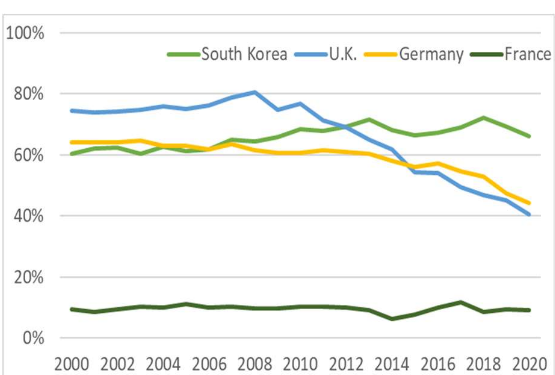


**Fig.25**. Fossil Fuel Share in the Electricity Generation

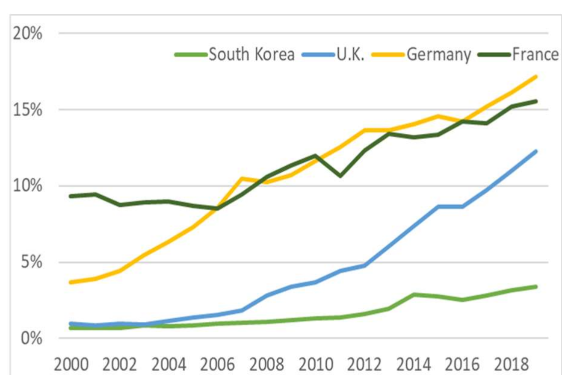


**Fig. 26.** Renewable Share in the Energy Consumption

### *4.4. South Korea's GHG emissions projection (What-if analysis)*

The analysis results so far have shown a huge gap between South Korea and major European countries in terms of energy-related performance, such as energy intensity and emissions intensity. Then, it will be interesting to see what level of GHG emissions reduction South Korea can achieve when it improves its energy and emission intensity levels to match those of leading countries. This sub-section shows the reduction results when South Korea's intensities have improved to the major European countries' levels. Scenarios are divided into two cases: the case of achieving the average level of three European countries (scenario 1) and the case of achieving the level of the U.K., which has demonstrated the most significant GHG emissions reduction among the three countries (scenario 2). The GHG emissions for each scenario were calculated by applying South Korea's added value (economic structure) in 2020 and the energy intensity and emission intensity in 2020 of advanced European countries for each of the sub-sectors. Exceptionally, sectors such as Agriculture, forestry and fishing, and Construction, where South Korea's energy and emissions intensity are lower than that of European countries, applied South Korea's intensity levels. Although this approach may not yield precise comparisons, it can be beneficial in providing a rough estimate of the emissions reduction level.

Table 18 presents South Korea's GHG emissions estimated based on different scenarios. When South Korea's energy and emission intensity matched the average levels of the three European countries (Scenario 1), GHG emissions decreased by 49.6% compared to its actual emissions in 2020. And when the energy and emission intensity reached the level seen in the U.K. (Scenario 2), GHG emissions decreased by 57.2%. These results indicate that South Korea has the potential to achieve substantial reductions in GHG emissions through enhancements in the energy sector, even if it retains its current industrial structure. By sub-sector, in both scenarios, significant decreases are observed in Iron and steel / non-ferrous metals, Non-metallic minerals, Commercial and public service, etc.

**Table 18**
South Korea's GHG Emissions Scenario (Unit: Kt $CO_2$eq)

| | Emissions (Base) | Scenario 1 | | Scenario 2 | |
|---|---|---|---|---|---|
| | | Emissions | (%) | Emissions | (%) |
| **Total** | **504,665** | **254,329** | **-49.6** | **215,866** | **-57.2** |
| Agriculture/fishing | 31,638 | 31,638 | - | 31,638 | - |
| Mining&Quarrying | 4,646 | 2,093 | -55.0 | 1,402 | -69.8 |
| Food and Tobacco | 7,035 | 3,258 | -53.7 | 2,288 | -67.5 |
| Textile and Leather | 4,808 | 2,706 | -43.7 | 3,184 | -33.8 |
| Wood and Paper | 5,884 | 5,741 | -2.4 | 2,007 | -65.9 |
| Chemical&Petrochemi | 97,521 | 65,177 | -33.2 | 54,094 | -44.5 |
| Non-metallic min. | 46,906 | 8,834 | -81.2 | 4,969 | -89.4 |
| Iron&Steel/Non-ferrous | 122,210 | 41,087 | -66.4 | 22,254 | -81.8 |
| Machinery | 36,380 | 27,809 | -23.6 | 35,840 | -1.5 |
| Transport Equipment | 10,449 | 4,208 | -59.7 | 5,324 | -49.1 |
| Other Manufacturing | 12,441 | 1,759 | -85.9 | 2,957 | -76.2 |
| Construction | 2,095 | 2,095 | - | 2,095 | - |
| Transport | 49,229 | 34,994 | -28.9 | 32,833 | -33.3 |
| Commercial&Public | 73,424 | 22,930 | -68.8 | 14,981 | -79.6 |

Meanwhile, South Korea has recently raised its Nationally Determined Contribution (NDC) goal to achieve a 40% GHG emissions reduction compared to 2018 levels by the year 2030. It is difficult to directly compare emissions levels in this study and the national GHG emissions statistics due to differences in coverage. However, considering the reduction scale of GHG emissions examined in the above scenario analysis is at around 50%, it becomes apparent that achieving South Korea's NDC target will be exceedingly demanding. This holds particularly true when considering the two aspects. First, the remaining time until 2030 is less than seven years. Second, the intensity levels from major European countries used in the scenario analysis are the outcomes of decades of systematic efforts at the national level.

## 5. Conclusions

This study examined GHG emissions by industrial sub-sector in South Korea and major leading European countries that have succeeded in reducing GHG emissions, and attempted a decomposition analysis of the factors that contributed to changes in emissions. The key findings of the analysis can be outlined as follows: First, the activity effect was the most important factor in increasing GHG emissions across all countries. And both structure and energy intensity effects contributed to reducing GHG emissions in all countries. In terms of the level of contribution, the energy intensity effect was greater than the structure effect. On the other hand, the direction emission intensity effect was the opposite in South Korea and major European countries. While it played a pivotal role in decreasing emissions in European countries, in South Korea, it acted in the direction of slightly increasing emissions.

Based on the findings above, the following considerations and policy strategies are recommended to further reduce GHG emissions in South Korea.

1. **GHG emissions reduction is achievable without a drastic change in the industrial structure**. There is no doubt that the composition of industries within a country has a huge impact on the current GHG emissions levels it produces. However, this doesn't necessarily imply that reducing future GHG emissions is challenging for countries with a high ratio of carbon-intensive manufacturing. Major European countries have successfully reduced GHG emissions without significantly altering their industrial structure. Notably, Germany, which has a similar industrial structure to South Korea, has achieved substantial emissions reductions while maintaining a high share of manufacturing. In the pursuit of carbon neutrality in the future, some adjustments in industrial structure may arise. However, these adjustments are more likely to be autonomous, taking production costs into account, rather than artificial restructuring. Additionally, the form of industrial restructuring does not

necessarily mean a huge transformation, such as a shift from manufacturing to service industries. Even within specific manufacturing industries, upgrading main products or eco-friendly improvement of a production process can lead to GHG emissions reduction. In some respects, South Korea's high share of manufacturing and carbon-intensive sectors could serve as an opportunity to achieve even more GHG emissions reduction depending on future responses.

2. **Fundamental improvement in energy mix is the top priority**. The transition to green energy is a key prerequisite for decarbonization strategies, including industrial sector GHG reductions. As seen above, South Korea is the only country whose emission intensity effect has contributed to the increase of GHG emissions. South Korea's high dependence on fossil fuels has barely improved over the past few decades. Of course, unfavourable natural factors such as South Korea's small land area partially influenced this result, but it is also true that there was a lack of endeavours to make improvements at the national level. South Korea has been complacent with its economic growth dependent on inexpensive fossil fuels. Even though a wide range of policies have been released to promote renewable energy in electricity generation, the effectiveness of these policies and measures is not remarkable. Recently, South Korea set a goal to increase its share of electricity generation from renewable energy sources by over 21.6% in 2030 (Ministry of Trade, Industry and Energy, 2022). To achieve this goal, the government should establish comprehensive national-level action plans and proactively support technology development in related fields while enhancing the institutional system. It is also necessary to ease regulations and increase public acceptance to prevent procedural delays in promoting infrastructure projects related to renewable energy. Meanwhile, the insufficient power generation during the transition period from fossil fuels to renewable energy needs to be supplemented by leveraging nuclear power generation, which South Korea has technological strengths.

3. **Normalisation of the energy pricing structure is required.** As seen above, South Korea's energy intensity is gradually improving, but it still remains at a high level compared to other advanced countries. This is not only due to technological differences, but also to South Korea's abnormal energy prices, which affect energy consumption on the demand side. Generally, energy prices are higher in countries with lower energy self-sufficiency rates. However, in the case of South Korea, the government directly control energy prices by considering the inflation level and its industrial impact. Thus, it has kept energy prices relatively low, despite its low energy self-sufficiency rates. South Korea's electricity rates are only 59% of the OECD average for household use and 87% of the OECD average for industrial use (IEA, 2020). Such abnormal energy prices reduce the need for technology development in energy conservation and energy efficiency improvement, consequently negatively affecting GHG emissions reduction. There is a need for a practical reform of the energy price determination system to restore the proper functioning of the energy market.

4. **Differentiated policies and measures should be considered for various industrial sub-sectors to maximise the reduction performance**. In the case of Korea, the level of energy efficiency and the pace of improvement exhibit variations across industries, even in sub-sectors within the manufacturing sector. The energy intensity has been significantly improved in some sectors, such as Non-metallic minerals and Machinery, whereas the progress was not that remarkable in some other sectors, such as Wood and paper, Textile and leather, and Food and tobacco. This phenomenon indicates that the appropriateness of energy efficiency policies and measures varies among different sub-sectors. For those sub-sectors that have performed worse in energy efficiency improvement in the past few years, more detailed and innovative policies, specially tailored to their distinct features should be devised and enacted.

5. **More attention should be placed on supporting the private sector's voluntary efforts to reduce GHG emissions.** As seen above, almost 70% of South Korea's GHG emissions come from manufacturing. The performance of emissions reduction in manufacturing depends on the development of innovative future technologies, along with improvement in the energy sector. Unlike the energy sector, where the government has a relatively substantial role, the development of technology is primarily led by the private sector. The government should strengthen incentive-based support, such as increasing the budget for extensive research and development investments, expanding tax benefits, and offering financial support to companies. The government's support will help distribute the risks of the private sector during technology development and implementation, fostering an environment where more companies are encouraged to embark on such endeavours.

Every study has some limitations as well. There are some unaddressed issues in this study and things to be considered in further research. For example, this study mainly focused on numerically decomposing the country's GHG emissions factors but did not address the specific policy background of each country that affected the changes in factors. Examining the detailed GHG emissions reduction process of advanced countries and making specific policy recommendations for South Korea will be the author's next research task. In addition, due to the limitations of available data, industrial sub-sectors were classified into only 14 sectors. If sub-sectors can be further subdivided, it will be possible to more accurately measure the structure effect and compare energy and emissions intensity by sector. It would be highly beneficial if an international organization with public trust could produce sectoral emissions statistics compatible with the industry classification system since the emissions data is vital for formulating effective GHG emissions reduction strategies for each sector. Lastly, due to the lack of reliable data, the study didn't address the major emitting countries such as China and

India. Further analysis can be conducted from a broader range of perspectives by decomposing and comparing the GHG emissions factors of advanced and developing countries.

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# Appendix

**Table 1** [South Korea] Estimated GHG emissions by Industrial sub-sectors (Kt $CO_2$eq)

| | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Agriculture, forestry and fishing | 32,585 | 34,448 | 35,635 | 33,871 | 33,568 | 33,850 | 34,381 | 34,140 | 32,195 | 31,718 | 31,567 | 31,349 | 31,542 | 30,825 | 32,347 | 33,577 | 32,294 | 33,231 | 33,859 | 32,206 | 31,702 | 31,377 | 31,479 | 32,187 | 32,045 | 31,638 |
| Mining and quarrying | 2,644 | 2,666 | 3,459 | 3,543 | 3,412 | 3,690 | 3,879 | 2,852 | 3,254 | 4,423 | 3,845 | 3,420 | 3,399 | 3,590 | 3,746 | 3,946 | 3,736 | 3,611 | 3,459 | 3,054 | 3,016 | 2,938 | 3,696 | 3,171 | 3,031 | 4,646 |
| Food and Tabacco | 6,459 | 6,958 | 6,843 | 5,765 | 5,619 | 5,997 | 6,180 | 6,164 | 5,926 | 6,025 | 6,027 | 5,810 | 6,222 | 5,921 | 6,396 | 7,544 | 7,449 | 7,626 | 7,277 | 7,315 | 7,425 | 7,773 | 7,876 | 8,540 | 8,164 | 7,035 |
| Textile and Leather | 13,006 | 14,045 | 14,599 | 13,685 | 15,403 | 15,967 | 15,212 | 15,813 | 12,966 | 12,730 | 11,486 | 10,332 | 10,066 | 9,976 | 9,626 | 10,488 | 10,456 | 9,624 | 9,373 | 8,626 | 8,229 | 7,431 | 7,240 | 7,048 | 6,117 | 4,808 |
| Wood and Paper | 7,687 | 9,002 | 9,502 | 7,781 | 8,544 | 9,218 | 9,623 | 9,585 | 8,329 | 8,469 | 8,076 | 7,763 | 7,593 | 7,391 | 7,579 | 9,245 | 9,119 | 8,685 | 8,864 | 7,915 | 7,653 | 8,507 | 7,354 | 7,387 | 6,778 | 5,884 |
| Chemical and Petrochemical | 49,701 | 54,803 | 61,425 | 57,652 | 60,765 | 68,023 | 68,973 | 70,301 | 77,648 | 81,970 | 81,251 | 82,207 | 75,381 | 76,245 | 75,902 | 79,507 | 86,496 | 87,899 | 90,994 | 92,489 | 89,164 | 90,368 | 93,525 | 101,387 | 100,196 | 97,521 |
| Non-metalic minerals | 58,320 | 56,187 | 59,593 | 46,479 | 48,346 | 50,503 | 52,191 | 54,522 | 56,192 | 53,128 | 49,136 | 49,438 | 53,253 | 53,596 | 49,831 | 51,595 | 54,476 | 52,619 | 52,893 | 54,287 | 54,602 | 55,500 | 54,058 | 51,532 | 52,118 | 46,906 |
| Iron and Steel/Non-ferrous metals | 61,199 | 66,100 | 68,791 | 67,097 | 69,915 | 72,944 | 72,841 | 76,002 | 78,089 | 79,705 | 80,571 | 85,423 | 89,483 | 96,772 | 90,248 | 114,457 | 129,214 | 128,455 | 129,254 | 142,544 | 134,923 | 128,836 | 135,869 | 132,915 | 129,279 | 122,210 |
| Machinary | 8,189 | 12,056 | 13,075 | 11,063 | 12,857 | 13,694 | 14,720 | 16,242 | 16,543 | 18,565 | 20,802 | 21,536 | 22,387 | 25,025 | 27,253 | 33,443 | 34,543 | 35,789 | 37,864 | 36,066 | 37,285 | 36,708 | 39,069 | 43,179 | 40,639 | 36,380 |
| Transport Equipment | 3,250 | 4,450 | 5,145 | 4,050 | 4,557 | 5,209 | 5,195 | 5,641 | 6,147 | 6,734 | 6,518 | 6,804 | 9,776 | 10,369 | 10,503 | 12,922 | 13,783 | 13,953 | 14,886 | 13,442 | 13,860 | 14,194 | 13,282 | 13,083 | 12,079 | 10,449 |
| Other Manufacturing | 3,597 | 6,766 | 5,872 | 5,181 | 6,701 | 8,841 | 10,620 | 11,985 | 13,368 | 12,327 | 12,878 | 10,935 | 12,796 | 12,177 | 12,726 | 14,573 | 16,548 | 15,899 | 15,094 | 13,137 | 16,370 | 15,952 | 16,383 | 15,361 | 14,005 | 12,441 |
| Construction | 1,203 | 1,216 | 1,395 | 1,025 | 1,068 | 1,351 | 1,269 | 1,561 | 1,785 | 1,908 | 2,028 | 2,726 | 2,345 | 2,285 | 2,739 | 2,483 | 2,519 | 2,215 | 2,152 | 2,304 | 2,551 | 2,628 | 2,213 | 2,172 | 2,141 | 2,095 |
| Transport | 33,086 | 35,129 | 37,879 | 29,390 | 31,950 | 35,781 | 37,479 | 39,982 | 41,361 | 41,516 | 41,967 | 42,357 | 43,523 | 42,403 | 42,883 | 43,755 | 43,620 | 44,291 | 45,236 | 45,246 | 48,079 | 50,533 | 50,385 | 50,403 | 51,789 | 49,229 |
| Commercial and Public Service | 37,337 | 41,323 | 47,384 | 39,326 | 44,955 | 45,975 | 50,059 | 54,008 | 55,781 | 56,651 | 64,196 | 66,962 | 69,848 | 73,802 | 80,674 | 85,114 | 86,584 | 88,868 | 89,499 | 81,779 | 85,062 | 85,688 | 87,182 | 92,498 | 85,181 | 73,424 |
| **Total** | **318,262** | **345,149** | **370,599** | **325,910** | **347,659** | **371,041** | **382,623** | **398,797** | **409,583** | **415,869** | **420,348** | **427,063** | **437,614** | **450,377** | **452,455** | **502,652** | **530,836** | **532,766** | **540,705** | **540,412** | **539,919** | **538,435** | **549,610** | **560,863** | **543,563** | **504,665** |
| Manufacturing | 211,407 | 230,367 | 244,846 | 218,755 | 232,705 | 250,395 | 255,555 | 266,254 | 275,208 | 279,652 | 276,745 | 280,248 | 286,956 | 297,472 | 290,065 | 333,776 | 362,083 | 360,550 | 366,499 | 375,821 | 369,510 | 365,271 | 374,655 | 380,433 | 369,376 | 343,633 |
| *(%)* | *66.4%* | *66.7%* | *66.1%* | *67.1%* | *66.9%* | *67.5%* | *66.8%* | *66.8%* | *67.2%* | *67.2%* | *65.8%* | *65.6%* | *65.6%* | *66.0%* | *64.1%* | *66.4%* | *68.2%* | *67.7%* | *67.8%* | *69.5%* | *68.4%* | *67.8%* | *68.2%* | *67.8%* | *68.0%* | *68.1%* |
| Carbon Intensive Manufacturing | 169,220 | 177,090 | 189,810 | 171,228 | 179,025 | 191,470 | 194,006 | 200,826 | 211,929 | 214,802 | 210,958 | 217,068 | 218,117 | 226,613 | 215,981 | 245,559 | 270,185 | 268,973 | 273,142 | 289,321 | 278,689 | 274,704 | 283,451 | 285,834 | 281,594 | 266,636 |
| *(%)* | *53.2%* | *51.3%* | *51.2%* | *52.5%* | *51.5%* | *51.6%* | *50.7%* | *50.4%* | *51.7%* | *51.7%* | *50.2%* | *50.8%* | *49.8%* | *50.3%* | *47.7%* | *48.9%* | *50.9%* | *50.5%* | *50.5%* | *53.5%* | *51.6%* | *51.0%* | *51.6%* | *51.0%* | *51.8%* | *52.8%* |

**Table 2** [U.K.] Estimated GHG emissions by Industrial sub-sectors (Kt $CO_2$eq)

| | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Agriculture, forestry and fishing | 56,545 | 57,337 | 56,337 | 56,488 | 56,372 | 54,089 | 51,922 | 51,539 | 52,410 | 52,475 | 52,150 | 50,931 | 50,312 | 48,845 | 48,139 | 48,680 | 48,523 | 48,314 | 47,892 | 49,375 | 48,899 | 48,503 | 48,896 | 48,252 | 48,305 | 46,483 |
| Mining and quarrying | 36,147 | 35,857 | 37,328 | 36,100 | 34,909 | 34,151 | 33,850 | 32,675 | 30,850 | 29,609 | 27,808 | 26,204 | 25,010 | 25,029 | 24,819 | 24,960 | 22,668 | 20,993 | 20,150 | 20,075 | 20,182 | 18,867 | 18,649 | 18,125 | 18,312 | 18,015 |
| Food and Tabacco | 12,748 | 12,875 | 12,105 | 11,851 | 12,001 | 11,962 | 12,306 | 11,927 | 11,702 | 11,993 | 11,353 | 11,304 | 11,121 | 10,880 | 9,250 | 10,139 | 9,698 | 10,050 | 9,783 | 8,894 | 7,740 | 6,950 | 6,756 | 6,835 | 6,459 | 5,927 |
| Textile and Leather | 6,422 | 6,188 | 6,082 | 6,534 | 6,719 | 7,850 | 7,317 | 6,418 | 7,080 | 6,821 | 7,413 | 7,201 | 6,918 | 6,106 | 5,610 | 5,559 | 5,092 | 4,764 | 4,736 | 4,458 | 3,119 | 2,959 | 2,879 | 2,677 | 2,429 | 2,257 |
| Wood and Paper | 9,583 | 8,769 | 8,421 | 8,188 | 8,343 | 9,630 | 9,905 | 9,686 | 10,154 | 10,252 | 10,810 | 10,732 | 10,188 | 9,698 | 7,921 | 9,030 | 8,265 | 8,512 | 8,301 | 7,579 | 5,750 | 4,925 | 4,262 | 4,009 | 3,610 | 3,142 |
| Chemical and Petrochemical | 107,375 | 107,816 | 104,250 | 99,834 | 76,871 | 75,414 | 72,716 | 72,977 | 69,642 | 64,499 | 64,451 | 60,193 | 60,984 | 58,363 | 50,674 | 52,345 | 48,946 | 47,320 | 44,851 | 39,935 | 38,973 | 37,692 | 37,569 | 36,048 | 34,512 | 31,348 |
| Non-metalic minerals | 17,966 | 18,193 | 18,225 | 18,487 | 17,358 | 17,520 | 16,918 | 16,919 | 16,985 | 17,426 | 17,240 | 17,450 | 17,701 | 15,680 | 11,437 | 12,082 | 12,238 | 11,799 | 12,139 | 11,771 | 11,378 | 10,771 | 10,515 | 10,305 | 10,158 | 8,952 |
| Iron and Steel/Non-ferrous metals | 42,441 | 43,843 | 42,473 | 40,839 | 41,991 | 36,275 | 34,724 | 30,787 | 33,756 | 33,590 | 33,120 | 34,792 | 34,422 | 33,010 | 25,154 | 24,357 | 22,624 | 22,310 | 23,885 | 23,584 | 21,268 | 15,204 | 14,457 | 13,613 | 13,717 | 13,383 |
| Machinary | 18,458 | 16,007 | 15,384 | 16,089 | 15,809 | 17,521 | 16,578 | 14,941 | 15,661 | 16,066 | 17,206 | 16,750 | 16,401 | 14,859 | 12,662 | 12,774 | 11,670 | 11,958 | 11,436 | 10,362 | 11,957 | 11,184 | 11,158 | 10,863 | 9,924 | 9,290 |
| Transport Equipment | 6,371 | 9,663 | 9,179 | 9,513 | 9,933 | 10,990 | 10,918 | 9,737 | 10,372 | 10,321 | 10,768 | 10,245 | 9,476 | 8,490 | 7,558 | 8,516 | 8,218 | 8,312 | 8,835 | 8,503 | 6,676 | 6,483 | 6,233 | 6,158 | 5,583 | 4,683 |
| Other Manufacturing | 13,490 | 13,790 | 13,351 | 13,502 | 13,463 | 14,662 | 16,176 | 15,782 | 15,788 | 18,185 | 18,222 | 19,029 | 18,865 | 18,363 | 15,222 | 16,031 | 14,467 | 16,168 | 14,292 | 13,198 | 12,678 | 11,425 | 11,265 | 11,340 | 10,280 | 8,609 |
| Construction | 5,526 | 5,338 | 5,145 | 5,462 | 5,361 | 6,011 | 5,875 | 5,111 | 4,576 | 3,759 | 4,133 | 3,838 | 3,747 | 4,605 | 4,132 | 4,099 | 3,734 | 3,542 | 3,612 | 3,574 | 4,081 | 4,255 | 4,524 | 4,466 | 4,221 | 4,059 |
| Transport | 70,847 | 72,955 | 73,396 | 73,775 | 73,500 | 72,472 | 72,529 | 73,476 | 73,824 | 72,604 | 73,475 | 73,353 | 74,288 | 70,242 | 67,221 | 67,343 | 65,687 | 65,252 | 64,709 | 65,755 | 67,425 | 68,753 | 68,909 | 68,023 | 66,515 | 56,679 |
| Commercial and Public Service | 76,150 | 77,392 | 73,259 | 73,671 | 71,936 | 74,475 | 78,626 | 70,757 | 72,398 | 73,586 | 73,938 | 74,223 | 72,309 | 74,690 | 65,984 | 70,056 | 63,185 | 70,425 | 68,420 | 58,489 | 52,591 | 45,979 | 42,449 | 40,353 | 37,732 | 33,072 |
| **Total** | **480,068** | **486,023** | **474,935** | **470,332** | **444,566** | **443,022** | **440,360** | **422,731** | **425,198** | **421,188** | **422,088** | **416,246** | **411,741** | **398,861** | **355,782** | **365,970** | **345,014** | **349,719** | **343,040** | **325,550** | **312,717** | **293,949** | **288,521** | **281,066** | **271,757** | **245,897** |
| Manufacturing | 234,853 | 237,144 | 229,471 | 224,836 | 202,488 | 201,824 | 197,558 | 189,174 | 191,140 | 189,153 | 190,584 | 187,697 | 186,076 | 175,450 | 145,488 | 150,833 | 141,217 | 141,194 | 138,257 | 128,282 | 119,539 | 107,592 | 105,094 | 101,848 | 96,671 | 87,590 |
| *(%)* | *48.9%* | *48.8%* | *48.3%* | *47.8%* | *45.5%* | *45.6%* | *44.9%* | *44.8%* | *45.0%* | *44.9%* | *45.2%* | *45.1%* | *45.2%* | *44.0%* | *40.9%* | *41.2%* | *40.9%* | *40.4%* | *40.3%* | *39.4%* | *38.2%* | *36.6%* | *36.4%* | *36.2%* | *35.6%* | *35.6%* |
| Carbon Intensive Manufacturing | 167,781 | 169,852 | 164,948 | 159,160 | 136,220 | 129,209 | 124,359 | 120,683 | 120,382 | 115,515 | 114,812 | 112,435 | 113,107 | 107,053 | 87,265 | 88,785 | 83,807 | 81,429 | 80,875 | 75,290 | 71,619 | 63,666 | 62,541 | 59,966 | 58,387 | 53,683 |
| *(%)* | *34.9%* | *34.9%* | *34.7%* | *33.8%* | *30.6%* | *29.2%* | *28.2%* | *28.5%* | *28.3%* | *27.4%* | *27.2%* | *27.0%* | *27.5%* | *26.8%* | *24.5%* | *24.3%* | *24.3%* | *23.3%* | *23.6%* | *23.1%* | *22.9%* | *21.7%* | *21.7%* | *21.3%* | *21.5%* | *21.8%* |

**Table 3** [Germany] Estimated GHG emissions by Industrial sub-sectors (Kt $CO_2eq$)

| | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Agriculture, forestry and fishing | 71,440 | 72,956 | 70,861 | 70,885 | 71,064 | 69,741 | 70,832 | 68,415 | 67,521 | 66,636 | 66,433 | 65,589 | 65,747 | 66,460 | 66,175 | 66,701 | 67,378 | 67,398 | 67,622 | 70,371 | 69,700 | 69,424 | 67,935 | 65,997 | 64,819 | 63,866 |
| Mining and quarrying | 68,566 | 59,754 | 51,538 | 44,928 | 43,995 | 42,747 | 38,621 | 38,262 | 35,970 | 35,256 | 32,531 | 30,516 | 29,064 | 26,191 | 21,310 | 24,053 | 24,047 | 18,420 | 17,945 | 16,669 | 16,613 | 16,167 | 15,974 | 15,576 | 12,638 | 11,773 |
| Food and Tabacco | 9,884 | 10,064 | 9,355 | 9,584 | 8,915 | 9,847 | 10,301 | 9,462 | 10,300 | 10,047 | 9,793 | 9,881 | 10,522 | 10,236 | 9,999 | 10,202 | 10,195 | 10,886 | 10,957 | 11,019 | 10,439 | 10,542 | 9,835 | 9,838 | 8,131 | 7,093 |
| Textile and Leather | 10,666 | 10,196 | 10,236 | 9,862 | 8,808 | 8,806 | 8,628 | 8,088 | 7,251 | 5,868 | 5,525 | 5,455 | 5,289 | 4,499 | 3,691 | 4,184 | 4,004 | 3,989 | 3,516 | 3,439 | 3,672 | 3,440 | 3,384 | 2,879 | 2,437 | 1,980 |
| Wood and Paper | 15,563 | 15,276 | 15,154 | 15,112 | 15,776 | 17,406 | 18,110 | 17,508 | 22,153 | 24,958 | 26,147 | 25,239 | 27,560 | 25,183 | 25,341 | 29,200 | 30,636 | 31,587 | 30,567 | 29,836 | 28,163 | 28,827 | 27,265 | 24,510 | 20,939 | 18,572 |
| Chemical and Petrochemical | 127,796 | 126,202 | 123,443 | 108,867 | 102,352 | 98,977 | 101,333 | 102,304 | 105,872 | 102,731 | 104,144 | 107,617 | 114,954 | 111,182 | 104,475 | 101,416 | 98,669 | 100,154 | 100,497 | 97,820 | 96,711 | 98,879 | 97,073 | 92,658 | 84,682 | 76,626 |
| Non-metalic minerals | 51,437 | 49,598 | 49,951 | 49,454 | 48,960 | 48,420 | 44,478 | 42,640 | 42,840 | 43,244 | 39,911 | 41,296 | 43,952 | 41,962 | 37,280 | 38,740 | 40,721 | 39,506 | 38,359 | 39,294 | 38,559 | 38,466 | 39,135 | 38,857 | 36,996 | 35,720 |
| Iron and Steel/Non-ferrous metals | 78,184 | 72,806 | 76,986 | 78,651 | 73,381 | 80,307 | 74,796 | 74,590 | 74,401 | 75,713 | 76,409 | 78,271 | 81,182 | 77,475 | 56,445 | 74,357 | 71,408 | 68,965 | 70,161 | 72,035 | 78,227 | 77,393 | 78,774 | 76,062 | 69,433 | 60,604 |
| Machinary | 29,016 | 29,606 | 29,262 | 27,401 | 26,433 | 26,274 | 26,859 | 26,714 | 34,037 | 35,438 | 34,174 | 36,414 | 36,303 | 42,163 | 36,159 | 39,533 | 38,004 | 38,740 | 40,112 | 38,788 | 34,833 | 35,511 | 34,879 | 31,057 | 27,620 | 23,671 |
| Transport Equipment | 24,668 | 25,736 | 25,634 | 24,653 | 24,160 | 24,233 | 25,258 | 25,049 | 24,165 | 23,318 | 22,390 | 22,362 | 21,961 | 20,240 | 17,038 | 19,371 | 19,031 | 19,896 | 20,873 | 19,282 | 19,076 | 20,267 | 19,855 | 17,333 | 15,426 | 12,982 |
| Other Manufacturing | 15,310 | 14,895 | 13,595 | 13,288 | 16,043 | 14,181 | 15,421 | 15,439 | 15,206 | 15,238 | 14,371 | 15,366 | 16,893 | 12,011 | 11,333 | 11,938 | 11,952 | 12,148 | 12,236 | 12,093 | 11,967 | 12,133 | 11,551 | 10,948 | 9,587 | 8,617 |
| Construction | 8,777 | 8,191 | 8,769 | 9,048 | 8,653 | 8,364 | 7,613 | 7,040 | 5,491 | 5,055 | 4,933 | 5,287 | 5,292 | 5,346 | 5,297 | 6,459 | 6,330 | 6,385 | 5,447 | 6,405 | 6,154 | 6,190 | 6,379 | 15,894 | 16,292 | 15,701 |
| Transport | 92,299 | 92,604 | 93,517 | 96,801 | 100,397 | 99,755 | 96,951 | 94,751 | 89,245 | 87,844 | 84,282 | 84,476 | 82,527 | 82,019 | 81,209 | 84,038 | 84,526 | 86,001 | 88,357 | 86,726 | 88,814 | 90,387 | 91,473 | 89,251 | 89,581 | 81,526 |
| Commercial and Public Service | 120,590 | 134,822 | 124,037 | 124,800 | 119,372 | 125,565 | 134,902 | 135,752 | 135,868 | 131,678 | 126,879 | 133,428 | 122,238 | 128,060 | 123,199 | 119,623 | 114,216 | 120,545 | 120,861 | 109,529 | 111,987 | 108,225 | 102,063 | 94,002 | 82,596 | 71,760 |
| **Total** | **724,195** | **722,706** | **702,339** | **683,334** | **668,308** | **674,624** | **674,103** | **666,016** | **670,320** | **663,024** | **647,923** | **661,195** | **663,484** | **653,027** | **598,950** | **629,815** | **621,117** | **624,621** | **627,511** | **613,305** | **614,915** | **615,851** | **605,575** | **584,863** | **541,179** | **490,491** |
| Manufacturing | 362,524 | 354,379 | 353,617 | 336,872 | 324,827 | 328,451 | 325,184 | 321,795 | 336,225 | 336,556 | 332,864 | 341,899 | 358,616 | 344,951 | 301,761 | 328,942 | 324,619 | 325,871 | 327,279 | 323,605 | 321,647 | 325,457 | 321,751 | 304,142 | 275,253 | 245,866 |
| *(%)* | *50.1%* | *49.0%* | *50.3%* | *49.3%* | *48.6%* | *48.7%* | *48.2%* | *48.3%* | *50.2%* | *50.8%* | *51.4%* | *51.7%* | *54.1%* | *52.8%* | *50.4%* | *52.2%* | *52.3%* | *52.2%* | *52.2%* | *52.8%* | *52.3%* | *52.8%* | *53.1%* | *52.0%* | *50.9%* | *50.1%* |
| Carbon Intensive Manufacturing | 257,417 | 248,605 | 250,380 | 236,972 | 224,693 | 227,704 | 220,607 | 219,535 | 223,113 | 221,688 | 220,464 | 227,183 | 240,087 | 230,619 | 198,200 | 214,513 | 210,797 | 208,625 | 209,018 | 209,149 | 213,497 | 214,738 | 214,981 | 207,578 | 191,111 | 172,951 |
| *(%)* | *35.5%* | *34.4%* | *35.6%* | *34.7%* | *33.6%* | *33.8%* | *32.7%* | *33.0%* | *33.3%* | *33.4%* | *34.0%* | *34.4%* | *36.2%* | *35.3%* | *33.1%* | *34.1%* | *33.9%* | *33.4%* | *33.3%* | *34.1%* | *34.7%* | *34.9%* | *35.5%* | *35.5%* | *35.3%* | *35.3%* |

**Table 4** [France] Estimated GHG emissions by Industrial sub-sectors (Kt $CO_2eq$)

| | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Agriculture, forestry and fishing | 91,507 | 92,253 | 92,485 | 92,757 | 93,270 | 95,132 | 94,762 | 93,020 | 90,234 | 91,435 | 90,133 | 89,253 | 89,855 | 90,796 | 90,140 | 88,609 | 87,690 | 87,107 | 87,184 | 88,860 | 88,629 | 86,673 | 86,837 | 85,408 | 84,232 | 82,643 |
| Mining and quarrying | 9,802 | 8,624 | 7,957 | 7,974 | 7,840 | 6,716 | 6,290 | 5,426 | 5,567 | 4,913 | 4,616 | 4,511 | 4,183 | 3,926 | 3,681 | 3,739 | 3,879 | 3,534 | 3,532 | 3,602 | 3,773 | 3,687 | 3,799 | 3,696 | 3,611 | 2,913 |
| Food and Tabacco | 12,636 | 12,626 | 12,279 | 12,766 | 12,947 | 12,074 | 12,177 | 12,400 | 12,195 | 11,510 | 12,484 | 12,436 | 12,507 | 11,645 | 10,772 | 12,065 | 11,129 | 10,969 | 10,985 | 10,158 | 10,234 | 10,566 | 10,236 | 10,053 | 10,014 | 8,993 |
| Textile and Leather | 1,898 | 2,046 | 1,851 | 1,899 | 1,816 | 3,067 | 3,525 | 3,496 | 3,351 | 2,924 | 1,286 | 1,321 | 1,024 | 1,061 | 723 | 635 | 674 | 596 | 605 | 513 | 524 | 535 | 605 | 551 | 493 | 410 |
| Wood and Paper | 9,117 | 9,567 | 9,460 | 10,136 | 9,559 | 9,108 | 8,776 | 8,511 | 8,649 | 8,249 | 7,104 | 6,683 | 6,360 | 6,059 | 5,374 | 5,631 | 4,731 | 4,763 | 5,240 | 4,565 | 4,616 | 4,831 | 4,749 | 4,677 | 4,258 | 3,981 |
| Chemical and Petrochemical | 75,141 | 77,890 | 77,962 | 68,547 | 62,440 | 61,516 | 63,759 | 57,971 | 57,845 | 54,199 | 55,818 | 53,385 | 52,680 | 51,572 | 47,194 | 43,435 | 40,930 | 37,571 | 36,198 | 34,687 | 33,690 | 33,251 | 33,019 | 31,326 | 30,033 | 26,914 |
| Non-metalic minerals | 27,749 | 27,399 | 26,223 | 27,060 | 26,959 | 26,236 | 26,970 | 25,869 | 25,735 | 26,429 | 26,263 | 27,361 | 27,495 | 26,276 | 23,038 | 23,838 | 23,525 | 22,248 | 21,752 | 20,972 | 19,886 | 20,184 | 19,538 | 20,235 | 20,248 | 18,448 |
| Iron and Steel/Non-ferrous metals | 32,136 | 31,646 | 33,047 | 34,757 | 35,632 | 35,357 | 32,515 | 35,340 | 34,421 | 33,044 | 33,090 | 33,800 | 34,318 | 30,683 | 20,906 | 26,542 | 24,647 | 24,096 | 25,359 | 25,271 | 25,092 | 25,748 | 27,298 | 26,577 | 24,356 | 21,162 |
| Machinary | 6,023 | 6,688 | 6,051 | 6,839 | 6,453 | 3,977 | 3,852 | 3,750 | 3,769 | 3,612 | 4,489 | 4,525 | 4,361 | 4,056 | 3,474 | 3,638 | 3,555 | 3,671 | 3,831 | 3,125 | 3,094 | 3,158 | 3,148 | 2,815 | 2,805 | 2,475 |
| Transport Equipment | 1,190 | 1,257 | 1,112 | 1,488 | 1,411 | 2,510 | 2,428 | 2,346 | 2,431 | 2,431 | 2,830 | 2,524 | 2,589 | 2,105 | 1,941 | 1,914 | 1,637 | 1,694 | 1,699 | 1,356 | 1,399 | 1,526 | 1,619 | 1,489 | 1,491 | 1,210 |
| Other Manufacturing | 1,812 | 1,949 | 1,648 | 2,253 | 2,101 | 2,208 | 2,279 | 2,351 | 2,651 | 2,611 | 3,228 | 2,392 | 2,189 | 1,471 | 1,228 | 1,676 | 1,620 | 1,718 | 1,688 | 1,383 | 1,448 | 1,508 | 1,591 | 1,423 | 1,410 | 1,262 |
| Construction | 2,188 | 2,239 | 1,904 | 3,285 | 2,829 | 2,149 | 2,653 | 3,598 | 3,378 | 3,159 | 4,312 | 3,814 | 3,382 | 3,901 | 2,616 | 2,916 | 3,234 | 3,170 | 3,120 | 2,989 | 2,984 | 2,945 | 3,033 | 2,984 | 3,198 | 3,028 |
| Transport | 75,953 | 76,758 | 78,821 | 81,081 | 82,703 | 82,542 | 83,226 | 84,287 | 82,755 | 83,786 | 82,657 | 82,195 | 81,329 | 77,817 | 76,026 | 77,040 | 78,121 | 76,927 | 76,569 | 75,704 | 76,906 | 76,700 | 77,926 | 76,646 | 76,400 | 64,861 |
| Commercial and Public Service | 36,094 | 39,354 | 36,314 | 40,976 | 40,101 | 38,242 | 37,581 | 36,056 | 40,558 | 40,576 | 42,037 | 38,642 | 38,752 | 39,626 | 42,601 | 43,417 | 34,572 | 38,168 | 38,880 | 31,599 | 33,736 | 34,369 | 36,608 | 33,228 | 32,036 | 29,163 |
| **Total** | **383,248** | **390,296** | **387,114** | **391,818** | **386,060** | **380,835** | **380,791** | **374,421** | **373,540** | **368,877** | **370,347** | **362,843** | **361,025** | **350,992** | **329,715** | **335,096** | **319,943** | **316,230** | **316,642** | **304,784** | **306,011** | **305,682** | **310,005** | **301,108** | **294,585** | **267,462** |
| Manufacturing | 167,703 | 171,067 | 169,633 | 165,745 | 159,318 | 156,053 | 156,281 | 152,034 | 151,048 | 145,008 | 146,592 | 144,427 | 143,524 | 134,927 | 114,650 | 119,375 | 112,447 | 107,325 | 107,357 | 102,030 | 99,983 | 101,308 | 101,802 | 99,145 | 95,109 | 84,855 |
| *(%)* | *43.8%* | *43.8%* | *43.8%* | *42.3%* | *41.3%* | *41.0%* | *41.0%* | *40.6%* | *40.4%* | *39.3%* | *39.6%* | *39.8%* | *39.8%* | *38.4%* | *34.8%* | *35.6%* | *35.1%* | *33.9%* | *33.9%* | *33.5%* | *32.7%* | *33.1%* | *32.8%* | *32.9%* | *32.3%* | *31.7%* |
| Carbon Intensive Manufacturing | 135,027 | 136,935 | 137,232 | 130,364 | 125,031 | 123,110 | 123,244 | 119,180 | 118,002 | 113,672 | 115,172 | 114,547 | 114,494 | 108,531 | 91,138 | 93,815 | 89,101 | 83,915 | 83,309 | 80,931 | 78,668 | 79,183 | 79,854 | 78,138 | 74,638 | 66,524 |
| *(%)* | *35.2%* | *35.1%* | *35.5%* | *33.3%* | *32.4%* | *32.3%* | *32.4%* | *31.8%* | *31.6%* | *30.8%* | *31.1%* | *31.6%* | *31.7%* | *30.9%* | *27.6%* | *28.0%* | *27.8%* | *26.5%* | *26.3%* | *26.6%* | *25.7%* | *25.9%* | *25.8%* | *25.9%* | *25.3%* | *24.9%* |

University of Exeter

# Desirable Directions for Energy Transition Policy to Achieving Carbon Neutrality in South Korea : Lessons from Advanced Countries

**Joong Jin Lee**

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# Abstract

The energy sector plays a significant role in achieving the ambitious climate policy target of carbon neutrality. To this end, the transition to renewable energy is becoming an irresistible global trend, and countries have already deployed a variety of policy options to promote renewables. However, South Korea still lags behind in this field, recording the lowest renewable energy share among OECD countries. In this context, this study focuses on finding policy factors that have led to performance differences by comparing the renewable energy policy development of South Korea and two successful countries, the UK and Germany.

Both the UK and Germany have been able to maintain a consistent policy stance on renewable energy expansion for decades through statutory renewable energy deployment targets and the supra-national framework of the EU. They also ensured policy effectiveness by introducing appropriate institutional reforms tailored to the maturity of the renewable energy market, which transitioned through the 'introduction of support system → supplementation → introduction of competitive system'. In contrast, South Korea introduced similar support schemes to other countries, but faced severe fluctuations in the intensity of support with regime changes, and failed to implement relevant policy improvements considering market circumstances, resulting in insufficient renewable energy investment.

The findings suggest that setting proactive goals and building a bipartisan consensus on expanding renewables are urgently required to further accelerate renewable energy deployment in South Korea. Moreover, reforming the renewable energy support scheme and increasing public acceptance should be considered to maximise policy effectiveness.



* ***Keywords*****:** Energy transition, Renewable energy, Policy consistency

## 1. Introduction

Extreme weather events and natural disasters worldwide have made the international community aware of the severity of rapid climate change. With the adoption of the Paris Agreement in 2015, the international community has launched a new climate change regime that brings global action to limit the global temperature increase to well below 2 degrees Celsius, preferably to 1.5 degrees Celsius, above pre-industrial levels. Recently, many countries have been working towards achieving 'carbon neutrality,' aiming to eliminate net carbon emissions from a specific point onward. Currently, over 150 countries have declared goals for carbon neutrality, although the timing and form of these declarations vary (Net Zero Tracker, 2023). Aligning with global trends, South Korea is also actively taking steps to address the issue of climate change by setting a goal of achieving carbon neutrality by 2050. To achieve this objective, South Korea established the 2050 carbon neutrality scenario and strengthened the Nationally Determined Contribution (NDC) by 2030 as an interim target of the carbon neutrality goal (Jointly with Relevant Ministries, 2021a; 2021b).

In the process of addressing climate change, the most critical aspect is energy-related policies. This is primarily because over 70% of worldwide greenhouse gas (GHG) emissions originate from energy-related activities. As reported in 2016, approximately 73.2% of global GHG emissions stemmed from energy-related sectors like industry, transportation, and buildings (Ritchie, 2020). In other words, realising carbon neutrality goals cannot succeed without dramatic reductions in energy-related GHG emissions. According to estimates by the International Renewable Energy Agency (IRENA), achieving the 1.5 degrees Celsius scenario requires a significant shift towards renewable energy sources, with 91% of global electricity generation expected to be derived from renewables by 2050 (IRENA, 2023a, p.35). This represents a more than threefold increase from the 28% recorded in 2020.

Against this backdrop, many countries, particularly in Europe, have actively pursued the transition to greener energy for decades, resulting in significant renewable energy deployment and GHG emissions reductions. They are now setting even more ambitious renewable energy targets and accelerating their initiatives for transitioning towards cleaner energy sources. For example, the European Union (EU) announced plan to increase the share of renewables in the region's final energy consumption from 22% in 2021 to 45% by 2030 (European Commission, 2022, p. 6). At the Conference of the Parties (COP) 28, which is the supreme decision-making body of the United Nations Framework Convention on Climate Change (UNFCCC), over 130 countries pledged to increase their renewable energy generation capacity by more than three times by 2030 (COP, 2023).

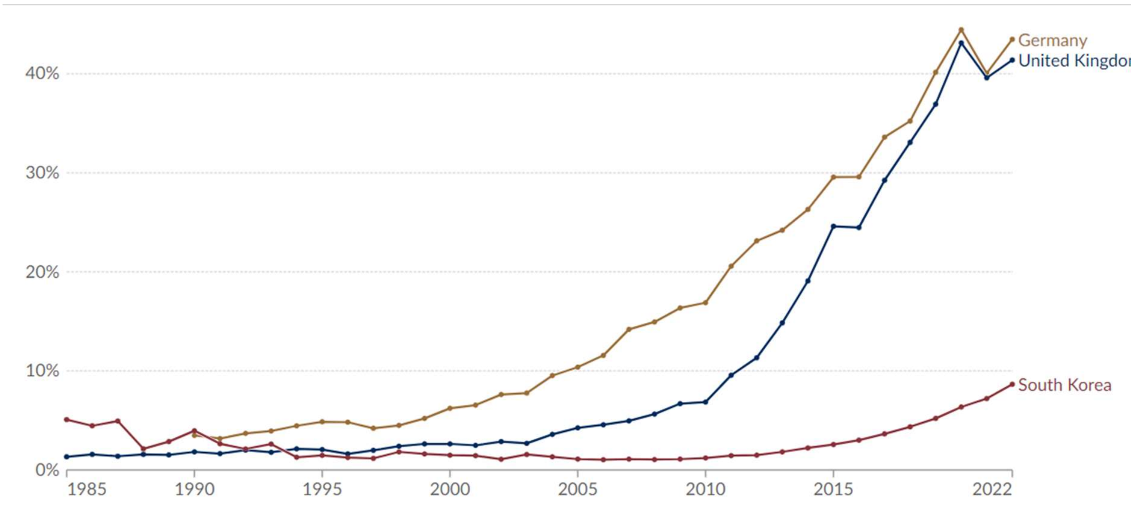
However, compared to this global movement, South Korea's progress so far in the energy transition, particularly regarding the deployment of renewable energy sources, has been sluggish. As of 2022, South Korea's share of electricity generation from renewable sources was 8.7%, well below the OECD average (31.4%) and the lowest among member countries. Moreover, there are rising concerns about weakening the policy momentum as the government has recently revised the target of renewable share in electricity generation downwards[3](MOTIE, 2023, p. 46). It isn't easy to directly compare renewable energy penetration across countries as many factors affect the level, such as geographical conditions, economic development, and history of energy mix. However, considering that South Korea is one of the most advanced economies in Asia and has a higher responsibility to mitigate emissions contributing to the climate crisis, the current situation is clearly not up to scratch.

**In this context, this study aims to examine and understand the policy differences that have led to South Korea's low performance through a comparison with cases from leading**

[3] In 2023, South Korea announced the 10th Basic Plan for Electricity Supply and Demand, adjusting the target share of renewable energy in power generation to 21.6% by 2030, previously set at 30%.

**countries.** The study specifically addresses the cases of the UK and Germany. As these two countries have been successful in promoting renewable energy through active policy support from an early stage, examining their cases holds substantial policy significance from South Korea's perspective. This is especially true considering that both countries' share of renewable power generation was almost the same level as South Korea before 2000 (Figure 1).

**Figure 1. Trends in Share of Renewable Electricity Generation (%)**




* Source: Our World in Data - Electricity Mix

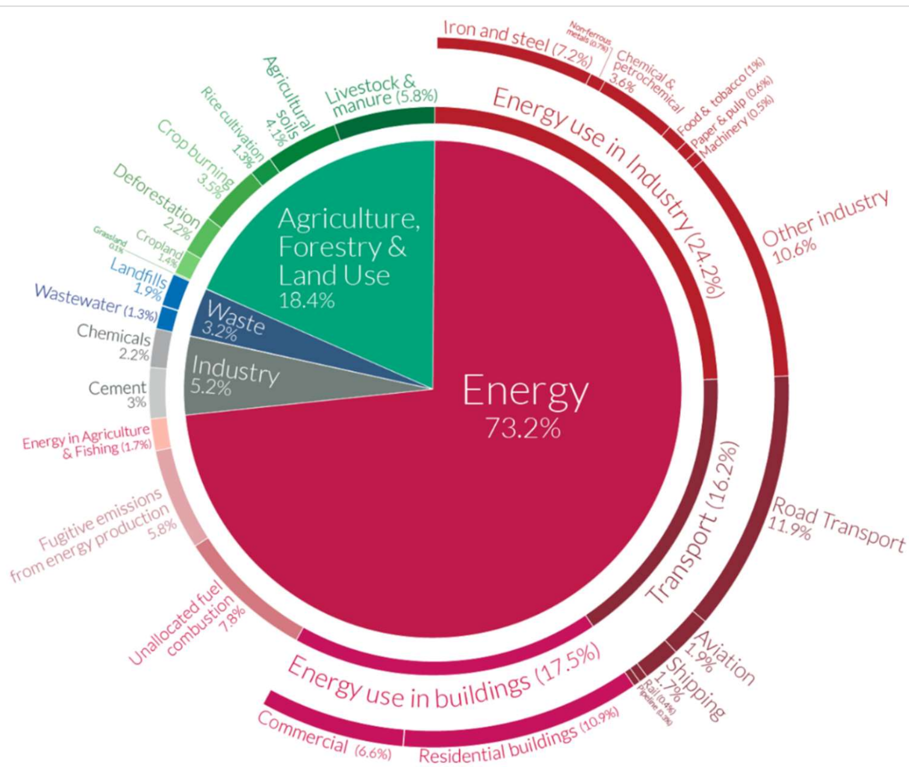
The rest of the study is organised as follows. Chapter 2 addresses the relationship between energy and climate change, as well as global trends in renewable energy deployment, before delving into the main analysis. Chapter 3 examines the trends and policies regarding renewable energy deployment in South Korea. Beyond simply introducing past policies, it identifies causes and obstacles hindering the expansion of renewable energy in the country. Chapters 4 and 5, respectively, explore the development process of energy transition policies in the UK and Germany. Lastly, Chapter 6 propose specific policy recommendations for effective renewable energy deployment in South Korea.

## 2. Theoretical Background

### 2.1. Energy and GHG emissions

Identifying the sources of GHG emissions is crucial for developing an effective strategy to address climate change. As noted earlier, the energy sector is the most significant source of GHG emissions. Figure 1 provides a breakdown of global GHG emissions. In 2016, 73.2% of global GHG emissions came from the energy sector, which includes electricity, heat, and gasoline. Agriculture accounted for 18.4%, industry 5.2%, and waste 3.2%. The industry sector covers solely emissions generated in the production process and does not include electricity or heat used as an energy source. Within the energy sector, emissions can be further categorised based on their usage, with 24.2% from industry, 17.5% from buildings, and 16.2% from transportation (Figure 2).

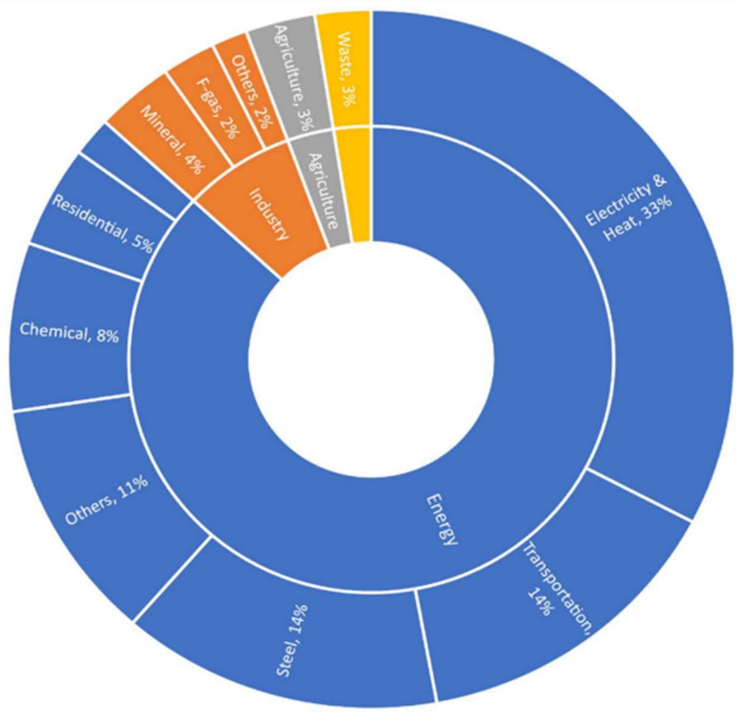
**Figure 2. Global Greenhouse Gas Emissions by Sector (2016)**




* Source: Ritchie. H (2020)

The dominance of energy-related GHG emissions is particularly evident in South Korea. As of 2021, 87% of South Korea's total GHG emissions are from the energy sector. The industrial process and agriculture sectors accounted for 8% and 3%, respectively (Figure 3). This substantial reliance on energy-related emissions can be attributed to South Korea's economic and industrial landscape, which is characterised by a significant presence of energy-intensive industries such as steel and petrochemicals.

**Figure 3. South Korea's Greenhouse Gas Emissions by Sector (2021)**




* Source: Ministry of Environment, Greenhouse Gas Inventory and Research Centre (2023)

## 2.2. Importance of Energy Transition

Energy transition refers to the global energy sector's shift from fossil-based systems of energy production and consumption — including oil, natural gas and coal — to renewable energy sources like wind and solar. In a specific context, it refers to the transition of the power generation mix from fossil fuels to renewable sources. In a broader context, it refers to the comprehensive transformation of the energy sector, including optimisation of the power generation mix, development of efficient energy consumption structure, and fostering the energy industry as a whole (Policy Briefs, 2020).

### *2.2.1. Tackling Climate Crisis*

As the energy sector is the primary source of GHG emissions, the fundamental purpose of energy transition is mitigating GHG emissions. 'Energy intensity' and 'Carbon intensity' are key indicators for assessing the effectiveness of emissions reductions resulting from the energy transition. Various theoretical analyses on the drivers of GHG emissions change indicate that the amount of GHG emissions is influenced by shifts in economic activity and population, alongside changes in the economy's energy intensity and carbon intensity. This relationship can be expressed as an equation below, called the KAYA identity.

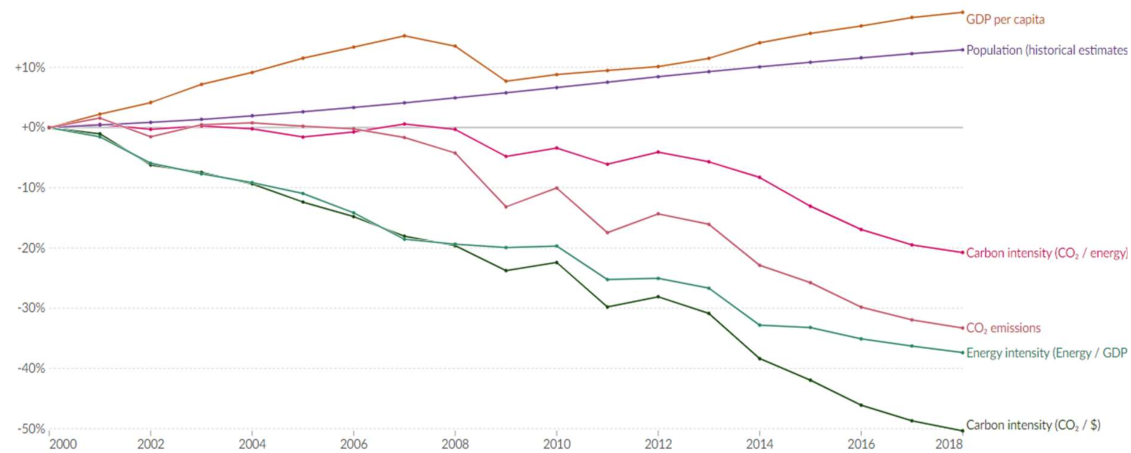
$$Total\ CO_2\ Emissions = Population \times \frac{GDP}{Population} \times \frac{Energy}{GDP} \times \frac{CO_2}{Energy}$$

** Energy / GDP = Energy Intensity    ** $CO_2$ / Energy = Carbon Intensity*

According to the KAYA identity, if a country wants to reduce its GHG emissions while maintaining economic growth, it must focus on reducing its energy and carbon intensity. Figure 4 indicates that developed countries such as the UK and Germany are achieving both economic growth and emissions reduction through huge improvements in their energy and carbon intensity. On the other hand, South Korea has been experiencing a steady increase in GHG emissions as its energy and carbon intensity improvements have been insufficient to offset the increased GHG emissions from economic growth.

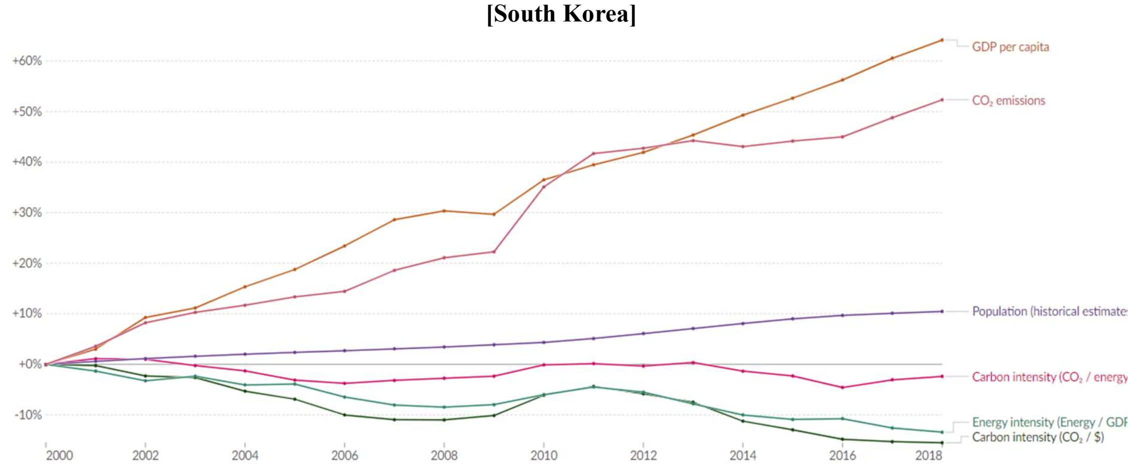
**Figure 4. Drivers of CO2 emissions of countries (2000-2018)**

**[U.K.]**




**[Germany]**


**[South Korea]**




* Source: Global Carbon Budget (2023) – with major processing by Our World in Data

To reduce energy intensity, improving energy efficiency is necessary. Energy intensity and energy efficiency are generally inversely related. Reducing energy intensity means reducing the amount of energy consumed to generate a certain level of added value, which in turn means increasing the efficiency of that energy. Energy efficiency generally improves through technology development.

To reduce the carbon intensity, changes in energy mix is vital. The carbon intensity can be further decomposed as follows.

$$\frac{CO_2}{Energy} = \sum_i \frac{Energy_i}{Energy} \times \frac{CO_{2\,i}}{Energy_i}$$

The first term refers to energy mix, the proportion of a specific source of total energy. The second term refers to the $CO_2$ emissions per unit of a particular energy source, i.e., the emission factor. The emissions factor typically remains a constant value, so the key to reducing carbon intensity is to improve the energy mix, i.e. to shift the proportion of energy sources to those with lower emissions factors. Thus, renewable energy deployment, the primary focus of this study, are regarded as a key policy to reduce carbon intensity.

### *2.2.2. Responding Global Economic Competition*

Recent changes in the global policy landscape are increasing the significance of the energy transition from an economic perspective either. There has been a shift from 'recommendations' based on multilateral agreements to 'norms and standards' led by advanced countries and enterprises. Most notably, the EU plans to fully implement the Carbon Border Adjustment Mechanism (CBAM) in 2026, imposing extra charges for products imported from countries that are not sufficiently reducing their GHG emissions. In order to operate the CBAM, it is necessary to calculate the carbon content in products, which will include not only the carbon directly generated in the production process but also the indirect emissions from generating electricity and heat used. As a result, countries that emit substantial GHG emissions in the energy sector will face tangible economic damage when exporting their goods to the EU.

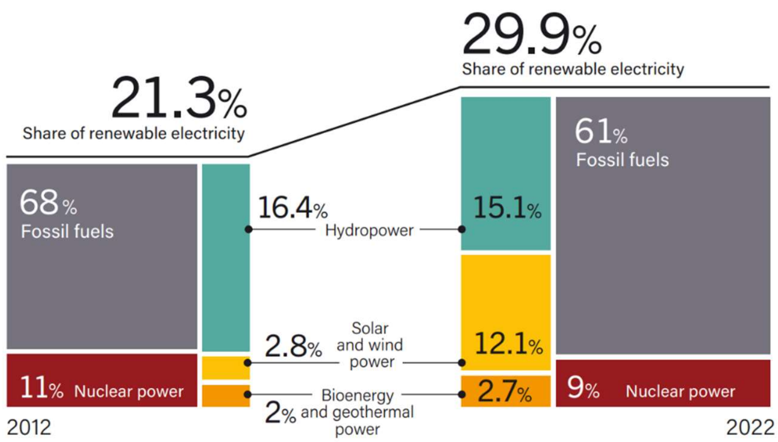
In the private sector, the Renewable Electricity 100% (RE100) initiative is widely spreading, with companies pledging to procure 100% of their electricity usage from renewable sources by 2050. Currently, nearly 300 major global companies are participating in this initiative. The RE100 discussion is important because participating companies can demand these standards from other companies they engage with. Indeed, some participants are requiring their suppliers to deliver components produced only using electricity from renewable sources. Consequently, companies in countries with insufficient renewable energy penetration will encounter challenges to meet these standards.

## 2.3. Global Trends in Renewable Energy

### *2.3.1. Power Generation from Renewables*

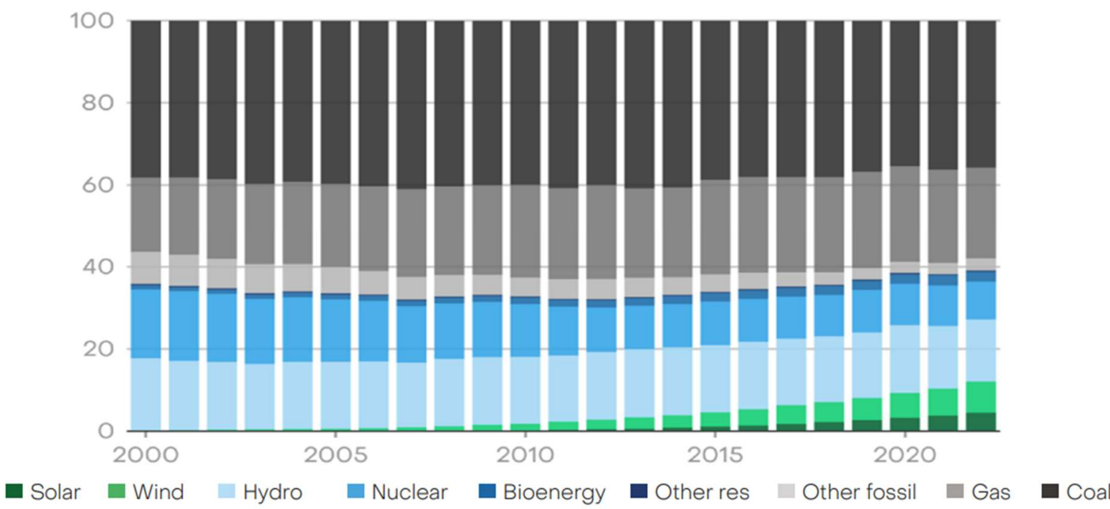
In 2022, renewable energy sources contributed 29.9% to global electricity production, marking an increase of nearly 9 percentage points compared to a decade prior (Figure 5). By source, fossil fuels accounted for 61%, nuclear for 10%, hydropower for 15%, solar and wind for 12% of total energy production. While fossil fuels still dominate the global electricity mix, renewables have shown a significant expansion. Among renewables, hydropower holds the largest share at 15 percent, but the adoption of solar and wind energy has surged since the 2010s, propelling the overall increase in renewable energy generation (Figure 6).

**Figure 5. Share of Renewable Electricity Generation, by Energy Source**




* Source: REN21 (2023), Renewables 2023 Global Status Report collection

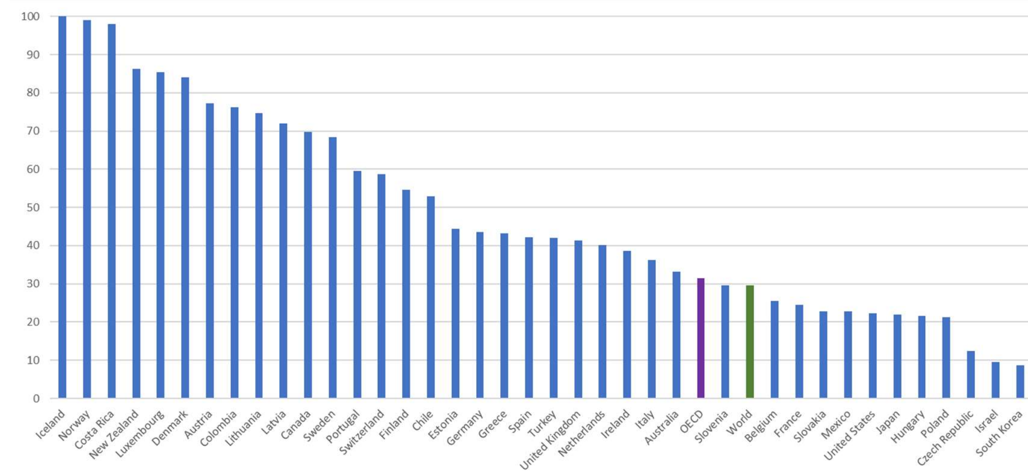
**Figure 6. Global Electricity Mix: Share of Total Electricity Generation (%)**




* Source: Ember (2023), Global Electricity Review 2023

Meanwhile, the trends vary significantly among countries. Figure 7 shows the share of renewable electricity generation by OECD countries in 2022. Countries like Iceland and Norway, where the share of renewable energy is close to 100%, predominantly rely on hydropower generation. Only 11 countries fall below the global average (29.9%), including South Korea, where the share of renewable is 8.7%, the lowest among OECD countries.

**Figure 7. Share of Renewable Electricity Generation in OECD Countries (%)**




* Source: Ember Electricity Data Explorer

### 2.3.2. Renewable Power Generation Costs

The expansion of renewable energy deployment globally has been primarily driven by improvements in the cost side. Substantial investment and rapid technology development have led to market activation, consequently driving down the cost of renewable energy generation. As of 2022, global levelised cost of energy (LCOE) of renewables are 89 percent lower than in 2010 for Solar PV, 69 percent lower for onshore wind (Table 1).

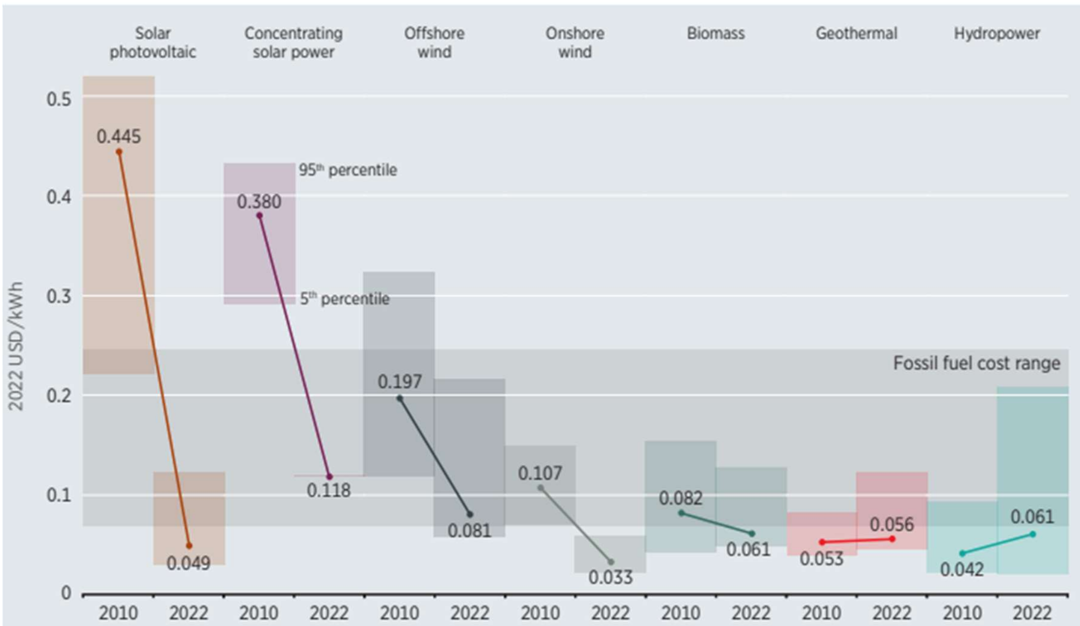
**Table 1. Total installed cost, capacity factor and LCOE trend (2010 and 2022)**

| | Total installed costs (2022 USD/kW) | | | Capacity factor (%) | | | Levelised cost of electricity (2022 USD/kWh) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2022 | Percent Change | 2010 | 2022 | Percent Change | 2010 | 2022 | Percent Change |
| **Bioenergy** | 2,904 | 2,162 | -26% | 72 | 72 | 1% | 0.082 | 0.061 | -25% |
| **Geothermal** | 2,904 | 3,478 | 20% | 87 | 85 | -2% | 0.053 | 0.056 | 6% |
| **Hydropower** | 1,407 | 2,881 | 105% | 44 | 46 | 4% | 0.042 | 0.061 | 47% |
| **Solar PV** | 5,124 | 876 | -83% | 14 | 17 | 23% | 0.445 | 0.049 | -89% |
| **CSP** | 10,082 | 4,274 | -58% | 30 | 36 | 19% | 0.380 | 0.118 | -69% |
| **Onshore wind** | 2,179 | 1,274 | -42% | 27 | 37 | 35% | 0.107 | 0.033 | -69% |
| **Offshore wind** | 5,217 | 3,461 | -34% | 38 | 42 | 10% | 0.197 | 0.081 | -59% |

* Source: IRENA (2023b), Renewable Power Generation Costs in 2022

The decrease in unit costs has already positioned renewables as cost-competitive with fossil-fuelled generation. Figure 8 shows that the LCOE bands for most renewables have fallen past grid parity, reaching levels below the cost bands for fossil fuels.

**Figure 8. Global LCOE from newly commissioned utility-scale renewable power technologies**




* Source: IRENA (2023b), Renewable Power Generation Costs in 2022

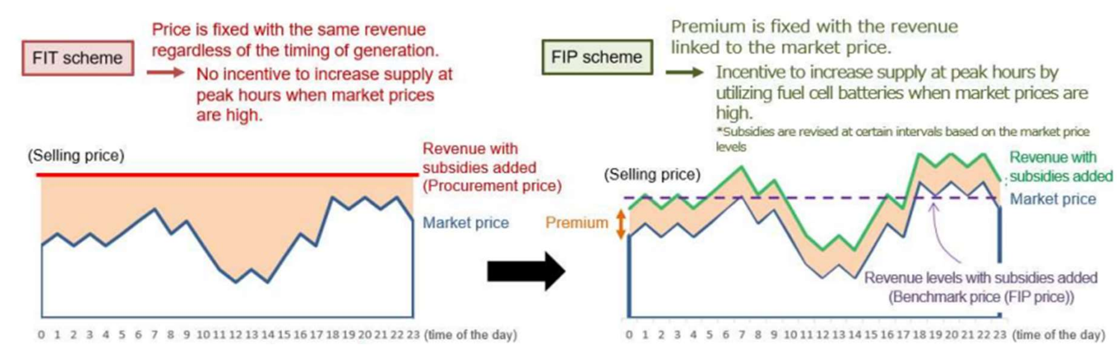
## 2.4. Policies to Promote Renewable Energy

In the early stage, when the cost of renewable electricity generation is higher than that of conventional sources such as fossil fuels, energy suppliers face challenges in securing profitability. As a result, when relying solely on the electricity market to drive renewable energy penetration, the supply level often leads to a lower than socially desirable level. Therefore, many countries have been implementing various support policies aimed at expanding renewable energy. Key policies include feed-in tariffs (FIT), renewable portfolio standards (RPS), and auction systems. The main contents of each support scheme are as follows.

### *2.4.1. FiT (Feed-in Tariff) / FiP (Feed-in Premium)*

The core principle of FiT / FiP is to increase the price paid to renewable energy producers by adding a subsidy to the market price. Both schemes share a common characteristic as price-based support mechanisms. However, their approach differs: FiT entails the government setting a fixed price for each renewable source and compensating for the difference between the fixed and market prices, whereas the government provides a fixed premium level for FiP (Figure 9).

**Figure 9. FiT vs FiP Scheme**




* Source: Ministry of Economy, Trade, and Industry in Japan (2022), 6th Strategic Energy Plan

FiT plays a role in easing market entry for small-scale producers by ensuring a fixed revenue. Hence, many countries have favoured FiT schemes in their initial stages. However, determining an appropriate standard price can be challenging, and subsidies can increase the government's fiscal burden. In addition, a drawback is the lack of incentives to stimulate competition among producers to improve their profitability (Jang & Gong, 2022, p.69).

### *2.4.2. RPS (Renewable Portfolio Standards)*

RPS mandates electricity suppliers to procure a designated proportion of their electricity from renewables. Under the scheme, the government sets a total renewable energy supply target and allocates it to the suppliers. Electricity suppliers meet their obligations by generating renewable energy themselves or purchasing credits from other producers. A government agency issues Renewable Energy Certificates (RECs) for renewable electricity generation. Renewable energy producers can sell RECs to make additional revenue alongside electricity sales. RPS has the advantage that it is easy to control the total amount of renewable energy supply, and it reduces the financial burden on the government. In addition, as the RECs are traded in the market, the scheme can promote cost-reduction competition among power generators. On the other hand, the renewable energy business entails a higher level of uncertainty than the FiT, as the revenue fluctuates based on electricity and REC trading prices (Jang & Gong, 2022, p.70).

### *2.4.3. Auction Systems*

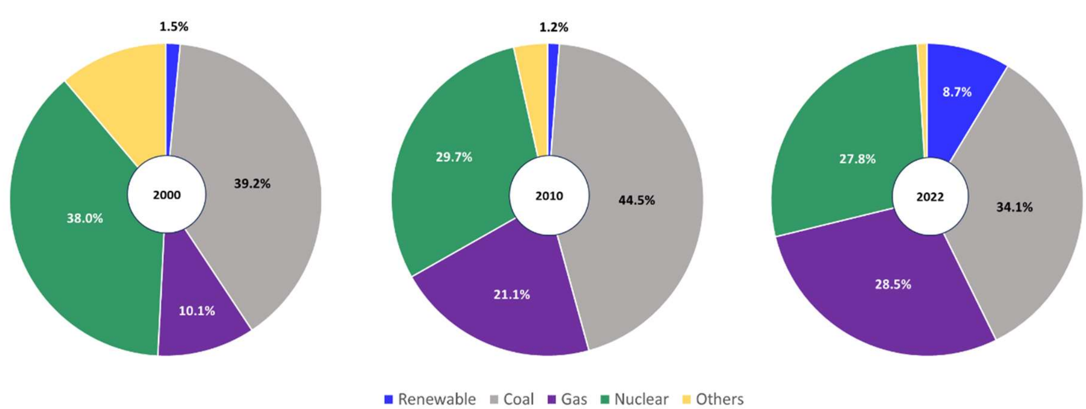
The auction system determines both the quantity and price of renewable energy supply through competitive bidding. Auctions involve bidding for either the capacity of facilities or the electricity output, and the contracts are typically awarded to projects offering the lowest prices. The main advantage of the auction system is that it encourages the cost-effective deployment of renewable energy. In an auction market, suppliers compete in the bidding process so they can directly reflect cost improvements to the price of renewable energy. On the other hand, increased competition may weaken the willingness of new suppliers to enter the market. Therefore, in countries implementing auction systems, there are often separate support mechanisms like FiT, particularly targeting small-scale projects (Jang & Gong, 2022, p.71).

# 3. Current Status of South Korea

## 3.1. Overview

As of 2022, renewables accounted for 8.7% of South Korea's electricity generation. As seen above, this figure is significantly lower than the global average (29.9%). Although the absolute figure remains relatively low, the proportion of renewable energy in 2022 has increased nearly sevenfold compared to 2010. However, it is worth noting that the pace of growth has been accelerating in recent years. When examining the overall power generation mix, fossil fuels account for approximately 60%, comparable to the global average (61% in 2022), whereas nuclear power comprises around 30%, nearly three times the global average (9% in 2022). The relatively low amount of renewable energy generation is offset by the substantial proportion of nuclear power (Figure 10).

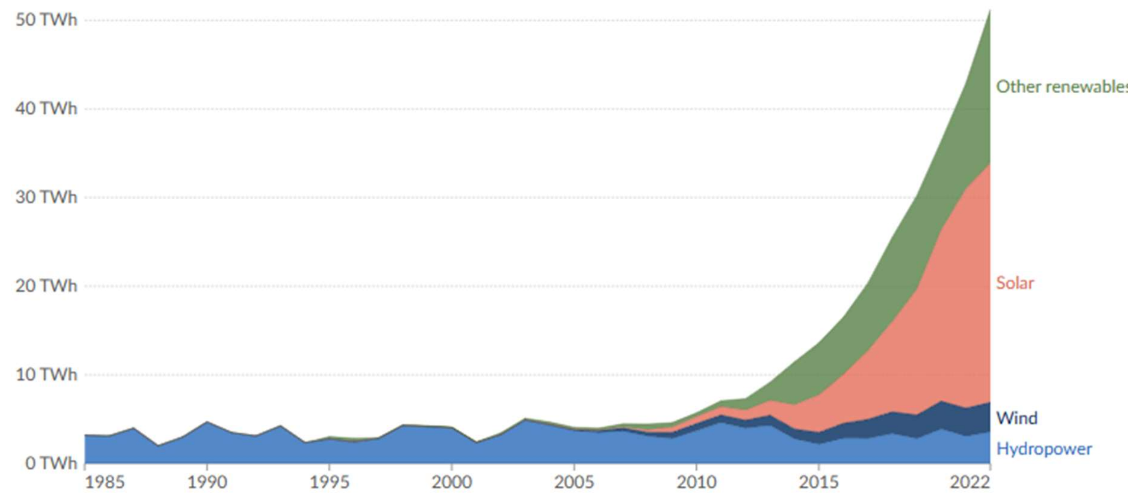
**Figure 10. Electricity Generation Mix by Energy Source**




* Source: Ember - Yearly Electricity Data (2023)

Within renewable energy sources, solar power has expanded significantly in recent years, accounting for 52.7% of total renewable power generation in 2022. On the other hand, the adoption of wind power remains sluggish, accounting for 6.6% (Figure 11).

**Figure 11. Share of Renewable Electricity Generation, by Energy Source**




* Source: Energy Institute - Statistical Review of World Energy (2023)

## 3.2. Key Policies for Energy Transition

### 3.2.1. History of Key Policies

#### Basic Plan for New and Renewable Energy (2001-)

South Korea's renewable energy promotion policy dates back to the 1980s. After experiencing oil shocks, the need to diversify energy sources from fossil fuels emerged. Consequently, the New and Renewable Energy Act was enacted in 1987, establishing the groundwork of policy direction. Full policy support commenced in 2001 with the establishment of the 1st Basic Plan for New and Renewable Energy. This plan was the first comprehensive plan for promoting renewable energy and encompassed several key measures, including the introduction of the FiT system, mandatory use of renewable energy by the government and public institutions, and enhanced support for renewable energy R&D.

The Basic Plan for New and Renewable Energy has been established five times with five-year intervals, outlining medium- to long-term targets for renewable energy deployment. The plan also contains deployment promotion frameworks, green housing initiatives, regional support programs, and financial support to achieve these objectives. The third plan, established in 2008, proposed introducing the RPS system, which has been the core policy in South Korea to date. From the fourth plan onwards, the government focuses more on expanding renewable energy through market mechanisms, fostering related industries, and supporting overseas expansion. The targets and main contents of each plan are as follows.

**Table 2. The contents of the Basic Plan for New and Renewable Energy**

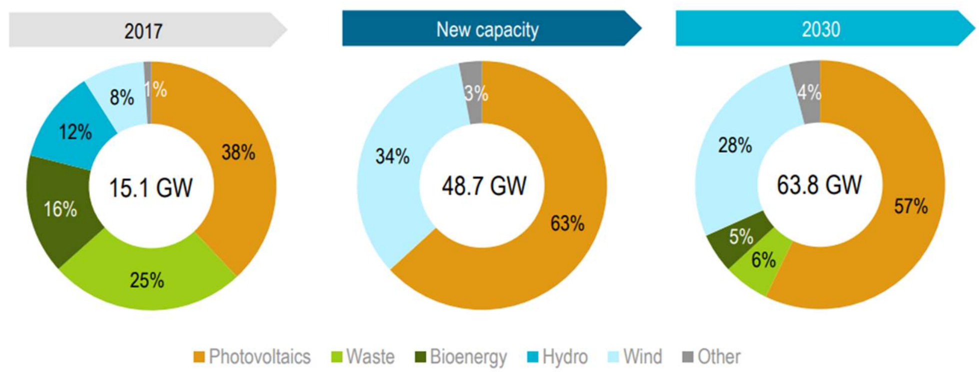
| | | 1st Plan | 2nd Plan | 3rd Plan | 4th Plan | 5th Plan |
|---|---|---|---|---|---|---|
| Policy Period | | 2001~2003 | 2003~2012 | 2009~2030 | 2014~2035 | 2021~2034 |
| Renewable Target | of Primary Energy | 2% by 2003 | 5% by 2011 | 11% by 2030 | 11% by 2035 | 13.7% by 2034 |
| | of Power Generation | - | 7% by 2011 | 7.7% by 2030 | 13.4% by 2035 | 25.8% by 2034 |
| Main Policies | | · Introducing FiT<br>· Mandatory use of public sector<br>· R&D focus on Solar and Wind | · 100,000 solar house supply<br>· Supporting local energy project<br>· Supporting small energy supplier | · Introducing RPS<br>· 1 million Green Home supply<br>· Building 200 Green Village | · Introducing a revenue-sharing program<br>· Supporting overseas market expansion | · Restructuring RPS Scheme<br>· Strengthening local engagement<br>· Supporting RE100 initiatives |

* Source: Ministry of Trade, Industry and Energy (MOTIE)

## *Energy Transition Roadmap and Implementation Plan 3020 (2017-)*

With the inauguration of the Moon administration in 2017, South Korea's renewable energy policy is entering a new phase. Previously, promoting renewable energy was positioned as a subordinate tool under the primary goal of ensuring a stable energy supply. However, since 2017, the promotion of renewable energy for the transition to a low-carbon economy has been placed at the top priority of the energy policy. In October 2017, the government announced the Energy Transition Roadmap, which includes main objectives of 1) the expansion of renewable energy and 2) the phasing out nuclear power. Then, in December 2017, the government announced the Renewable Energy Implementation Plan 3020, which set out an ambitious renewable power generation target of 20% by 2030. It specifies individual targets for each technology by production capacity, which altogether would increase from 15.1 GW in 2017 to 63.8 GW in 2030, mainly driven by accelerated growth in solar and wind power (Figure 12).

**Figure 12. South Korea’s new and renewable energy targets (2017-2030)**




* Source: MOTIE (2017), Renewable Energy Implementation Plan 3020

To achieve these goals, plan 3020 proposed significant policy measures, including reintroducing the FiT system ('the Korean FiT'), increasing the share of renewable energy supply under the RPS scheme, deregulating facility locations, and expanding financial support. Due to this active policy support, newly installed renewable electricity generation capacity during 2017-2021 more than tripled compared to the previous five-year period (2012-2016)[4].

### *Revising policy in response to shifts in the policy landscape (2022-)*

The active policy support implemented since 2017 has facilitated the rapid growth of renewable energy adoption, but it has also caused side effects, including disorderly expansion of small-scale solar power and many conflicts with local residents (MOTIE, 2022). In

[4] Installed renewable electricity generation capacity (GW): (2012-2016) 5.9 → (2017-2021) 18.3

particular, the nuclear power phase-out policy, which was implemented without sufficient public consensus, has caused intense social controversy.

The Yoon administration, which took office in 2022, has declared a new energy policy direction centred on abolishing the nuclear phase-out policy and strengthening the nuclear industry ecosystem. For renewable energy, the new government has more focused on setting achievable goals and addressing inefficiencies that occurred in the past. In November 2022, the government announced the Improvement Plan for Renewable Energy Policy, which mainly includes measures to moderate the pace of renewable energy diffusion and increase public acceptance of energy policy, such as lowering the RPS mandatory supply ratio, enhancing the monitoring system of the renewable energy project, and minimizing inefficient fiscal support. In addition, the government also announced the 10th Basic Plan for Electricity Demand and Supply, which shows the adjusted energy mix by increasing the share of nuclear power generation and lowering the target for renewable power generation (Table 3).

**Table 3. Changes in 2030 target of electricity mix (%)**

| | Coal | Gas | Nuclear | Renewables | Etc. |
|---|---|---|---|---|---|
| 9th Power Plan (established '19.12) | 29.9 | 23.3 | 25.0 | 20.8 | 1.0 |
| 2030 NDC (established '21.10) | 21.8 | 19.5 | **23.9** | **30.2** | 4.6 |
| 10th Power Plan (established '23.1) | 19.7 | 22.9 | **32.4** | **21.6** | 3.4 |

* Source: Ministry of Trade, Industry and Energy (MOTIE)

### 3.2.2. Key Renewable Energy Deployment Policies

#### FiT (2001 - 2011)

South Korea's FiT system was introduced in 2001 under the Renewable Energy Act. To ensure the profitability of renewable energy investments, the government set a fixed contract price for each source and compensated for the gap between fixed and market prices. Renewable energy producers could get this contract price for 15 or 20 years from the commencement date of operations. The FiT has contributed to expanding the domestic industry in the early stages of renewable energy deployment. Renewable energy power generation increased from 203 GWh in 2002 to 17,345 GWh in 2011. However, unlike other countries where the cost of subsidies is directly reflected in the retail electricity price, in South Korea, the government entirely funded the subsidies. This structure led to an increase in the government's financial burden, and the FIT scheme was terminated in 2011. By 2021, the cumulative amount of support under the scheme was approximately 40 billion USD (KEA, 2022, pp.628-631).

### *RPS (2012 - Current)*

The South Korean government introduced the RPS in 2012 to replace the FiT scheme. RPS aims to solve the financial burden by directly imposing renewable energy supply obligations on power producers, and also aims to lower the renewable energy costs through competition among power producers. In South Korea, the obligations only apply to power producers with more than a certain amount (500MW) of generation facilities, which is 24 producers in 2022. Obligated producers fulfil their obligations by securing Renewable Energy Certificates (RECs) up to the allocated capacity and submitting them to the government. They can receive full reimbursement for the cost of compliance (REC purchase cost) from the Korea Electric Power Corporation (KEPCO). The obligation rate has been gradually increased each year in line with the renewable energy target.

**Table 4. RPS obligation rate (%)**

| 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2030 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.0 | 2.5 | 3.0 | 3.0 | 3.5 | 4.0 | 5.0 | 6.0 | 7.0 | 9.0 | 12.5 | 13.0 | 13.5 | 14.0 | 15.0 | 25.0 |

* Source: Ministry of Trade, Industry and Energy (MOTIE)

### *The Korean FiT (2018 - 2023)*

In 2018, the government introduced the Korean FiT, a restricted reinstatement of the FiT, which was abolished in 2011. The scheme allows solar power generators below a certain size to sell their electricity to KEPCO's subsidiary companies at a fixed price for 20 years without any market transaction. It differs from the original FiT scheme in that it applies solely to small-scale solar power generators and is not directly funded by government finance. Implementing the Korean FiT has led to a rapid expansion of solar power generation since 2018. However, problems such as fraudulent contracts continued to occur, and the stability of the power grid system suffered due to the increase in small-scale solar power. As a result, the government abolished the Korean FiT in July 2023.

## 3.3. Discussion: Reasons Behind Low Performance

### *3.3.1. Literature Review*

In this section, we examine the reasons why renewable energy promotion policies in South Korea have not achieved satisfactory results so far. In academia, some research has identified factors that have contributed to success in renewable energy deployment by analysing advanced countries.

Lipp (2007) pointed out important factors through case studies of Germany, Denmark, and the UK, including 1) political commitment, 2) appropriate policy features and design detail, and 3) creating a balance between conventional energy sources and renewable energy. Particularly in the case of Germany, Lipp argues that political factors such as the presence of the Green Party and the emergence of various advocacy coalitions that could influence the design of renewable energy policies were crucial to its success.

Hass et al. (2011) argued, by comparing cases of EU countries, that the detailed design within a specific policy scheme is far more crucial to the success of renewable energy deployment than the choice of support models such as FiT or RPS. Additionally, they emphasised that the reliability of the system greatly influences the effectiveness of policy tools. The key point is that potential investors need to be assured that the policy direction will be sustained, regardless of the specific policy in place.

Meckling et al. (2022) identified three factors - insulation, compensation, and market - as key determinants influencing the performance of renewable energy policies. They argue that in countries driving policy shifts, policymakers need to be insulated from political influence or sector-specific interests, and appropriate compensation policies should be provided during the implementation process. They also suggest that countries pursuing market-led transitions are significantly influenced by leading nations with cost-competitive technologies.

In summary, the success of renewable energy deployment can be influenced by a complex array of factors, such as political conditions, institutional design, market functions, etc., rather than being driven solely by a single dominant factor.

### *3.3.2. Reasons for Low Performance*

#### *Lack of commitment*

While looking at South Korea's renewable energy promotion policies, the first question that arises is whether the government's will and efforts to expand renewable energy were sufficient.

From the enactment of the Renewable Energy Act in 1987, renewable energy expansion has long been a secondary priority in country’s energy policies. When examining energy policy decision-making structure, the government first establishes an "Energy Master Plan" every five years, which presents a long-term (20-year) vision for energy policy. In accordance with this plan, a "Basic Plan for Electricity Supply and Demand" is formulated every two years to specify the mid-and long-term proportion of power generation by sources. Although a separate "Basic Plan for Renewable Energy" is established every five years, the primary policy direction is practically determined within the overarching framework of the higher-level plans.

Indeed, the top-down approach of setting the overall framework and formulating specific sub-plans is not necessarily problematic. However, in South Korea, the underlying principle of providing inexpensive and reliable energy to the industry sector to support sustained economic growth has long been embedded in the process of determining the direction of energy policy. This approach has led to a policy prioritising the expansion of nuclear power rather than renewables[5].

### *Lack of "Insulation"*

In South Korea, energy policy is considered a highly political issue. Conservative administrations tend to favour nuclear power, while progressive ones lean towards renewable energy. Bureaucrats responsible for formulating energy policies are not entirely insulated from the political ramifications of election results. A prime example is the shift from emphasis on nuclear phase-out in the Moon administration, followed by the reversal in Yoon administration. Policy adjustments in response to changes in the policy environment are necessary to some extent, but decisions should not be solely based on changes in political power without sufficient consensus-building. So far, South Korea's policies have struggled to receive high evaluations in this regard.

[5] "The nuclear power expansion should be maximised within feasible limits as it meets both environmental and economic criteria simultaneously (facility share 41%, generation share 59% by 2030) (MOTIE, 2008)."
"There are no alternatives to replace the role that nuclear power plays in energy security, industrial competitiveness, and greenhouse gas reduction (MOTIE, 2014)."

Another aspect to consider regarding insulation is the organisational structure of the government. The Ministry of Trade, Industry and Energy (MOTIE), which oversees energy policy in South Korea, is primarily tasked with promoting industry and supporting corporate activities. This organisational characteristic makes it easier for the industry's interests to be prioritised over issues such as tackling climate change in the process of formulating energy policy. The entrenched prioritisation of nuclear power in energy policy can also be attributed to these organisational characteristics.

### *Lack of appropriate policy design*

In terms of policy details, one of the most significant changes in South Korea was the transition from the FiT to the RPS in 2012. While there is no consensus on which system is superior, generally, FiT is considered adequate in stimulating initial investment, while RPS is viewed as a more market-friendly mechanism. Considering these characteristics, the transition from operating the FiT initially to nurturing the early industry and then shifting to the RPS can be seen as a natural (Kwon, 2014, p. 8).

However, there are doubts regarding whether such a policy transition was necessary and whether the timing of the transition was appropriate. The main reason the government discontinued FiT was not due to the lack of effectiveness but rather because of the increased financial burden associated with subsidies. In principle, the government could have offset the funds by raising retail electricity prices. However, such a decision was not among the options available due to the political barrier in raising electricity tariffs in South Korea. In 2011, when FiT was abolished, the share of renewable electricity generation was only 3.46%. After all, there could be criticism for prematurely discontinuing the policy due to an excessive focus on financial aspects despite the market not being sufficiently mature.

### *Lack of policy monitoring, assessment, and feedback*

To achieve the intended outcomes of the policy, it is crucial to have a continuous process of monitoring and evaluating the current policies, and then reflecting on the results to refine and develop the policies. However, this process has not been sufficient in the case of renewable energy deployment policies in South Korea. For example, in the Basic Plan for Renewable Energy, policy targets such as the share of renewable power generation were set with each plan, but in subsequent plans, there was no analysis of whether the goals of the previous plan were achieved or the reasons behind any shortcomings.

Monitoring of individual policies or projects has also been lacking in a systematic manner. The recent audit results regarding the progress of renewable energy projects revealed numerous irregularities in project approvals, contracts, and other aspects accumulated over several years (BAI, 2023). If the government had conducted systematic management and regular monitoring, it could have prevented such issues and further increased the effectiveness of the policy.

### *Lack of public support*

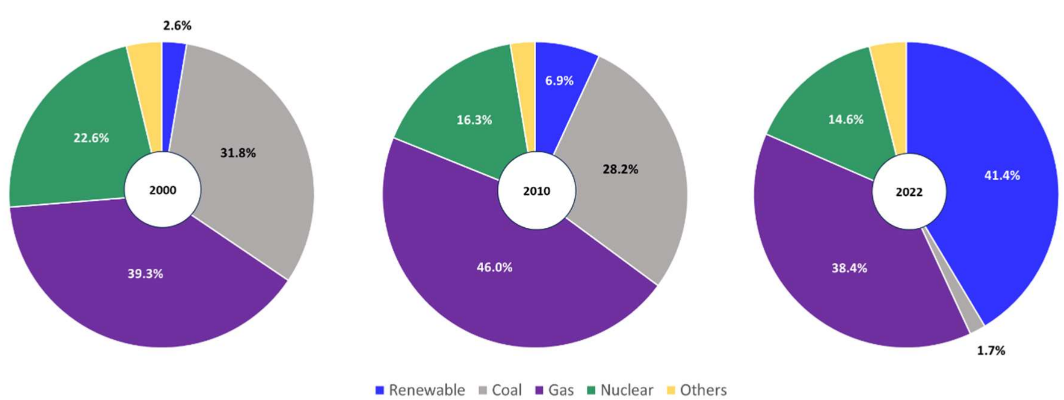
In South Korea, where nuclear power has been a longstanding policy priority, renewable energy has generally been perceived as an expensive energy source with limited feasibility. Due to a lack of promotion or educational efforts by the government regarding the importance of renewable energy, public perception on this matter has not easily changed. In a survey conducted in 2017, following the announcement of the "Energy Transition Roadmap", only 41% of respondents deemed the government's energy policy appropriate (KOFST, 2017). Even until a few years ago, there wasn't sufficient public consensus on expanding renewable energy. In particular, the previous government's approach caused intense social conflicts surrounding energy policy. The actual contents of the energy transition plan involved a gradual reduction of nuclear power over the long term. However, the government's emphasis on the term of "nuclear phase-out" created a distorted perception among the public, an immediate withdrawal from nuclear power. This controversy has fueled scepticism towards the deployment of renewable energy by generating fake news such as power shortages and soaring electricity prices.

# 4. Energy Transition in the UK

## 4.1. Overview

The UK was considered a country lagging in renewable energy just over a decade ago. However, since the 2010s, it has rapidly emerged as a global leader. When examining the energy mix of the UK, it is evident that decarbonisation in the power sector has been successfully pursued within a relatively short period. The share of renewable energy in electricity generation increased approximately sixfold, from 6.9% in 2010 to 41.4% in 2022. Looking at other energy sources, in 2022, the share of natural gas in 38.4%, and the share of nuclear power is 14.6%, showing little difference compared to 2010. Meanwhile, the UK has made enormous progress in reducing the use of coal, accounting for only 1.7% of the UK's electricity mix in 2022, compared with 30% almost a decade ago[6]. Overall, the declining share of coal-fired power generation is being replaced by an expansion of renewable energy generation. (Figure 13).

**Figure 13. Electricity Generation Mix by Energy Source**

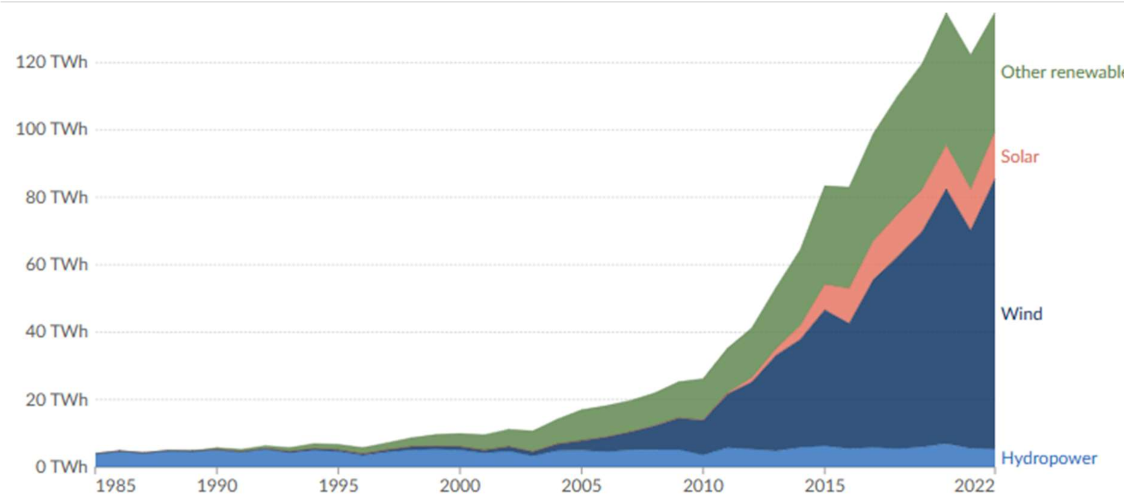



* Source: Ember - Yearly Electricity Data (2023); Ember - European Electricity Review (2022)

[6] The UK government declared in 2021 that they would remove unabated coal from the UK's energy mix by October 2024.

Renewable energy power generation gradually increased during the 2000s and has experienced rapid growth since 2010, particularly in wind power generation. As of 2022, the total renewable power generation is approximately 135 TWh, with wind power accounting for around 60%. The UK is particularly known as a global leader in wind power, primarily due to its geographical characteristics, including its extensive coastline and strong winds. Solar power generation accounts for approximately 10% of the total renewable energy power generation in 2022. While relatively slower than wind, it continues to show a growth trend (Figure 14).

**Figure 14. Trends in Renewable Electricity Generation**




* Source: Energy Institute - Statistical Review of World Energy (2023)

## 4.2. History of Energy Policies

### *1990s: Non-Fossil Fuel Obligation (NFFO)*

The UK's renewable energy support policy began with the introduction of the Non-Fossil Fuel Obligation (NFFO) scheme, implemented in conjunction with the privatisation of the electricity market in 1989. NFFO refers to a series of mandates requiring electricity suppliers to purchase a certain amount of electricity generated from nuclear power and renewable energy sources.

NFFO aimed to create a protected market for nuclear and renewable energy power projects. Nuclear and renewable power producers participated in competitive bidding organized by the government-led Non-Fossil Purchasing Agency (NFPA), ensuring electricity prices above wholesale prices during the contract period. The bidding round under the scheme operated five times until 1998. The associated costs were covered through the fossil fuel levy imposed on consumers.

However, the NFFO scheme exhibited a side effect during its operation, with support concentrated more on the nuclear sector than on renewables. The European Commission also raised concerns that the fossil fuel levy was primarily a subsidy for nuclear power, potentially violating the EC's fair competition 'state aid' rules (Elliot, 2019, pp. 83-85).

### *Early 2000s: Renewable Obligation (RO)*

The adoption of the Kyoto Protocol in 1997 led to an expansion of global interest in renewable energy. In particular, the EU adopted the directive on the promotion of renewable energy sources in 2001 (Directive 2001/77/EC), which specifically allocated renewable energy power generation targets for each member state up to the year 2010. According to the directive, the UK was mandated to increase its renewable power generation share from 1.7% in 1997 to 10% by 2010 (EU, 2001, p. 39). To achieve these goals, the UK government embarked on various renewable energy promotion policies, including the Renewable Obligation (RO) in 2002.

The UK's RO scheme, similar to the previously discussed RPS, imposed an obligation on electricity suppliers, requiring them to supply a certain proportion of their total electricity supply from renewable sources. Renewable energy producers sell the electricity to suppliers and could earn additional income by selling Renewable Obligation Certificates (ROCs) acquired through renewable energy power generation. Unlike the previous NFFO, the RO focused exclusively on supporting renewable energy and implied neoliberalism that renewable energy goals could be achieved cost-effectively through market trading of ROCs.

After implementing the RO, the proportion of renewable energy power generation gradually increased. However, the market uncertainty inherent in the RO scheme failed to attract sufficient renewable energy investment, leading to an inability to meet the annual targets for renewable energy supply (Wood and Dow, 2011, pp. 2229-2231).

**Table 5. RO target and percentage of electricity derived from renewable sources (%)**

| | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|
| **Target** | | | 3.0 | 4.3 | 4.9 | 5.5 | 6.7 | 7.9 | 9.1 |
| **Outturn** | 1.6 | 1.9 | 2.4 | 3.6 | 4.2 | 4.5 | 5.0 | 5.5 | 6.6 |

* Source: Wood and Dow (2011)

### *Late-2000s: The beginning of the transformation*

In 2007, the EU announced the 2020 Climate and Energy Package, presenting the "20-20-20 targets" in three key areas: reducing GHG emissions, expanding renewable energy, and improving energy efficiency[7]. The EU Renewable Energy Directive in 2009 (2009/28/EC) specified each country's target for expanding renewable energy. For the UK, the target was set to derive 15% of final energy consumption from renewable sources by 2020 (EU, 2009, p. 46). Within the UK, concerns were raised that the existing RO scheme would not be sufficient to achieve the 10% renewable energy generation target by 2010. In response, the government announced reform plans for the RO in 2009 to enhance the effectiveness of the scheme. Under the reformed RO, the government extended the support period for new renewable projects up to 20 years to reduce investment risks, and differentiated the issuance of ROCs by renewable

[7] To reduce carbon dioxide emissions by 20%, to increase the share of renewable energy to 20%, and to achieve energy savings of 20% or more.

sources to encourage the development of various technologies. Additionally, in 2010, to expand local renewable energy deployment, a Feed-in Tariff (FiT) scheme was selectively introduced for small-scale generation facilities of less than 5MW, aiming to complement the existing RO scheme (Wood and Dow, 2012, pp. 2231-2235).

During this period, significant changes occurred across the overall climate change policies encompassing renewable energy. In 2008, the Climate Change Act (CCA) was enacted as the legal foundation for driving related policy initiatives. The CCA specified a minimum 80%[8] reduction target in carbon emissions by 2050 compared to 1990 levels and mandated the establishment of five-yearly carbon budgets to achieve the goal. Many changes occurred in organisational aspects as well. In 2008, the Brown administration established the Department of Energy and Climate Change (DECC) by merging functions related to energy of the Department for Business, Enterprise and Regulatory Reform (BERR) and those relating to climate change of the Department for Environment, Food and Rural Affairs (DEFRA). Additionally, under the CCA, the Committee on Climate Change (CCC) was also established as an independent advisory body from the government.

### *2010s: Electricity Market Reform (EMR)*

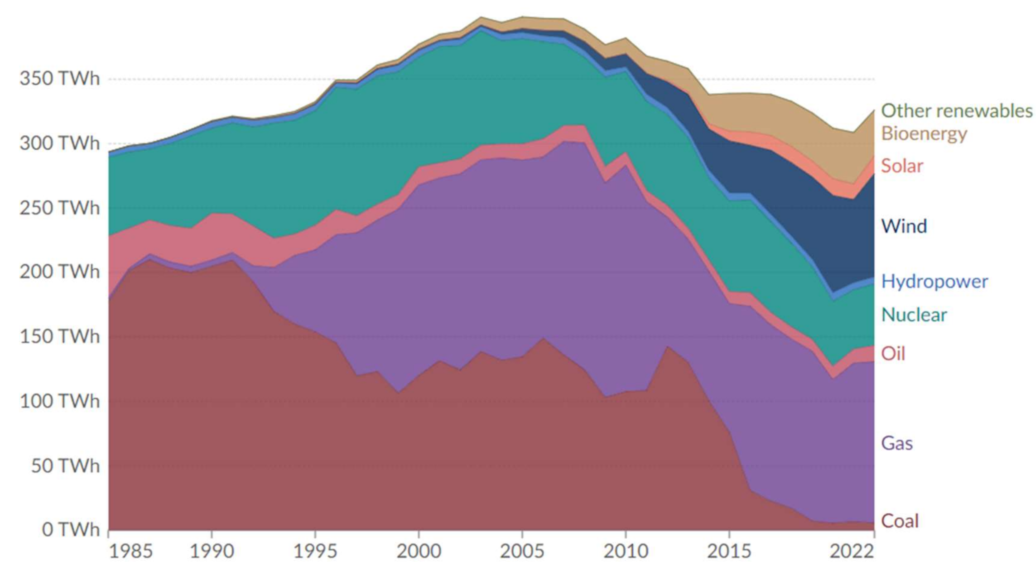
In December 2010, the DECC announced the Electricity Market Reform (EMR) plan. EMR is considered the most fundamental reform measure since the privatisation of the electricity market in 1989, driven by the judgment that the existing system cannot sufficiently incentivise low-carbon investments. Its key components include transitioning from the RO to the FiT scheme for supporting renewable energy deployment and introducing measures like the Carbon Price Floor to raise the cost of fossil fuels (Grubb & Newbery, 2018, pp. 10-12).

[8] The target was revised to achieve a 100% reduction by 2050 in 2019.

In line with the EMR plan, the renewable energy support scheme gradually transitioned from the RO to the Contract for Difference (CfD), which combines the FiT scheme and government-led auction methods[9]. The CfD contracts are signed between electricity generators and the government-owned Low Carbon Contracts Company (LCCC). Successful bidders receive support for the difference between the reference price and the strike price for 15 years. The reference price is set based on the average electricity sale price in the UK electricity market, while the strike price is set at a level reflecting the investment cost of low-carbon generation sources. The generator receives compensation for the difference if the reference price is lower than the strike price. Conversely, the generator repays the difference if the reference price exceeds the strike price.

The EMR and the implementation of the CfD brought about a dramatic turnaround in the UK's energy transition. Since the 2010s, there has been a significant decrease in the proportion of fossil fuels and a rapid expansion of renewable energy deployment (Figure 15).

**Figure 15. Trends in Electricity Generation by Sources**




* Source: Ember - Yearly Electricity Data (2023); Ember - European Electricity Review (2022)

[9] The CfD was introduced in 2014, and the RO scheme completely ceased its new support in March 2017.

### *2020s: Emphasis on energy security*

With Brexit in 2020, the pressure for expanding renewable energy from a supranational perspective diminished. However, the UK continues solidifying its position as a global leader in renewable energy. In the Nationally Determined Contribution (NDC) announced in 2020, the government expanded its GHG emissions reduction target for 2030 from 40% to 68% compared to 1990 levels. In 2021, the government announced the 'UK Net Zero Strategy - Build Back Greener' to outline the implementation plan for achieving carbon neutrality. The strategy specifies that by 2035, all electricity will come from low-carbon energy sources. Additionally, it includes plans for extensive investment in innovative technologies such as offshore wind expansion, CCUS (Carbon Capture, Utilization, and Storage), and bioenergy to achieve this goal (HM government, 2021, p. 94).

The most recent plan for energy transition can be found in the 'British Energy Security Strategy' announced in April 2022. This strategy additionally sets a target of 95% of electricity from low-carbon energy sources by 2030. Furthermore, with the increased importance of energy security after the Russia-Ukraine war, the strategy emphasizes nuclear power as well as renewables. It specifies the installation of up to 8 new reactors by 2030 and aims to supply 25% of the electricity demand through nuclear by 2050 (HM government, 2022, pp. 16-21).

## 4.3. Implications

### *Policy consistency*

The UK's energy transition has consistently pursued the expansion of renewable energy supply, despite variations in its specific details over time. The background for the continuity of policies lies in their solid legal foundation, which provided them with robust enforceability under medium to long-term objectives. In particular, the enactment of the CCA in 2008 provided a foundation for systematically addressing carbon reduction policies, including the promotion of renewable energy. This system can be recognised as the driving force that allowed the strong momentum for renewable energy expansion to be maintained even during the transition from a Labour Party government to a Conservative Party administration in 2010.

### *Continuous policy improvement*

To achieve policy objectives, timely and contextually appropriate responses are required. Especially when existing policies fail to yield sufficient results, the government should consistently make efforts to improve and supplement them. The UK is a prime example of a country that has transitioned its support mechanisms for renewable energy. In the early stage, the government preferred market-friendly mechanisms and introduced the RO scheme. However, as the RO failed to achieve the intended outcomes, the government made a transition to the FiT-based CfD scheme. At the same time, they also introduced schemes like the carbon price floor, providing more precise signals for investment in low-carbon energy sources. If the UK government had persisted with the RO scheme, they might not have achieved the same level of success in energy transition.

The UK case provides implications for South Korea in particular. South Korea's renewable energy support scheme transitioned from FiT to RPS in 2012, in contrast to the UK. Ironically, one of the representative cases South Korea benchmarked during its adoption of RPS was the UK's RO scheme, which was discontinued a few years later.

### *Efficient policy implementation system*

Government restructuring can play a crucial role in increasing the momentum of policy implementation and adapting flexibly to social changes. The background of the UK's strong drive for renewable energy policies during the 2010s included the DECC's role. DECC was formed in 2008 by merging DEFRA's climate change affairs and the DBERR's energy-related tasks. The DEFRA was the lead department for climate policy, but its political influence was limited, making it difficult to prioritise climate change as the primary goal over other economic and financial concerns (Carter, 2014, p. 425). The DBERR was responsible for various tasks beyond energy policy, including company law, trade, business growth, and regional economic development. With the establishment of DECC, energy policy was integrated as a central function rather than as a subordinate task within industrial-related departments. Furthermore, it was possible to achieve the transition to CfDs, which entails additional financial expenditures, through negotiations with the powerful HM Treasury (Lee, 2017, p. 159).

### *Complementary role of renewable energy and nuclear power*

One notable feature of the UK's energy mix is its commitment to achieving carbon neutrality by balancing the expansion of renewable energy with nuclear power generation. Since 2010, while the deployment of renewable energy has rapidly expanded, the share of nuclear power generation has remained at around 15%. Recently, plans for expanding nuclear power capacity to four times its current level by 2050 have been announced (DESNZ, 2024). As the share of renewable energy increases, the intermittency of power supply becomes more pronounced. Therefore, there are arguments suggesting that nuclear power, which is difficult to control output, may face challenges in coexisting with the expansion of renewable energy. Since South Korea also aims to achieve carbon neutrality by expanding both renewable energy and nuclear power generation, it would be meaningful to examine further how the UK will balance the expansion of renewable energy with nuclear power generation in the future.

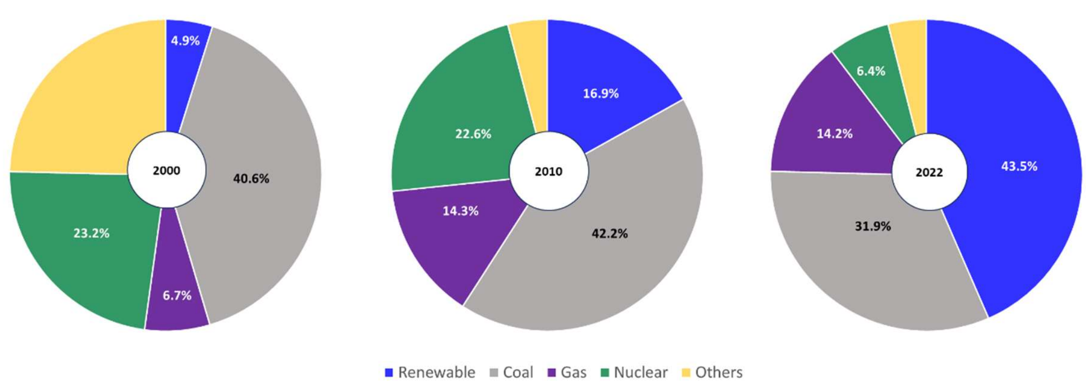
# 5. Energy Transition in Germany

## 5.1. Overview

Germany is considered a global leader in renewable energy deployment. When examining Germany's electricity generation mix, the share of renewable energy, which was only 4.9% in 2000, expanded to approximately 43.5% in 2022, nearly ten times higher. Looking at other energy sources, the share of coal decreased from 40.6% in 2000 to 31.9% in 2022, but it still holds a significant position[10]. On the other hand, the share of nuclear power generation decreased rapidly from 23.2% in 2000 to 6.4% in 2022. Recently, Germany completed its nuclear phase-out plan by shutting down all nuclear power plants in April 2023.

Overall, the rapid growth of renewable energy is remarkable. However, the growth of renewable energy so far has primarily replaced another low-carbon energy source, nuclear power, rather than fossil fuels. The share of fossil fuel generation, including coal and natural gas combined, remained high at 46.1% in 2022 (Figure 16).

**Figure 16. Electricity Generation Mix by Energy Source**

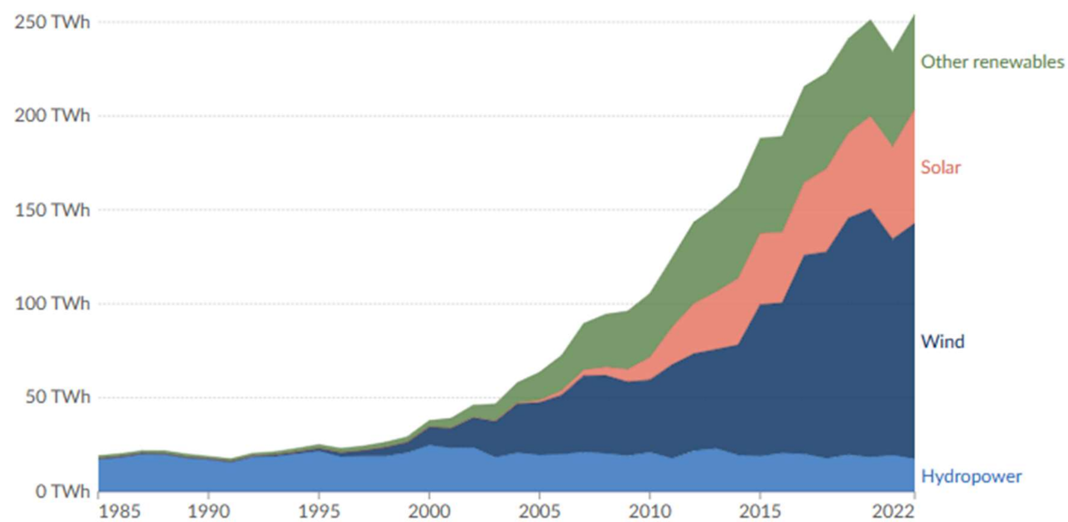



* Source: Ember - Yearly Electricity Data (2023); Ember - European Electricity Review (2022)

[10] The government plans to phase out all coal-fired power generation by 2030.

The trend of renewable energy generation has experienced rapid growth since 2000, primarily driven by wind and solar power. Solar power growth was particularly pronounced in the early 2010s, while since the mid-2010s, wind power has become the primary source driving overall renewable energy growth. As of 2022, total renewable energy generation stands at 254 TWh. Wind power accounts for approximately 50%, while solar power accounts for around 24% (Figure 17).

**Figure 17. Trends in Renewable Electricity Generation**




* Source: Energy Institute - Statistical Review of World Energy (2023)

## 5.2. History of Energy Policies

### *1980s-1990s: Anti-nuclear movement and renewable energy*

The pivotal starting point for Germany's energy transition policy was the Chernobyl nuclear disaster in 1986. Until then, Germany had perceived nuclear power as a stable and suitable future energy source, relying on it for approximately 30% of its total electricity generation. However, the nuclear accident at Chernobyl, which occurred 1,300km away from Germany, also affected regions in southern Germany, including the state of Bavaria, amplifying political debates on energy policy. Civil society began to gain momentum in support of the nuclear phase-out, prompting political parties to abandon their previously passive stances and make nuclear power a political agenda. The Cole government established the Ministry for Environment, Nature Conservation and Nuclear Safety (Ministerium für Umwelt, Naturschutz und Reaktorsicherheit) in 1986. Subsequently, environmental compatibility became increasingly emphasised as a goal of energy policy, alongside ensuring the stability of the energy supply (Jung, 2016, pp. 216-218).

### *1998-2005: The start of full-pledged energy transition*

The Schröder coalition government formed in October 1998, consisting of the Social Democratic Party (SPD), Alliance 90/The Greens, attempted a fundamental paradigm shift in energy policy. In 2000, the government and energy supply companies agreed to phase out nuclear power generation. Based on the agreement, the Nuclear Energy Act was revised in 2002. The revised Act prohibited the construction of new nuclear power plants. It also imposed a limit of 32 years on the operational lifespan of existing plants, effectively enforcing the shutdown of nuclear power operations by 2021.

Around the same time, the government also implemented measures to expand renewable energy. The most notable among these was the enactment of the Renewable Energy Act (EEG: Erneuerbare Energien Gesetz 2000) in 2000. The EEG primarily focuses on two key aspects. Firstly, it mandates that electricity suppliers prioritise purchasing electricity generated from renewable sources. Secondly, it implements the Feed-in Tariff (FiT) system, which guarantees a fixed rate for renewable energy generated for 20 years. Therefore, renewable power generators are able to sell all the electricity they produce at a fixed price, ensuring them a stable income over the long term. After the introduction of EEG, the deployment of renewable energy has expanded rapidly.

### *2005-2014: 'Energiekonzept' and 'Energiewende'*

The Merkel coalition government, which took office in 2005, announced the first national long-term energy plan, Energy Concept (Energiekonzept), in 2010. The Energiekonzept encompasses medium to long-term goals in three main areas: 1) reducing GHG emissions, 2) expanding the use of renewable energy, and 3) reducing energy consumption. Specifically, it set targets to reduce GHG emissions by 40% by 2020 and achieve a minimum of 35% of energy generation from renewable sources by 2020 (Table 6). Following this, the Merkel government's energy transition policy (Energiewende) consistently pursued two main axes: expanding renewables and improving energy efficiency.

**Table 6. Target of Energyconcept 2010 (%)**

| | 2011 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|
| **GHG emissions reduction** (compared to 1990 level) | -26.4 | -40 | -55 | -70 | -80 to -95 |
| **Electricity Generation from renewables** | 20.3 | At least 35 | At least 50 | At least 65 | At least 80 |
| **Final Energy Consumption from renewables** | 12.1 | 18 | 30 | 45 | 60 |

* Source: Han and Park (2022)

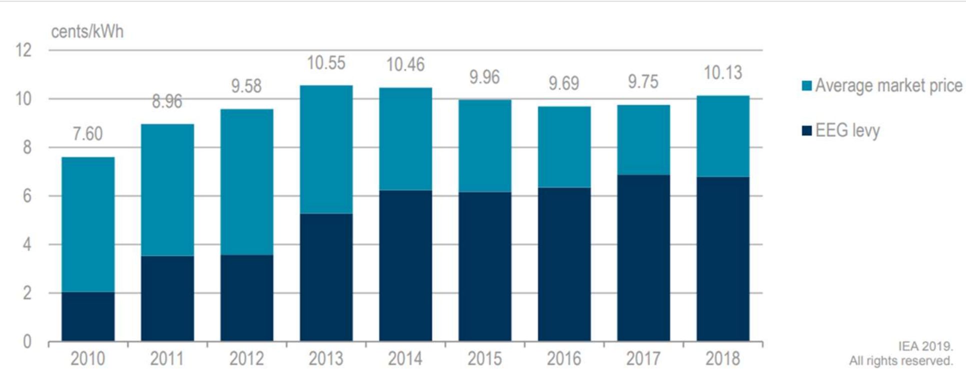
The early Merkel government was more favourable towards nuclear power generation than the previous Red-Green Coalition. They believed using nuclear power as a temporary bridge during the transition to renewable energy was necessary. So, Energiekonzept includes a plan to extend the operating lifespan of nuclear power plants by 8 to 14 years. However, following the Fukushima nuclear disaster in 2011, the government revoked the decision to extend nuclear power operations, instead reaffirming the policy to shut down all nuclear power plants by 2022.

### *Late-2010s: Transitioning to market-driven support*

Germany's renewable energy expansion has continued its rapid growth thanks to solid support policies represented by FiT. However, some critics have raised concerns that these support mechanisms are excessively inefficient in terms of cost. In Germany, the funding necessary for the support schemes has been raised through a surcharge on electricity bills, known as the EEG levy. As renewable energy expanded and more projects became eligible for FiT support, the amount of the surcharge also increased. This has resulted in a problem where consumers face continued increases in electricity bills (Huenteler et al., 2012, p. 8).

In response, the government enacted a revision of the Renewable Energy Act in 2014 (EEG 2014). Under this revision, the government removed the FiT scheme for new projects above a certain scale and required projects to use a direct marketing scheme. The Renewable Energy Act was further amended in 2017 (EEG 2017), introducing competitive auctions based on the Feed-in Premium (FiP) scheme. Germany's auction system applies to wind and solar projects with a capacity of 750 kW or more. The government sets annual installation capacity limits to manage the number of projects eligible for bidding. The winning bidder receives a guaranteed electricity price for 20 years, which includes the premium added to the actual market price These reforms have been effective in reducing the average cost of renewable energy projects, in particular solar PV. This has led to stabilising the EEG levy and a slowdown in electricity price growth (IEA, 2020a, pp. 92-94).

**Figure 18. EEG levy and average wholesale electricity market price, 2010-18**




* Source: IEA (2020a)

### *2020s: Accelerating efforts to promote renewable Energy*

In the 2020s, Germany continues its legislative and policy efforts to promote renewable energy. In particular, the Russia-Ukraine war, which threatened Germany's energy security, has served as a catalyst for accelerating efforts to transition to renewable energy. The traffic light coalition government[11], which took office at the end of 2021, announced the Easter Package (Osterpaket) in April 2022, reflecting this policy direction. The Easter Package consists of six legislative amendments, including the Renewable Energy Act, the Offshore Wind Energy Act, and the Energy Industry Act. The revised Renewable Energy Act (EEG 2023) has increased the target for renewable energy electricity generation to a minimum of 80% by 2030 and provided specific expansion targets for each renewable energy source (Table 7).

Meanwhile, Germany completely ended nuclear power generation in April 2023. After the Russia-Ukraine war and the subsequent energy crisis, there were some voices in Germany calling for reconsidering the nuclear phase-out schedule. However, the government opted to set a response direction by accelerating the expansion of renewable energy. This is in contrast to other major countries, such as the UK and France, which have recently considered expanding the role of nuclear power in achieving their carbon neutrality goals.

**Table 7. Key targets set by legislation**

<table>
<tr><th></th><th colspan="7">Target</th></tr>
<tr><td>GHG emissions reduction<br>(compared to 1990 level)</td><td colspan="7">65% reduction by 2030, 88% reduction by 2040 and carbon neutrality by 2045</td></tr>
<tr><td>Electricity Generation from renewables</td><td colspan="7">At least 80% of total electricity consumption from renewable sources by 2030</td></tr>
<tr><td rowspan="4">Power Generation Capacity<br>(GW)</td><td></td><td>2024</td><td>2026</td><td>2028</td><td>2030</td><td>2035</td><td>2040</td></tr>
<tr><td>Solar PV</td><td>88</td><td>128</td><td>172</td><td>215</td><td>309</td><td>400</td></tr>
<tr><td>Onshore Wind</td><td>69</td><td>84</td><td>99</td><td>115</td><td>157</td><td>160</td></tr>
<tr><td>Offshore Wind</td><td>-</td><td>-</td><td>-</td><td>30</td><td>40</td><td>70</td></tr>
</table>

* Source: Jang & Gong (2022)

[11] Social Democratic Party of Germany (SPD), the Free Democratic Party (FDP) and Alliance 90/The Greens.

## 5.3. Implications

### *Consistent policy drives with a long-term perspective*

Germany's energy transition policy has been developed over a long period of social discussions and preparations. Germany has recognised the importance of renewable energy supply since the 1980s. The country had already reached a nuclear phase-out agreement and enacted the Renewable Energy Sources Act (EEG) in the early 2000s, when other countries were focusing on fossil fuels and nuclear power. This policy stance persisted even through a change of government in 2005, and led to the Energy Concept of 2010, which is the basis of Germany's current energy transition policy. Due to the long-term continuity of a consistent policy stance, Germany's energy transition policy is underpinned by bipartisan consensus and public support. In particular, Germany has secured binding force and enforceability by legislating detailed policy objectives, such as renewable energy deployment targets, into law within the framework of EU energy policies.

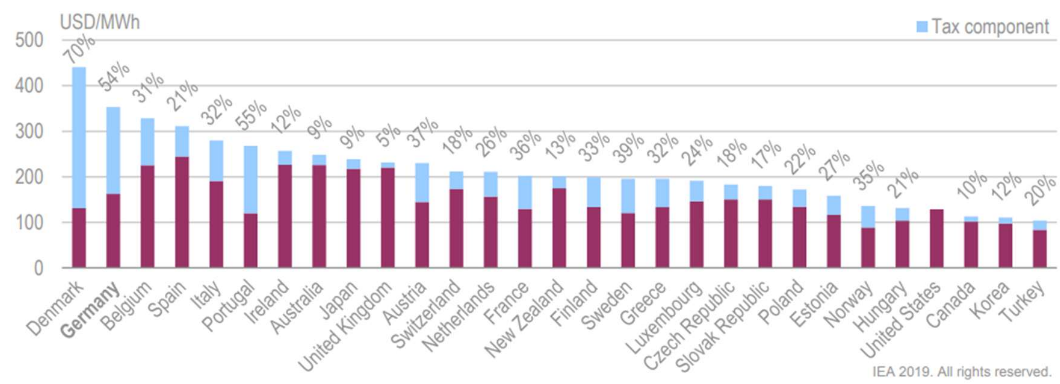
### *Relevant institutional improvements considering the circumstances*

Germany's early renewable energy deployment policies, represented by FiTs, have become a benchmark for many other countries. Despite its successful policies, Germany has not neglected efforts to enhance policy effectiveness through ongoing monitoring and institutional reform. Since the 2010s, as concerns grew over the inefficiency of FiT support and consumer burdens, Germany responded by setting upper limits on FiT support levels and introducing auction systems to induce price competition. These institutional adjustments are in line with market principles, initially aimed to incentivise sufficient business participation through profit guarantees, and after achieving a certain level of deployment, to encourage market competition.

### *Policy implementation based on public acceptance*

Germany has one of the highest electricity prices, especially for households, among major countries. This high electricity price is due to the burden placed on electricity consumers in the form of surcharges to support renewable energy deployment[12]. Since the introduction of renewable energy support policy in 2000, electricity prices have shown a steady upward trend. The significant increase in electricity prices was made possible largely due to high levels of public support and recognition of the necessity of expanding renewable energy sources.

**Figure 19. Household electricity prices in IEA member countries, 2018**




* Source: IEA (2020a), Energy Policy Review

One of the key characteristics of an energy system centred around renewable energy, as opposed to one reliant on large-scale power plants and fossil fuels, is the emphasis on small-scale distributed generation. Therefore, the successful deployment of renewable energy relies not only on overall public support but also on the acceptance of local residents where facilities are actually installed and operated. Indeed, Germany's success in renewable energy deployment owes much to the creation of various citizen participation and benefit-sharing models, such as Energy Cooperatives, which are composed of local residents[13].

[12] As of 2019, the EEG levy accounted for 23% of the total electricity price.

[13] As of 2021, there are 914 Energy Cooperatives in Germany.

### *Balanced renewable energy mix*

Another notable aspect of Germany's renewable energy policy is its pursuit of a balanced mix between solar and wind power generation. As of 2022, wind power facilities account for 31.4% of Germany's installed capacity, while solar power facilities account for 30.9%. As a traditional powerhouse in wind energy, Germany had a high proportion of wind power generation in the early stages of its energy transition policy. So, the government took measures such as increasing FiT subsidies for solar power projects, supporting the introduction of agricultural solar installations, and mandating the installation of solar panels on buildings. Recently, the government has been actively promoting the expansion of offshore wind power, which has relatively lower deployment compared to solar and onshore wind energy, through the amendment of the Offshore Wind Energy Act (WindSeeG) in 2022. The policy direction of pursuing balance among renewable sources carries significant implications for South Korea. As of 2022, South Korea's renewable power generation structure is heavily skewed towards solar power, with a ratio of 93:7 between solar and wind power capacity.

## 6. Conclusion and Recommendations

So far, this study has examined the importance of energy transition for achieving carbon neutrality and the development processes and key contents of energy transition policies in countries including South Korea, the UK, and Germany. Upon reviewing the results, South Korea's renewable energy support schemes do not significantly differ from those of countries that have succeeded in renewable energy expansion at first glance. This is because many of South Korea's policies have been adopted by benchmarking systems that were previously attempted in advanced countries. Consequently, the differences in the performances of renewable energy deployment among countries seem to stem more from variations in policy management rather than inherent issues with the support systems themselves. Specifically, it is evaluated that efforts that have been observed in the UK and Germany, such as consistent policy implementation from a long-term perspective, appropriate institutional adjustments tailored to the situation, and securing public support, have been lacking in South Korea.

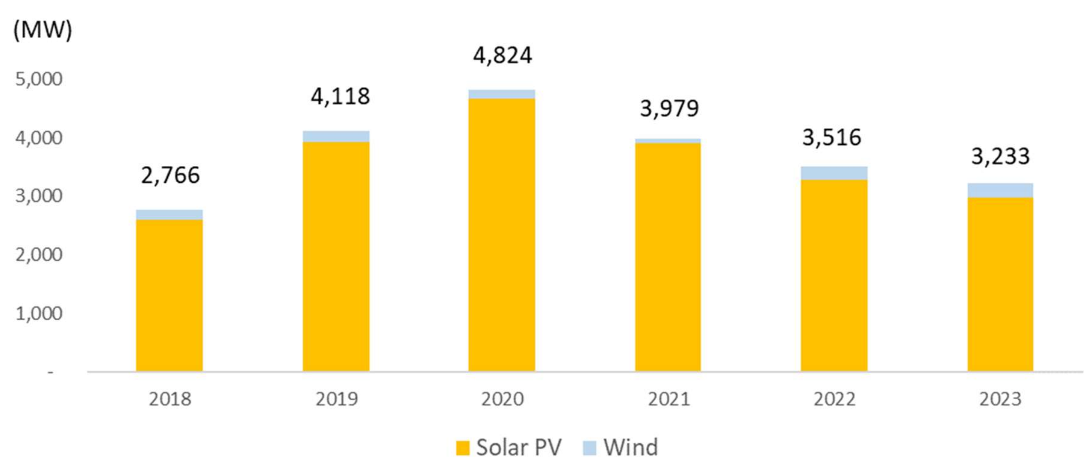
Energy transition has become a matter of how quickly it is done rather than whether to do it or not. South Korea's energy policy is also at a critical moment. In particular, expanding renewable energy is crucial not only for achieving the carbon neutrality goal but also for securing the competitiveness of the economy and industry. Based on these considerations, the following policies are recommended to expand renewable energy in South Korea effectively.

### *Setting more proactive goals for expanding renewable energy*

In 2023, South Korea announced the 10th Basic Plan for Electricity Supply and Demand, adjusting the target share of renewable energy in power generation to 21.6% by 2030, previously set at 30%. The government explains this adjustment as a necessary measure, taking into consideration a rational and achievable level.

The target for renewable energy deployment serves as a kind of guideline for government policy direction and influences the private sector. Setting ambitious targets sends a positive signal to investors and can attract finance. Conversely, if policy intentions are unclear, investment tends to stagnate. Recent movements in renewable energy investment suggest concerns about such market contraction. The capacity of newly installed renewable energy facilities in South Korea has decreased for three consecutive years since 2020 (Figure 20). With this trend, achieving even the target of 21.6% by 2030 seems increasingly challenging. Around 5GW of new renewable energy capacity needs to be added each year to achieve the goal (MOTIE, 2022). However, the investment performance in 2023 (tentative) has already fallen significantly short of this baseline. Considering recent market trends and reduced government support[14], there is a high possibility that the future investment scale will decrease even further.

**Figure 20. Newly installed capacity of Solar PV & Wind power generation (MW)**




* Source: KEA, 2023 & KEPCO, 2024

As a latecomer, South Korea requires more proactive goal-setting and policy support to accelerate the deployment of renewable energy. Specifically, in the 11th Basic Plan for

[14] The Korean Feed-in Tariff (FiT) system, which had been a key factor in expanding solar power facilities since 2018, was abolished in July 2023.

Electricity Supply and Demand, to be announced in 2025, there is a need to revise the target for the upward share of renewable energy. The expansion of renewable energy share does not necessarily conflict with the current government's emphasis on nuclear power utilisation. Other countries, such as the UK, are also pursuing nuclear power utilisation alongside the continuous expansion of renewable energy share.

### *Building a bipartisan consensus on scaling up renewables*

While it's natural for some differences to arise in specific policies depending on the ruling government in any country, South Korea's energy policy has often experienced excessively huge fluctuations. Plans established by the previous administration were easily replaced by new plans under the subsequent administration. This lack of consistency undermines the reliability of government plans and causes confusion in various government budgets and private-sector investments. In contrast, in the UK and Germany, a common understanding of the necessity for renewable energy transition has allowed for consistent energy policy implementation even during changes in administration. This has resulted in the current achievements in deployment.

At this point, South Korea should also seek ways to establish a societal consensus on the necessity for renewable energy transition through bipartisan agreement and explore measures to ensure consistent policy implementation. Specifically, the mid-to-long-term renewable energy penetration targets currently being finalised in the administration's plan should be stipulated in the Renewable Energy Act to ensure binding force. In this case, the credibility of government policies would increase, and even if adjustments to the targets are needed due to changes in administration, they can be carried out through sufficient societal discussions.

### *Reforming renewable energy deployment support scheme*

As discussed above, appropriate reforms tailored to each country's situation significantly influence policy outcomes. Such reforms are also necessary in South Korea. First, the government should maintain the Korean FiT scheme for small-scale renewable energy generators. The Korean FiT, introduced in 2018, has since contributed significantly to the spread of renewable energy, but the government abolished the scheme in 2023, citing difficulties with small-scale solar PV proliferation and illegal subsidy acquisition. However, the reasons raised by the government are more related to operational management issues, so it is difficult to justify the abolition based solely on these grounds. Rather, the existing Korean FiT had a problem of being too restrictive in support scope by only targeting facilities of less than 30KW. Therefore, while maintaining the support system, it is necessary to consider expanding the scope of facilities by considering standards from countries like Germany (Less than 750KW) and the UK (Less than 5MW).

Next, it is necessary to reform the current RPS scheme. The RPS in South Korea is evaluated as not fully achieving its intended effects of promoting renewable energy technology development and industrial growth through market competition due to the unique electricity market structure where the state-owned Korea Electric Power Corporation (KEPCO) monopolises the retail electricity market. The government has also acknowledged this inefficiency and recently announced plans to phase out the RPS system in the medium to long term and prepare a new framework, such as auction systems (MOTIE, 2022). Looking at the evolution of institutional changes in advanced countries, it has typically progressed through the 'introduction of support system → supplementation → introduction of competitive system'. Considering this, transitioning RPS to an auction system would be a desirable direction in the long term. However, the transition timing should be carefully examined, considering the maturity of the renewable energy market in South Korea and other relevant factors. Even after the decision to transition to an auction system is made, it will be important to allow for an adequate period before the complete termination of the RPS support to prevent market disruptions.

### *Establishing an efficient organisational system to strengthen policy implementation*

Currently, climate change response tasks in South Korea are managed by the Ministry of Environment (MOE), while energy-related tasks are overseen by the Ministry of Trade, Industry and Energy (MOTIE), along with industrial, trade, and commercial affairs. This governance structure can be seen as very similar to the situation in the UK before the establishment of the DECC. However, currently, MOE does not have significant influence over other ministries, and MOTIE handles various other industrial-related tasks, which limits its ability to address energy policy from a perspective of climate crisis response. Achieving carbon neutrality goals requires a solid pivotal point within the government to coordinate policies consistently across various ministries regarding climate change response. Therefore, it is necessary to consider establishing an independent department dedicated to climate change response and energy transition, taking inspiration from the example of the UK's DECC.

Next, efforts to increase the independence of the Presidential Commission on Carbon Neutrality and Green Growth (PCCNGG) are also necessary. PCCNGG was established in 2021 to coordinate inter-ministerial policies for carbon neutrality and reflect social discussions. However, as a committee under the government, it has limitations in that it is not free from government policy direction. Therefore, it is necessary to reform the current PCCNGG into an independent organisation, referring to the case of the UK's CCC. In particular, as achieving carbon neutrality is a long-term task until 2050, there is a need for improvements in the composition of the commission to ensure stable operation unaffected by regime changes. In terms of its function, the most crucial role of the commission should be to objectively review and evaluate key government policies, including energy transition, from a neutral standpoint.

### *Enhancing efforts to increase the public acceptance of renewable energy*

Even if the government is keen to expand renewable energy, it can be challenging to proceed with projects when local residents oppose them. In fact, many individual projects in South Korea are being delayed due to complaints from neighbouring residents. As such conflicts are likely to further escalate in the process of renewable energy expansion, active institutional improvement efforts are needed at the government level. Specifically, it is necessary for the government to establish renewable energy site plans. Currently, the government is mainly focused on setting deployment targets and operating support systems for renewable energy, leaving site selection to be driven by private generators during the actual deployment phase. This makes it difficult to implement systematic deployment from a country-wide perspective and leads to conflicts due to indiscriminate sitting. At the central government level, it is imperative to collaborate with local authorities to proactively establish site selection plans considering factors such as potential development capacity and unused land, aiming to minimise the possibility of conflicts arising afterwards.

Next, the government need to expand the community benefit-sharing model. Leading countries in renewable energy, such as Germany, have addressed community acceptance issues by introducing a model that shares benefits from power projects with local communities. South Korea has also operated a community participation renewable energy system since 2017, but participation levels still remain low. The government should explore ways to activate this system further. Currently, the government only supports by issuing additional Renewable

Energy Certificates (RECs) to selected projects. There is a need to enable the implementation of other benefit-sharing methods utilised in advanced countries, such as making local community funds and supporting electricity bills, in parallel with the current system.

Finally, it is also important to increase the acceptance of the general public, who potentially could become local residents. For this purpose, systematic and continuous education and promotion through various online and offline channels are necessary to convey the necessity and benefits of transitioning to renewable energy.

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