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Identifying the Sustainable Industry by Input–Output Analysis Combined with CO₂ Emissions: A Time Series Study from 2005 to 2015 in South Korea

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Abstract: Preventing global warming caused by increased CO₂ emissions is a major global problem. It is necessary to find and cultivate an efficient industry with a small amount of CO₂ emissions and a great impact on the national economy. This article used input–output analysis to quantify the linkage effects on the Korean economy by dividing the Korean industries into 36 categories, according to the OECD (Organization for Economic Cooperation and Development) industrial classification criteria. In addition, the total amount of carbon dioxide emitted during the year was described by its criteria to compare how much of one industry emits carbon dioxide. The analysis shows that Korea still has an economic structure centered on traditional manufacturing and the characteristics of these industries include CO₂ emissions. According to the result, in the construction industry, the carbon dioxide emissions are considerably high, but the linkage effects of the industry is small. By quantitatively analyzing the impact of an industry on the economy and carbon dioxide emissions generated in the production process, this study aimed to identify Korea's eco-friendly and highly related industries with other industries and objectively present sustainable development.

Keywords: CO₂ emissions; input output table series; linkage effects; sustainable industry

1. Introduction

Since the Industrial Revolution, countries around the world have emitted huge amounts of greenhouse gases (GHGs) through development and advancement. Global GHG emissions are projected to continue to increase from 52.7 Gt CO₂ in 2014 to 65 Gt CO₂ in 2030 and 87 Gt CO₂ in 2050. The main cause of GHG emissions is carbon dioxide emitted from the raw material refinement process, which was measured at 36.2 Gt CO₂ in 2015, accounting for 68% of global GHG emissions. As a result, abnormal climate events such as global warming occur. The raw material refinement process directly affects industrial activities because industries cannot take action without the refined fuel. Hence, it is not only an environmental problem, but an economic problem. In addition, there is a movement to link environmental issues such as CO₂ emissions trading with international trade. Korea, highly dependent on energy imports and on international trade, is greatly affected by GHG emissions regulations.

The Paris Agreement (2015. 12. Adopted by 195 countries around the world and concluded in the UN Framework Convention on Climate Change. Unlike the Kyoto Protocol, it is bound by international law (after November 2016)) is the product of various countries' hard work to realize the seriousness of natural disasters by global warming and reduce carbon emissions. When the new climate agreement that replaces the Kyoto Protocol (this refers to an amendment to the Climate Change Convention, an international convention for the regulation and prevention of global warming which came into effects in 1995) is conducted, it is mandatory for all countries whether advanced or underdeveloped, to reduce

carbon emissions. Nevertheless, GHG emissions are steadily increasing around the world, and the Intergovernmental Panel on Climate Change (IPCC) forecasts that global average temperature will rise 38.3 °F by 2100 [1].

Korea has tried to reduce GHG emissions in various sectors such as by implementing an emissions trading system since 2015, and announced its intention to reduce carbon dioxide emissions by 37% compared to BAU (Business as Usual) by 2030. If a GHG emissions reduction policy is implemented in earnest, regulations on industries that emit a lot of GHGs will be strengthened and will change the industry's competitive environment. It is argued in the industry that GHG reduction policies such as the implementation of stronger GHG emission trading institutions, will eventually lead to the relocation of production plants and avoidance of foreign investment. Due to emissions trading, this can lead to the overseas transfer of domestic production and production restrictions at domestic business sites in Korea. It may also delay the development of new technologies and preoccupation of new markets. Recently, external actors such as the government, non-governmental organizations, public opinion, and creditors have requested companies report on and reduce emissions [2,3]. According to the Group on Climate Change in Australia and New Zealand (IGCC), banks and corporations are investing heavily in the fields of new and renewable energy, green building, and renewable energy under low carbon policies around the world. Recently, CO₂ emissions analyses have gained importance for sustainable projects for the future [4]. The ultimate goal of research on carbon emissions is to reduce carbon emissions globally, and many studies have thus investigated the factors that increase CO₂ emissions using a decomposition analysis [5]. Wang et al. [6] analyzed the driving forces for the change in CO₂ emissions in the city of Beijing from both production and final demand perspectives over 1997–2010. According to the results, the CO₂ emissions growth in Beijing was driven mainly by production structure changes and population growth. The emissions were partly offset by the decline in CO₂ emission intensity and per capita final demand. Feng et al. [7] analyzed the factors affecting U.S. emissions from 1997–2013 and the results showed that the changes of emissions were primarily driven by economic growth and fuel mix. For Singapore, Su et al. [8] investigated the key driving factors of emission changes during the period 2000–2010. Cansino et al. [9] deconstructed the changes in CO₂ emissions at the sectoral level in Spain for the period 1995–2009 and based on the results, they suggested policies against climate change.

In order to effectively reduce carbon emissions, regulations on carbon emissions must have a small impact on industrial activities and the national economy. To do so, it is important to understand the structure of carbon dioxide emissions according to the production activities by the national economy sector. Therefore, it is of great significance to analyze the amount of carbon dioxide emissions by industry through input–output (IO) analysis. As there are interactions in economic activities between industries, the CO₂ emissions structure can be analyzed by each industry and can be used to establish effective carbon dioxide emission reduction policies according to the nature of each industry by these results.

Studies on environmental impact analysis using IO analysis have been conducted in a variety of ways, from the analysis of the impact of changes in final demand on energy demand and the environment to studies focusing on energy consumption and the environmental impact of international trade. The purpose of this study was to find a sustainable industry in Korea that emits a small amount of carbon dioxide with high efficiency. For the aim, we first conducted the IO analysis using the input–output (IO) table. The results of the IO analysis show how many linkage effects that industries have on the Korean economy. Having a great linkage effect means that they have great impacts on the national economy. In other words, it is a strategic industry because it has a role as a leader in the national economy. Second, the carbon dioxide emissions by industry are presented for the period of 1995–2015. The time series data analysis shows whether efforts have been made to reduce carbon dioxide emissions or whether carbon dioxide emissions are increasing or decreasing despite radical technological development. Finally, by combining the results of the analysis by the two methodologies,

we can figure out an eco-friendly industry that reduces environmental pollution and has a huge effect on the national economy.

The rest of this paper is organized as follows. We review the literature on the importance of CO₂ emissions and IO analysis in the environment in Section 2. In Section 3, we briefly delineate the method of measuring the linkage effect from the IO table from 36 industries in Korea. The results of the IO analysis appear in Section 4, and the discussion and conclusions are drawn in Section 5.

2. Literature Review

2.1. Importance of CO₂ Emissions Analysis

The energy use of carbon-based fuel has become a major concern in recent years because CO₂ emissions are the key factor in the resulting climate change. Many studies have used carbon emissions and carbon footprint such as the studies conducted in [10–20].

Alcantara and Padillar [10] estimated the elasticity of carbon dioxide emissions according to industrial activities by using added value as a control variable using the energy IO table. Hatzigeorgiou et al. [11] performed more comprehensive decomposition analysis of the changes in Greece's CO₂ emissions from 1990 to 2002, calculating the effects of four factors: income, population, energy intensity, and fuel share. This study was one of the few to consider the effect of population. Acharyya [12] analyzed the effects of foreign direct investment inflows on India's GDP growth from 1980 to 2003 and the carbon emissions during this period. Lim et al. [13] conducted a decomposition analysis of Korea's industrial emissions over 1990–2003 using the input–output structural decomposition analysis (IO-SDA) method. The study considered seven factors: energy intensity, carbon intensity, economic growth, domestic final demand, exports, production technology, and imports of final, and intermediate goods. The empirical results implied that Korea's industrial CO₂ emissions drastically declined after the 1998 Asian crisis [13]. The authors also reported that CO₂ reductions resulted from changes in energy intensity and final energy demand over 1995–2000 [13]. Yoon and Kim [14] examined the operation status of each country on CO₂ emissions reduction and asserted the justification for the transition of national economic structure to high efficiency low carbon structure. Timilsina and Shrestha [15] concentrated on CO₂ emissions from the transport sector in 20 Latin American and Caribbean countries during 1980–2005. Using the LMDI(Log Mean Divisia Index) method, they analyzed the influences of four factors on CO₂ emissions: fuel mix, modal shift and economic growth, emission coefficients, and transportation energy intensity. The empirical findings showed that economic growth and transportation energy intensity were the major determinants of the transport sector's CO₂ emissions growth in the countries studied. Pao [16] used the panel cointegration analysis for BRIC(Brazil, Russia, India and China) countries from 1980 to 2007 to address the impact of economic and financial development on environmental degradation. Except in Russia (1992–2007), in terms of long-term equilibrium, carbon dioxide emissions have been shown to have a resilient effect on energy consumption and foreign direct investment. Ren et al. [17] calculated the emissions of carbon dioxide used in China's trade from 2000 to 2010 and examined whether it had a causal relationship with economic growth. As a result, as China's trade surplus increased rapidly, carbon dioxide emissions also tended to increase. Large-scale foreign direct investment inflows exacerbate China's CO₂ emissions, and the per capita income and CO₂ emissions in the industrial sector show an inverted U-curve relationship, the so-called environmental Kuznets curve (EKC). Therefore, in order to achieve environmentally sustainable economic development, China should make the effort to develop a low-carbon economy by changing trade growth patterns, adjusting the structure of foreign investment, and increasing energy efficiency. Kisielewicz [18] et al. measured the contribution to GHG emissions through decomposition analysis and concluded that the growth of GHG emissions increased with economic growth, but the correlation between economic growth and increased emissions showed a decoupling. The result of the analysis suggests that technological developments between 1995 and 2012 weakened the relationship between economic growth and carbon emissions. Yu et al. [19]

quantitatively analyzed whether there was a GHG reduction in 2015 when the emission trading scheme was introduced and showed that the reduction effect was different for each industry. Busch and Lewandowski [20] analyzed the relationship between carbon performance and financial performance through meta-analysis. In the existing meta-analysis studies, various environmental problems and various environmental performances were measured, but in these studies, the research focused only on the carbon performance expressed by carbon dioxide emission levels. The result of the analysis reports that carbon emissions are inversely proportional to financial performance, which indicates that good carbon performance is generally positively related to financial performance.

Based on these previous studies, this study aimed to analyze the amount of carbon emitted by economic activities by industries, along with the relationship between industries in the Korean economy.

2.2. Input–Output Analysis in Environment

As proposed by Leontief [21], input–output (IO) analysis has become a tool widely used to analyze economic structure, international and domestic trade, and energy and environmental issues. Environmental impact analysis studies using inter-industry analysis have ranged from analyzing the impact of changes in final demand on energy demand and the environment [22–24], to the study focusing on energy consumption and the environmental impact of international trade [25–27]. The IO analysis method has been found to be an effective and widely used method to analyze the indirect CO₂ emissions in the construction industry.

In recent years, with the international community's continuous attention to environmental problems, flows and changes in a country or region's resources, energy and emissions have been estimated and analyzed with the IO framework [28].

For example, Alcántara [29] analyzed the forward and backward linkages of SO_x emissions for Catalonia (Spain). Lenzen [30] investigated greenhouse gases and primary energy consumption through an analysis of Australian domestic production and imports. Park and Heo [31] investigated the energy consumption caused by household consumption in South Korea during 1980–2000 using the input–output method, which concluded that the energy consumption by household industry accounted for 52% of the national total energy consumption. Grubb et al. [32] argued that there was a relationship between income and CO₂ emissions. However, they found that the relationship between income and CO₂ emissions was highly complex and could be generalized. On one hand, they found that the growth of GDP per capita was likely to be associated with the growth of CO₂ emissions and differed significantly depending on other factors specific to each country. Acquaye and Duffy [33] adopted the input–output approach for analyzing the emissions in the Irish construction industry and found that indirect CO₂ emissions in the Irish construction industry accounted for 91% of total CO₂ emissions. Okushima and Tamura [34] found that technological change is of great importance for curtailing energy use and CO₂ emissions in Japan. They argued that CO₂ emissions increased during 1970–1995 primarily because of the economic growth. In contrast, the effects such as technological change for labor or energy mitigated the increase in CO₂ emissions. Papathanasopoulou [35] used the input–output model to explore Greece's household consumption on fossil fuel and resulting carbon emissions and indicates that indirect energy consumption increased 60% from 1990 to 2006. It should be noted that the studies above imply that the main method to estimate indirect energy consumption and CO₂ emissions caused by household consumption is based on the input–output technique, which provides important reference for our study here. Alcantara et al. [36] analyzed the responsibility of the productive structure of an economic system with respect to the consumption and generation of electricity within an input–output framework. Piaggio et al. [37] applied IO tools to identify the key sectors in GHG emissions for Uruguay. Su et al. [8] researched carbon emission changes and the driving forces in Singapore. Yun et al. [38] compared the economic impact between the software and medical industry through an IO table by the Bank of Korea. The results showed that the software and the medical industry had different linkage effects between backward and forward. Furthermore, not only did they have a higher labor inducement coefficient than the average of the whole industry, but

also had a similar effect on labor induction. According to the results of this study, the software and medical industry have a high economic impact on the Korean economy, and therefore are intensively fostered by policy support. Tarancon et al. [39] used an input–output approach combined with a sensitivity analysis to analyze the direct and indirect consumption of electricity by 18 manufacturing sectors in 15 European countries.

Research works have also been conducted in the context of the Chinese construction industry in analyzing the CO₂ emissions by using the input–output model [40]. Lin and Sun [41] investigated carbon dioxide emissions in the international trade of China based on IO tables from 2005. Zhu et al. [42] investigated carbon emissions from residential consumption from 1992 to 2005 based on several IO tables from China. Xu et al. [43] used the LMDI method to determine the factors influencing carbon emissions due to energy consumption in China. In their work, the domestic production coefficient matrix was updated in 2007 to estimate the time-series domestic production coefficient matrix and domestic Leontief inverse matrix from 2006 to 2012. Chen et al. [40] explored the CO₂ emissions in the Chinese construction industry from 1995 to 2011 by using the input–output model from four perspectives, namely, the dynamic changes of the CO₂ emissions and carbon intensity in the construction industry, the difference between the indirect and direct CO₂ emissions, the difference between the process-based and energy related CO₂ emissions, and the contributions by industries to the construction CO₂ emissions. They found that the CO₂ emissions in the Chinese construction industry increased by 388.7% during the period from 1995 to 2011, whilst the carbon intensity decreased by 46.9%. Zhang et al. [44] proposed the input–output method to measure the direct and indirect CO₂ emissions caused by household consumption, decomposed the influencing factors for the indirect CO₂ emissions, and analyzed the direct and total CO₂ emissions intensity among key carbon intensive sectors during 2000–2010 in China. Zheng et al. [45] provided an overview of the direct and indirect carbon footprint of Chinese final demand according to the IO analysis. They updated the Chinese IO table series for the period of 1992–2020 by using the matrix transformation technique (MTT) and calculated the embodied carbon emissions year by year for the period of 1992–2020 from 29 industry producers to final demand, covering urban and rural residential consumption, government consumption, fixed capital formation, and net export in accordance with the time series IO tables. Finally, they analyzed the Chinese carbon footprint. The results showed that construction, other services, wholesale, retail trade, accommodation and catering, industrial machinery and equipment, transport, storage and postal services, and manufacture of foods and tobacco were the industries with the greatest carbon emissions from producers, while fixed capital formation and urban consumption were the largest emitters from the perspective of final demand.

3. Data and Methodology

3.1. Input–Output Analysis

This study used inter-industry analysis to quantify the linkage effects on the Korean economy by dividing the Korean industries into 36 categories, according to the OECD industrial classification criteria. In addition, the total amount of carbon dioxide emitted during the year was divided by the output of each industry to determine how much of one industry emits carbon dioxide.

The IO model measures the economic impact of one sector or industry on an economy [46]. It uses the Leontief's inverse matrix to estimate inducements of industries in a country. Therefore, it is useful to explain the linkage effect of each industry. Before analyzing the linkage effects, it is necessary to examine the significance of the IO table. This is because Leontief's inverse matrix is made from the IO table and shows how goods and services produced by one industry in a country are distributed to other industries over a period of time. It also presents how much they are put into other industries for production. Quantitative analysis of correlations between industries using the IO table is called inter-industry analysis or input–output analysis [47]. For example, output from industry A is input as raw material to industry B. Output from industry B can be input as raw material to industry C

and output from industry C as input to industry A. Then, we can say that each industry has a direct and indirect relationship. IO analysis using the IO table can find the relationship between input and output between industries in relation to the industrial structure. In addition, it is possible to grasp the relationship between the primary input factor sector and the industry and the transaction volume between the final output sector and each industry. The IO table includes the intermediate demand, representing inter-industry transactions that are directly input for production, the value-added sector that represents the cost of purchasing essential production factors such as wages, profits, and taxes, and final demand, where the goods and services of each industry are sold as final goods such as consumption, investment, and export [47]. Since IO analysis is a method that analyzes the input and output relations of each industry on the assumption that each industry's input changes, the output of one industry means a change in the output of another industry. Therefore, it is a useful tool for national economic forecasting and planning.

IO analysis proposed by Hirschman derives the production inducement coefficient using the input–output table in the national industry and the degree of industrial revitalization is indicated through the coefficient. Hirschman's input–output analysis is that an industry in a country induces production directly or indirectly in other industries, and the larger the induced coefficient produced, the more vital the industry across the country. The IO analysis can be divided into the backward linkage effect and forward linkage effect. Backward linkage effects are related to the pulling power that one industry has on the other industries through its demand for the products of the other industries as intermediate inputs in its own production process [48]. For example, demand for automobiles causes the production of engines, tires, etc. The backward linkage effect is a comparison of the degree of production inducement caused by demand for automobiles with the average of all industries. Demand for automobiles drives the production of engines and tires, which is a backward linkage effect. The backward linkage effect is compared with the average of all industries in terms of production inducement caused by demand for automobiles [47].

That is, this means that production induces an effect on the entire nation's industry, which occurs when the industry receives raw materials from other industries. As explained in various studies, the industry induces production in all industries through demand for intermediates, and production inducement promotes continuous production. The backward linkage effect is represented as the power of dispersion (POD) [49,50]. In other words, it can be said that the industry consumes intermediate products to activate production, thereby exerting production induced effects [51,52]. In conclusion, it is considered that the high value of this coefficient shows strength as a 'consumer' in the national industry [53].

The forward linkage effect is the overall production induced effect that occurs when a product in the industry is introduced as intermediate in other industries. In the steel industry, for example, production of all industrial sectors increases by one unit, causing the production of steel items. At the time, the forward linkage effect is a comparison of the level of production induction of steel with the average of all industries [47]. Forward linkage effects are related to the pushing power that one industry exerts on the other industries through the utilization of its products by the other industries in their production processes. Therefore, forward linkage captures the vertical relationship between an industry and its downstream business clients. Such linkage effects are directly caused by the interactions between industries in the form of intermediate demand and supply relations [48]. The forward linkage effect is expressed as the sensitivity of dispersion (SOD), which plays crucial roles in economic development and in supporting other industries [49–52]. Overall, the high value of this coefficient not only means having a strong capacity of growth, but its relational structure also facilitates the development of the national economy without strong dependencies [53].

Table 1 presents the structure of an IO table. Quadrant I shows the flows of products among the producing sectors. In Quadrant I, rows S_1 through S_n refer to n producing sectors in the economy. The sum of each row indicates the total intermediate supply for each sector. On the other hand, the columns represent the purchasing industries that buy the outputs produced by each of the industries in

the rows in order to make their own products. The sum of sectors in each column represents the total intermediate demand for each industry. Quadrant II shows the final demand, which is the demand of non-industry buyers such as households, governments, and export companies. The total output of an industry is the sum of its total intermediate demand and total final demand. The row representing value added consists of three components: compensation of employees, taxes on production and imports less subsidies, and gross operating surplus. The total input of an industry is the sum of its total intermediate demand and added value.

Table 1. Input–output table.

Producing Sector	Intermediate Goods and Services						Total Intermediate Demand	Total Final Demand	Total Output
S_1	S_1	S_2	S_3	S_4	$\cdot$	S_n	SX_{1n}	D_1	X_1
S_2	X_{11}	X_{12}	X_{13}	X_{14}	$\cdot$	X_{1n}	SX_{2n}	D_2	X_2
S_3	X_{21}	X_{22}	X_{23}	X_{24}	$\cdot$	X_{2n}	SX_{3n}	D_3	X_3
	X_{31}	X_{32}	X_{33}	X_{34}	$\cdot$	X_{3n}	SX_{4n}	Quadrant II	
S_n	X_{n1}	X_{n2}	X_{n3}	X_{n4}	$\cdot$	X_{nn}	SX_{nn}		X_n
	Total Purchase								
	Value Added								
	Total Input								

The output level of each sector can be written as

$$X = (I - A)^{-1}Y \quad (1)$$

where A is the technology matrix that conveys the amount of input needed from each sector in order to produce one unit of product in sector S_i . The ratios, which are known as technical coefficients, are obtained by dividing each entry in the IO table by the total for its column ($a_{ij} = x_{ij}/x_j$). I is the identity matrix, and $(I - A)^{-1}$ is called the inverse Leontief matrix. Y denotes the column vector showing external demand, and X denotes the column vector presenting the output level for each sector.

In an IO model, when the output of a particular sector j increases, there is both increased demand from sector j as a buyer (i.e., for the sector whose goods are used as inputs for production in j), and increased supply from sector j as a seller (i.e., for the sectors that use j 's goods in their production). Backward linkage measures the “interconnection of a particular sector with those sectors from which it purchases inputs,” while forward linkage measures the “interconnection of a particular sector with those sectors to which it sells its output [54]. The Leontief inverse $(I - A)^{-1}$ can be used to measure backward and forward linkages between economic sectors [55]. The backward linkage is defined by summing up the j th column of the inverse matrix and finding the average. Thus, the backward linkage is calculated by the formula

$$BL_j = \frac{\frac{1}{n} \sum_i B_{ij}}{\frac{1}{n^2} \sum_{ij} B_{ij}} \quad (2)$$

where $\sum_i B_{ij}$ is the sum of the column elements of the Leontief inverse matrix $(I - A)^{-1}$.

Similarly, the forward linkages can be obtained from the rows of the Leontief inverse matrix, the formula being

$$FL_i = \frac{\frac{1}{n} \sum_j B_{ij}}{\frac{1}{n^2} \sum_{ij} B_{ij}} \quad (3)$$

where $\sum_j B_{ij}$ is the sum of the row elements of the Leontief inverse matrix.

3.2. Data Sources

Two main data sources were used in this study. One source of the CO₂ emissions by industries in Korea was from the National Inventory Report, NIR from 2005 to 2015 [56]. It provides various types of GHG emissions and absorption by industrial sectors yearly. The 2019 edition of the *National Inventory Report* contains not only GHG emissions, but also key category analysis through level assessment and

the trend assessment method from 1990 to 2017. Of these, we used 11 times, from 2005 to 2015, of the CO₂ emissions by industries in Korea.

The IO table is a comprehensive statistical table that records the inter-industry trade relationship of all goods and services produced during the year [47]. Currently, internationally recognized IO tables are about seven, issued as announced by the EU(European Union), OECD(Organization for Economic Cooperation and Development)/WTO(World Trade Organization), ADB(Asian Development Bank), IDE-JETRO(Institute of Developing Economies, Japan External Trade Organization), and Purdue University. The data used in this study were the IO tables (OECD-IO), which provided the most recent years. The 2018 edition of the OECD-IO provides global inputs and outputs for 2005–2015 for a total of 65 countries (36 OECD members and 29 non-member countries) and 36 industries. Of these, 11 times from 2005 to 2015, Korean IO tables provided by the OECD were used in the research process.

4. Results

4.1. Contributions by Various Industries to CO₂ Emissions in Korean Industry

The CO₂ emission multiplier of an industry shows the total life-cycle emissions associated with unit final demand. Through the multipliers of final demand, we can determine the industries with the highest emissions in Korea. The calculated CO₂ emission multipliers of 36 industries from 2005 to 2015 are shown in Table 2.

When the total CO₂ emissions were allocated to each industry according to the final production volume, the largest carbon emission industry was found to be the fifteenth industry (computer, electronic, and optical products) throughout the 10 years. As the industry includes equipment sectors such as semiconductors and displays, it is necessary to obtain industrial responses for a large number of greenhouse gases and carbon emissions emitted during the production. From 2005 to 2010, No. 22 (Construction) produced the second-highest CO₂ emissions, but it fell to sixth from fifth in 2011, but recently industry number 18 (motor vehicles, trailers, and semi-trailers) has been seen as a high carbon emission industry. In addition, high carbon emissions were found in industries such as No. 10 (manufacture of chemicals and pharmaceutical products), no. 13 (manufacture of basic metals), and no. 9 (coke and refined petroleum products). These industries are thought to have high carbon emissions, depending on the role of intermediate inputs such as lubricants, which are necessary for industrial upgrading and production in the manufacturing industries.

On the other hand, no. 2 (mining and extraction of energy producing products), no. 3 (mining and quarrying of non-energy producing products), no. 7 (wood and products of wood and cork), and no. 20 (other manufacturing: repair and installation of machinery and equipment) were analyzed to have low CO₂ emissions. In particular, it can be seen that the knowledge service industry sectors such as no. 26 (publishing, audiovisual, and broadcasting activities) and no. 28 (IT and other information services) showed relatively less carbon emissions than other industries. These industries can be seen as new growth engines that bring about the synergy effect by integration within industries. The IT-based SW industry is a key element in the knowledge-based economy and the high value-adding of all industries. The competitiveness of software is a factor that determines the competitiveness of the entire industry and even the nation. The software industry itself is not only a high value-added industry, but also a key infrastructure industry that strengthens national and industry-wide competitiveness. Moreover, as the result of this study, the industry emits a small amount of carbon dioxide, so it can be classified in a group that needs to be nurtured for sustainable economic development.

Table 2. CO₂ emission multipliers of 36 industries from 2005 to 2015 in Korea.

Industry	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1	8.18	7.88	7.73	8.18	8.60	8.51	7.73	7.92	8.21	7.96	8.22
2	0.29	0.25	0.11	0.08	0.09	0.08	0.08	0.08	0.09	0.08	0.23
3	0.40	0.35	0.45	0.48	0.50	0.49	0.46	0.40	0.51	0.54	0.43
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	25.23	23.83	23.37	23.61	25.85	25.74	25.57	25.93	28.79	29.32	31.16
6	15.03	14.20	13.95	13.80	15.29	17.24	18.22	20.10	19.45	18.73	18.99
7	1.72	1.71	1.66	1.52	1.61	1.67	1.66	1.52	1.79	1.97	2.23
8	7.16	6.86	6.77	6.81	6.91	7.77	7.45	7.04	7.25	7.31	7.61
9	23.56	26.51	26.97	35.52	27.55	33.29	42.96	45.86	44.66	41.62	30.18
10	32.17	32.09	33.15	36.48	34.54	38.46	44.37	43.67	43.27	42.77	38.64
11	12.11	11.98	12.31	12.27	11.95	15.12	14.94	16.02	17.25	17.76	18.15
12	7.97	7.91	7.92	7.97	8.67	8.87	8.08	8.10	8.44	8.47	9.15
13	28.72	29.02	32.08	36.70	33.31	40.12	45.45	42.91	39.05	36.58	33.82
14	17.20	17.81	18.83	20.30	20.36	21.19	21.45	21.91	21.19	21.22	21.94
15	68.00	67.32	65.83	64.06	74.08	76.51	80.29	74.06	75.20	72.38	71.14
16	15.20	15.91	16.10	15.15	16.84	20.41	20.29	20.59	20.86	20.50	20.49
17	21.27	22.11	22.82	22.81	21.25	26.77	27.81	27.19	27.28	27.17	28.09
18	35.73	36.59	36.76	33.08	29.32	38.24	42.02	42.21	43.19	44.68	44.57
19	11.45	13.30	15.65	18.35	20.30	20.93	21.50	21.81	19.73	19.78	19.22
20	2.29	2.69	2.96	2.67	2.78	4.94	5.08	4.85	4.98	5.57	6.22
21	15.23	15.99	16.45	20.20	18.68	21.66	23.67	26.21	28.00	26.42	21.23
22	42.96	41.34	42.38	41.35	42.98	42.30	39.18	37.69	40.26	40.02	42.95
23	25.99	25.46	25.76	23.20	26.16	30.92	31.73	33.36	33.35	34.11	37.48
24	22.76	21.85	24.12	27.54	23.75	27.53	25.71	26.12	25.52	25.20	25.65
25	14.80	14.76	14.46	14.32	15.56	15.36	16.71	17.15	17.62	18.05	18.98
26	5.76	5.70	5.46	4.36	4.20	4.53	4.55	4.64	4.88	5.04	5.46
27	8.85	9.14	9.58	9.08	9.39	9.30	8.85	8.74	8.78	8.77	8.78
28	5.74	5.89	5.67	5.15	5.73	6.14	6.28	6.53	7.44	7.72	8.68
29	16.56	18.36	20.61	19.91	20.78	19.53	19.59	20.66	20.95	20.26	23.21
30	9.80	9.60	8.88	7.78	7.51	7.44	7.56	7.41	8.03	8.55	9.19
31	17.45	17.58	17.92	17.27	18.14	19.78	19.72	20.37	21.66	22.90	25.26
32	11.49	11.29	11.32	11.03	11.72	12.10	11.79	11.75	12.42	12.08	13.71
33	8.72	9.20	9.55	9.29	9.95	9.74	8.75	9.19	9.37	9.29	9.89
34	11.21	11.83	12.46	11.88	13.30	14.13	14.19	14.71	16.15	16.95	18.53
35	10.80	10.68	10.68	9.97	10.37	10.79	10.50	10.79	11.40	11.72	12.80
36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Note: Industry definitions: 1, Agriculture, forestry and fishing; 2, Mining and extraction of energy producing products; 3 Mining and quarrying of non-energy producing products; 4, Mining support service activities; 5, Food products, beverages and tobacco; 6, Textiles, wearing apparel, leather and related products; 7, Wood and products of wood and cork; 8, Paper products and printing; 9, Coke and refined petroleum products; 10, Chemicals and pharmaceutical products; 11, Rubber and plastic products; 12, Other non-metallic mineral products; 13, Basic metals; 14, Fabricated metal products; 15, Computer, electronic, and optical products; 16, Electrical equipment; 17, Machinery and equipment, nec (Not Elsewhere Classified); 18, Motor vehicles, trailers and semi-trailers; 19, Other transport equipment; 20, Other manufacturing; repair and installation of machinery and equipment; 21, Electricity, gas, water supply, sewerage, waste and remediation services; 22, Construction; 23, Wholesale and retail trade; repair of motor vehicles; 24, Transportation and storage; 25, Accommodation and food services; 26, Publishing, audiovisual and broadcasting activities; 27, Telecommunications; 28, IT and other information services; 29, Financial and insurance activities; 30, Real estate activities; 31, Other business sector services; 32, Public admin. and defense; compulsory social security; 33, Education; 34, Human health and social work; 35, Arts, entertainment, recreation and other service activities; and 36, Private households with employed persons.

Other industries that are continuously increasing their carbon emissions are no. 5 (food products, beverages and tobacco), no. 11 (rubber and plastic products), no. 12 (other non-metallic mineral products), no. 14 (fabricated metal products), no. 17 (machinery and equipment, nec), and no. 20 (other manufacturing; repair and installation of machinery and equipment), which mainly use oil and coal as fuel.

4.2. The Results of the Linkage Effects from 2005 to 2015

Industry correlation analysis is a method of quantitatively identifying the interrelationships between industries through the production of goods and services. The backward linkage effect is an influence generated by the input of intermediate goods into the product process owned by the industry, which means an attraction to all industries. The forward linkage effect is an interaction that directly represents the relationship between the demand for intermediate goods and the final product resulting from the input of the product by business customers [48].

In both the backward and forward linkage effect, high-value industries can be interpreted as major industrial sectors of the national economy. Miller and Blair [54] interpreted that when the forward linkage effect is greater than 1, it is highly sensitive to the demand of intermediate goods from other industries, and when the backward linkage effect is greater than 1, it has an influence on supplying intermediate goods of other industries. The results of the total linkage effects from 2005 to 2015 are presented in Appendices A and B.

Table 3 shows the top five industries with high backward linkage effect and the bottom five industries in Korea. Backward linkage effect is a representation of the production demand arising from the supply of raw materials from other industries to produce the final product of an industry. Looking at the backward linkage effect, which represents the industry responsible for driving the intermediate goods industry, these industries appeared in the following order: (1) Manufacture of motor vehicles, trailers and semi-trailers; (2) Manufacture of computer, electronic and optical products; (3) Manufacture of basic metals; (4) Manufacture of chemicals and pharmaceutical products; and (5) Manufacture of electrical equipment. This means that the sectors of manufacturing automobiles, computer, optical, and electronic devices are used as intermediate materials for other industries in the Korean economy.

Table 3. Backward linkage effects (From top 1–5 to bottom 1–5).

Rank	Industry No.	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1	18	1.33	1.33	1.32	1.31	1.26	1.31	1.30	1.30	1.28	1.31	1.23
2	15	1.27	1.27	1.25	1.24	1.28	1.25	1.28	1.24	1.20	1.21	1.18
3	13	1.21	1.22	1.24	1.26	1.24	1.22	1.23	1.24	1.22	1.23	1.23
4	10	1.24	1.25	1.24	1.25	1.22	1.20	1.22	1.23	1.22	1.25	1.21
5	16	1.25	1.25	1.26	1.24	1.24	1.24	1.24	1.24	1.20	1.21	1.20
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
32	31	0.81	0.80	0.79	0.77	0.78	0.78	0.77	0.77	0.76	0.77	0.79
33	32	0.72	0.71	0.71	0.70	0.70	0.70	0.69	0.68	0.68	0.68	0.70
34	4	0.58	0.58	0.58	0.56	0.70	0.69	0.70	0.68	0.95	0.55	0.53
35	33	0.70	0.70	0.70	0.69	0.70	0.69	0.67	0.68	0.67	0.67	0.68
36	30	0.63	0.62	0.61	0.59	0.58	0.57	0.57	0.57	0.57	0.58	0.60

Note: Industry number: (18) Motor vehicles, trailers and semi-trailers; (15) Computer, electronic and optical products; (13) Basic metals; (10) Chemicals and pharmaceutical products; (16) Electrical equipment; (31) Other business sector services; (32) Public administration and defense; compulsory social security; (4) Mining support service activities; (33) Education; (30) Real estate activities.

At the bottom of the list, these five industries appear in order: (1) Real estate activities, (2) Education, (3) Mining support service activities, (4) Public administration and defense; compulsory social security, and (5) Other business sector services. In the case of the bottom five industries, the number was less than 1, and there was no significant level of correlation as a backward industry of other industries. Analyzing the common features of the bottom five industries showed that the industry that human labor is directly involved in does not have a high backward linkage effect, so it has less influence on other industries. This can be interpreted in two aspects: one is that it does not take up a large portion of the Korean economy, and the other is that it is doing input and output activities independently within the industry. In other words, because it has a low linkage effect, it is not the industry being affected by economic crisis. This was not discussed in this paper because it should be analyzed by the total production of the industry among GDP of the country.

Forward linkage effects refers to the extent to which the output of an industry sector increases the output of that industry as an intermediate for another industry sector. The following Table 4 shows the top five industries with high forward linkage effect and the bottom five industries in Korea. The results of the forward linkage effect analysis are as follows: (1) Wholesale and retail trade; repair of motor vehicles—Sale, maintenance and repair of motor vehicles and motorcycles, (2) Mining and extraction of energy producing products—extraction of crude petroleum and natural gas, (3) Manufacture of chemicals and pharmaceutical products, (4) Manufacture of basic metals—basic iron and steel and non-ferrous metals, and (5) Manufacture of computer, electronic, and optical products. The top five industries had an average of forward linkage effect of around 1.9, indicating that the power of dispersion of the output of the industry that be used as a raw material for other industries is strong. For example, in the case of the automotive aftermarket industry, it is classified in automotive maintenance and repair business by ISIC (International Standard Industrial Classification) Rev. 4, but the size of this industry is not the same as before. In Korean culture, where cars are considered to represent their level of living beyond the means of transportation, the forward linkage effect of the industry is increasing because Koreans think that customized cars form part of one's identity. It should be noted that the mining and quarrying industry, which ranked second, has a high forward linkage effect. Industry no. 3 (manufacture of chemicals and pharmaceutical products) should also be given attention. It is natural that the pharmaceutical industry has a high forward linkage effect due to well-being and health concerns and the change to an aging society, but according to ISIC Rev. 4, the chemicals in this industry also include cosmetic materials, which means that the world-renowned K-beauty has to take into account the high forward linkage effect.

Table 4. Forward linkage effects (from top 1–5 to bottom 1–5).

Rank	Industry No.	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1	23	2.21	2.18	2.15	2.11	2.18	2.23	2.21	2.25	2.24	2.22	2.31
2	2	1.82	2.00	1.85	2.29	1.92	2.12	2.36	2.37	2.26	2.05	1.56
3	10	2.04	2.01	2.01	2.05	1.91	1.96	2.07	2.03	1.91	1.88	1.85
4	13	2.00	1.94	2.08	2.25	1.92	1.96	1.95	1.81	1.74	1.67	1.65
5	15	1.82	1.81	1.69	1.61	1.93	1.63	1.86	1.75	1.68	1.67	1.82
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
32	32	0.51	0.50	0.50	0.48	0.48	0.46	0.48	0.47	0.48	0.46	0.49
33	33	0.50	0.50	0.50	0.48	0.48	0.47	0.45	0.45	0.45	0.46	0.47
34	22	0.50	0.49	0.50	0.47	0.46	0.46	0.43	0.44	0.44	0.45	0.46
35	20	0.47	0.46	0.46	0.44	0.45	0.45	0.44	0.44	0.44	0.46	0.48
36	4	0.44	0.43	0.43	0.40	0.41	0.41	0.40	0.39	0.39	0.40	0.42

Note: Industry number: (23) Wholesale and retail trade; repair of motor vehicles; (2) Mining and extraction of energy producing products; (10) Chemicals and pharmaceutical products; (13) Basic metals; (15) Computer, electronic and optical products; (32) Public administration and defense; compulsory social security; (33) Education; (22) Construction; (20) Other manufacturing; repair and installation of machinery and equipment; (4) Mining support service activities.

For the bottom five industries, these appeared in the order: (1) Mining support service activities, (2) Other manufacturing; repair and installation of machinery and equipment, (3) Construction, the (4) Education, and (5) Public administration and defense; compulsory social security. In the declining Korean mineral industry, the mineral-related service provider industry has low relations with other industries, and its forward linkage effect is also low in the Korean economy. The machinery manufacturing industry is also concentrated in China, where labor costs are low and parts factories are gathered, so that of Korea has a low forward linkage effect. However, the fourth and fifth industries—Education and Public administration—have their own characteristics, and inputs and outputs are small because it is an industry in which humans provide intangible services. It is an indispensable industry in the national economy, so the low forward linkage effect on the economy can mean that it is not an inefficient and degenerate industry.

5. Discussion and Conclusions

This study presents the industries that have a great influence on the Korean economy and the amount of carbon dioxide emitted by the industries. Korea's total carbon dioxide emissions were divided into 36 industries, according to the International Standard Industrial Classification, which is what the OECD uses when classifying industries. Then, we calculated the linkage effects using IO tables by OECD to figure out what industries had significant effects on the Korean economy, and whether the backward or forward linkage effect of one industry had the number of 1 or higher, where the industry has a remarkable effect on other industries. That is to say, we found the industry with a meaningful influence on the Korean economy with less environmental pollution to develop as a sustainable industry.

Table 5 shows the carbon dioxide emissions generated by the direct inputs of each industry and summarizes the top 1–5 and bottom 1–5 industries for the 11 years of the study. Since the industry with the lowest carbon emissions was placed at the top, the higher the ranking, the less carbon emissions, so it can be said to be an eco-friendly industry. Three of the top five industries—first, mining support service activities, second, the mining and extraction of energy producing products, third, the mining and quarrying of non-energy producing products, fourth, the wood and products of wood and cork, and the fifth being other manufacturing; repair and installation of machinery, and equipment—are mineral-related, suggesting that the mining and quarrying sectors themselves do not have many CO₂ emissions. In addition, the wood processing industry, the fourth largest industry, showed that the amount of carbon dioxide generated was not much higher than the input amount for the final products. In the traditional primary and secondary industries, since the process of mechanization is not done much in modern society, and in Korea, there is not much demand, so people do the production work directly. It can be inferred that carbon dioxide emissions are not high due to this industrial environment. In industries where human beings do activities of production, maintenance and repair, high carbon dioxide levels are not emitted.

Table 5. CO₂ emissions (from top 1–5 to bottom 1–5).

Rank	Industry No.	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	2	0.29	0.25	0.11	0.08	0.09	0.08	0.08	0.08	0.09	0.08	0.23
3	3	0.40	0.35	0.45	0.48	0.50	0.49	0.46	0.40	0.51	0.54	0.43
4	7	1.72	1.71	1.66	1.52	1.61	1.67	1.66	1.52	1.79	1.97	2.23
5	20	2.29	2.69	2.96	2.67	2.78	4.94	5.08	4.85	4.98	5.57	6.22
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
32	13	28.72	29.02	32.08	36.70	33.31	40.12	45.45	42.91	39.05	36.58	33.82
33	18	35.73	36.59	36.76	33.08	29.32	38.24	42.02	42.21	43.19	44.68	44.57
34	10	32.17	32.09	33.15	36.48	34.54	38.46	44.37	43.67	43.27	42.77	38.64
35	22	42.96	41.34	42.38	41.35	42.98	42.30	39.18	37.69	40.26	40.02	42.95
36	15	68.00	67.32	65.83	64.06	74.08	76.51	80.29	74.06	75.20	72.38	71.14

Note: Industry number: (4) Mining support service activities; (2) Mining and extraction of energy producing products; (3) Mining and quarrying of non-energy producing products; (7) Wood and products of wood and cork; (20) Other manufacturing; repair and installation of machinery and equipment; (13) Basic metals; (18) Motor vehicles, trailers and semi-trailers; (10) Chemicals and pharmaceutical products; (22) Construction; (15) Computer, electronic and optical products.

The industry with the highest carbon emissions among the bottom five industries—(1) manufacture of Computer, electronic and optical products, (2) construction, (3) manufacture of chemicals and pharmaceutical products, (4) manufacture of motor vehicles, trailers and semi-trailers, (5) manufacture of Basic metals—is the manufacturing industry of computer, electronic and optical products. It was confirmed that the industry producing the goods necessary for the Fourth Industrial Revolution era emits the largest amount of carbon dioxide. One such reason is that many environmental pollutants are produced in the semiconductor production process, which is one of the main components of computers and electronic and optical devices. Since semiconductor chips function to store high-tech

technologies in a small size, it is inevitable to have to constantly research and develop them. However, many environmental pollutants are released during this development process, so the central or local government must impose responsibility on the companies who have these issues in their industry. Additionally, the behavior of modern consumers who want to use new products faster than anyone else, so called early adopters, makes it easier to throw away existing products and these abandoned products become garbage and pollute the environment. Considering the amount of waste emitted by these consumption patterns, the level of pollution in the industry would be more than the results of analysis. Particularly, in (10) manufacture of chemicals and pharmaceutical products, (13) basic metals, (15) computer, electronic and optical products, and (18) motor vehicles, trailers and semi-trailers industries, both backward and forward linkage effects were the largest among Korean industries. Ultimately, it is urgent to actively review the regulations on carbon dioxide emissions for these industries so as to not constrain them and prepare policies that support and reorganize the industries into being eco-friendly without losing their competitiveness.

The steel industry, which ranks fifth in carbon dioxide emissions, has very high backward and forward linkage effect. Korea is the world's fifth largest steel producer, and steel products are not only supplied as basic materials to the entire Korean industry including automobiles, shipbuilding, home appliances, machinery, and construction, but are also exported world-wide. Since the steel industry emits 15.1% of domestic GHG emissions [57], it is necessary for them to take responsibility for the environmental pollution and develop a more sustainable management system.

All this considered, industries that have great impacts on the Korean economy emit a lot of carbon dioxide. Therefore, to reduce CO₂ emissions by industry, it is necessary to increase the R&D costs in order to develop technologies that can increase production efficiency and introduce eco-friendly production methods.

In the case of the education industry, the industry has low backward and forward linkage effects and low carbon emissions. An industry that emits low carbon dioxide means a sustainable industry, but low linkage effects means a low share of the national economy. Therefore, can we say that this is an inefficient industry in the Korean economy? Can we say that it is not an important industry? Not likely. As the linkage effects show a relation to other industries and not the efficiency of production, the industry only lacks relations with other industries and cannot be said to be insignificant. In other words, the low correlation can be interpreted in two aspects: one of which is above-mentioned and the other is an independent, self-sustainable industry. This means that productivity can be steady because it has little connection with other industries and is not greatly affected by changes in the external environment such as economic fluctuation. As this can be interpreted in two ways, it needs to be further studied along with industrial efficiency.

Agreements relating to carbon emission reduction obligations have been imposed as penalties for violating trade or non-tariff barriers. Therefore, in Korea, where the trade dependence exceeds 80%, carbon reduction activities have long been a matter of survival. By mid-2000, environmental regulations and agreements were enforced in a number of European countries. However, with the advent of a global village where the world can be visited within 24 h, not only Korea, but also the United States, China, and Japan are actively participating in efforts to reduce carbon emissions. These countries are using environmental issues as a means of protecting their industries by limiting imports or creating technological barriers through environmental regulations. Therefore, Korea should find a way to reduce carbon emissions as much as possible without being disadvantaged by the international community due to environmental regulations. With this purpose, this study suggests that Korea's industrial structure, which has focused on manufacturing primary and secondary products and achieving high growth, needs to be changed in policies and perceptions to foster industries by combining sustainable environmental management. Thus, through carbon emissions by industry and inter-industry analysis, this study analyzed industries that have a significant impact on the Korean economy.

Since the 1980s, Korea has been actively investing and developing in the ICT industry such as telephone exchangers, semiconductors, displays, and mobile phones. As a result, the ICT manufacturing

industry accounted for 8.4% of Korea's GDP in 2012, and the economic growth contribution accounted for 20.8%. However, putting the results together, it shows skepticism about whether to foster a sustainable industry in terms of its high carbon emissions, but strong global influence and high impact on the Korean economy. Korea has a high backward linkage effect in automobile manufacturing, computer or electronic device manufacturing, chemical manufacturing, and the pharmaceutical industry. In addition, the service industry such as distribution, automobile maintenance, and repair, generally has a high forward linkage effect. In other words, the Korean economic structure is like the traditional manufacturing industry and forms the basis of the national economy, and the service industry producing intangible final goods utilizes the basis. Given the history of having invested heavily in IT technology since the 1980s, it is a pity that the R&D sector has low linkage effects. Additionally, it has the seventh highest level of carbon emissions, so it seems that the history of the investment has not been fully exercised.

When listed in order of carbon emissions among the analyzed industries, three of the five industries have high forward or backward linkage effect. One industry (manufacturing of computer, electronic, and optical products) even has high forward and backward, two-way linkage effects. This means that the output of the industry is an intermediate product of another industry, and the final output has a bidirectional effect, which is also used as intermediate goods for the production process of other industries. As previous studies have demonstrated, increasing carbon emissions with higher investment and production seems inevitable. Korea's industrial structure, like the previous studies, is highly competent in metal, chemical, and electronics manufacturing, transportation, and oil refining industries. However, there are clear obstacles in fostering sustainable industries: carbon dioxide emissions. To foster a sustainable industry, an industry with high forward and backward linkage effects, high market dominance, and low carbon dioxide emissions is suitable. If Korea's flagship industry, which has high carbon emissions, is still a high growth industry, the demands of those industries fluctuate greatly, according to the global economic conditions, and the proportion of these industries in the national economy is high, so there will be difficulties in sustainable environmental management. In order to solve such difficulties in the industry, regulations on the total amount of CO₂ emission allowances and reserves will be re-regulated in a variable form according to demand or supply volume, and it will be necessary to foster industries with higher linkage effects in comparison with carbon dioxide emissions, and not compared with absolute carbon dioxide emissions.

This study recognizes industries that will play a key role in stimulating the Korean economy. It is a quantitative representation of the linkage effects on a country's economy and can be used as a clear basis for finding future food and establishing government policies. The linkage effects analyzed which are experiencing stagnation, and made predictions about sustainable industries that require government investment. In particular, it is possible to specifically show whether to invest in forward or backward linkages within the industry.

In the case of the construction industry, the CO₂ emissions are quite high, but the forward and backward linkage effect are low. This means that the relationship with other industries is low, so the impact of regulations on the industry will not be significant. Therefore, these industries, similar to the construction industry, need to be monitored whether they make efforts to reduce carbon dioxide emissions in the production process and whether they make continuous efforts to develop the process sustainably.

The manufacturing industries of food products, beverages, and tobacco, and fabricated metal products have a higher level of forward and backward linkage effects than other industries, and rank among the top 10 in CO₂ emissions. Although they are not ranked in the top five, they have lower CO₂ emissions than those of other industries and have more significant backward and forward linkage effects. Therefore, these industries need to be fostered as sustainable industries. The findings imply that the characteristics of these industries are of high importance in the national economy relative to CO₂ emissions. Therefore, these industries should be fostered as a future industry model by combining sustainable development processes for future generations.

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Appendix A

Table A1. Backward linkage effects of 36 industries from 2005 to 2015 in Korea.

Industry	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1	0.82	0.82	0.84	0.88	0.88	0.87	0.83	0.84	0.86	0.85	0.86
2	0.92	0.91	0.79	0.76	0.76	0.74	0.74	0.73	0.77	0.81	0.88
3	0.81	0.80	0.84	0.84	0.86	0.86	0.84	0.83	0.85	0.86	0.84
4	0.58	0.58	0.58	0.56	0.70	0.69	0.70	0.68	0.95	0.55	0.53
5	1.19	1.18	1.19	1.20	1.22	1.21	1.19	1.20	1.21	1.22	1.24
6	1.19	1.18	1.20	1.18	1.18	1.20	1.20	1.22	1.19	1.20	1.21
7	1.17	1.18	1.18	1.19	1.17	1.17	1.16	1.18	1.18	1.19	1.20
8	1.16	1.16	1.17	1.18	1.15	1.19	1.18	1.16	1.15	1.16	1.17
9	1.24	1.24	1.16	1.15	1.16	1.13	1.12	1.13	1.15	1.19	1.23
10	1.24	1.25	1.24	1.25	1.22	1.20	1.22	1.23	1.22	1.25	1.21
11	1.18	1.19	1.19	1.22	1.19	1.21	1.21	1.22	1.21	1.23	1.20
12	1.13	1.14	1.15	1.14	1.12	1.12	1.12	1.13	1.12	1.14	1.13
13	1.21	1.22	1.24	1.26	1.24	1.22	1.23	1.24	1.22	1.23	1.23
14	1.20	1.20	1.22	1.26	1.23	1.21	1.21	1.20	1.17	1.17	1.16
15	1.27	1.27	1.25	1.24	1.28	1.25	1.28	1.24	1.20	1.21	1.18
16	1.25	1.25	1.26	1.24	1.24	1.24	1.24	1.24	1.20	1.21	1.20
17	1.21	1.22	1.23	1.23	1.20	1.23	1.23	1.21	1.19	1.20	1.18
18	1.33	1.33	1.32	1.31	1.26	1.31	1.30	1.30	1.28	1.31	1.23
19	1.20	1.20	1.21	1.20	1.21	1.20	1.23	1.23	1.21	1.24	1.24
20	1.04	1.07	1.10	1.10	1.08	1.20	1.21	1.20	1.18	1.20	1.21
21	1.01	1.02	1.01	1.12	1.07	1.05	1.09	1.10	1.09	1.06	0.98
22	1.10	1.09	1.11	1.13	1.12	1.12	1.12	1.11	1.10	1.10	1.09
23	0.84	0.83	0.83	0.80	0.82	0.84	0.84	0.84	0.83	0.85	0.87
24	0.99	0.98	0.99	1.03	1.01	1.02	1.02	1.02	1.00	1.00	0.98
25	1.01	1.00	1.00	1.00	1.02	1.00	1.02	1.03	1.03	1.03	1.04
26	1.08	1.06	1.06	1.02	0.99	1.00	1.00	1.00	0.99	1.00	1.02
27	0.90	0.93	0.98	0.99	1.03	1.02	1.05	1.04	1.01	1.02	1.02
28	0.87	0.85	0.84	0.81	0.83	0.83	0.83	0.83	0.84	0.85	0.88
29	0.76	0.78	0.80	0.79	0.81	0.76	0.75	0.78	0.79	0.78	0.82
30	0.63	0.62	0.61	0.59	0.58	0.57	0.57	0.57	0.57	0.58	0.60
31	0.81	0.80	0.79	0.77	0.78	0.78	0.77	0.77	0.76	0.77	0.79
32	0.72	0.71	0.71	0.70	0.70	0.70	0.69	0.68	0.68	0.68	0.70
33	0.70	0.70	0.70	0.69	0.70	0.69	0.67	0.68	0.67	0.67	0.68
34	0.89	0.89	0.89	0.88	0.88	0.87	0.88	0.87	0.87	0.88	0.88
35	0.93	0.92	0.91	0.89	0.89	0.89	0.88	0.88	0.88	0.89	0.92
36	0.44	0.43	0.43	0.40	0.41	0.40	0.39	0.39	0.39	0.40	0.42

Note: Industry definitions: (1) Agriculture, forestry and fishing; (2) Mining and extraction of energy producing products; (3) Mining and quarrying of non-energy producing products; (4) Mining support service activities; (5) Food products, beverages and tobacco; (6) Textiles, wearing apparel, leather, and related products; (7) Wood and products of wood and cork; (8) Paper products and printing; (9) Coke and refined petroleum products; (10) Chemicals and pharmaceutical products; (11) Rubber and plastic products; (12) Other non-metallic mineral products; (13) Basic metals; (14) Fabricated metal products; (15) Computer, electronic and optical products; (16) Electrical equipment; (17) Machinery and equipment, nec; (18) Motor vehicles, trailers and semi-trailers; (19) Other transport equipment; (20) Other manufacturing; repair and installation of machinery and equipment; (21) Electricity, gas, water supply, sewerage, waste and remediation services; (22) Construction; (23) Wholesale and retail trade; repair of motor vehicles; (24) Transportation and storage; (25) Accommodation and food services; (26) Publishing, audiovisual, and broadcasting activities; (27) Telecommunications; (28) IT and other information services; (29) Financial and insurance activities; (30) Real estate activities; (31) Other business sector services; (32) Public admin. and defense; compulsory social security; (33) Education; (34) Human health and social work; (35) Arts, entertainment, recreation and other service activities; (36) Private households with employed persons.

Appendix B

Table A2. Forward linkage effects of 36 industries from 2005 to 2015 in Korea.

Industry	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1	1.20	1.15	1.13	1.12	1.12	1.11	1.06	1.06	1.03	1.04	1.05
2	1.82	2.00	1.85	2.29	1.92	2.12	2.36	2.37	2.26	2.05	1.56
3	0.61	0.64	0.64	0.63	0.64	0.68	0.69	0.65	0.63	0.63	0.61
4	0.44	0.43	0.43	0.40	0.41	0.41	0.40	0.39	0.39	0.40	0.42
5	1.05	1.01	1.02	1.06	1.10	1.08	1.05	1.04	1.07	1.10	1.15
6	1.03	1.04	1.04	1.00	1.05	1.03	1.08	1.18	1.16	1.17	1.25
7	0.61	0.60	0.59	0.56	0.57	0.55	0.54	0.53	0.55	0.57	0.60
8	1.02	0.99	0.98	0.95	0.95	0.97	0.91	0.88	0.88	0.89	0.92
9	1.33	1.41	1.41	1.66	1.36	1.67	1.85	1.91	1.89	1.79	1.25
10	2.04	2.01	2.01	2.05	1.91	1.96	2.07	2.03	1.91	1.88	1.85
11	1.06	1.04	1.04	0.98	0.99	1.02	0.99	1.01	1.04	1.06	1.14
12	0.78	0.77	0.77	0.75	0.78	0.75	0.78	0.74	0.74	0.73	0.78
13	2.00	1.94	2.08	2.25	1.92	1.96	1.95	1.81	1.74	1.67	1.65
14	1.20	1.20	1.21	1.20	1.25	1.17	1.11	1.14	1.16	1.17	1.23
15	1.82	1.81	1.69	1.61	1.93	1.63	1.86	1.75	1.68	1.67	1.82
16	0.93	0.91	0.92	0.84	0.92	0.94	0.91	0.88	0.88	0.88	0.90
17	0.95	0.94	0.91	0.88	1.13	0.99	0.88	0.91	1.02	0.98	1.06
18	0.85	0.84	0.83	0.77	0.82	0.75	0.69	0.68	0.73	0.79	0.95
19	0.60	0.63	0.65	0.58	0.63	0.59	0.54	0.60	0.59	0.60	0.58
20	0.47	0.46	0.46	0.44	0.45	0.45	0.44	0.44	0.44	0.46	0.48
21	1.33	1.35	1.33	1.37	1.33	1.41	1.41	1.52	1.62	1.64	1.51
22	0.50	0.49	0.50	0.47	0.46	0.46	0.43	0.44	0.44	0.45	0.46
23	2.21	2.18	2.15	2.11	2.18	2.23	2.21	2.25	2.24	2.22	2.31
24	1.44	1.37	1.41	1.46	1.36	1.42	1.39	1.31	1.33	1.36	1.39
25	0.54	0.53	0.54	0.52	0.53	0.53	0.52	0.52	0.52	0.54	0.55
26	0.63	0.62	0.63	0.57	0.56	0.57	0.55	0.56	0.57	0.59	0.59
27	0.98	0.96	0.93	0.87	0.88	0.85	0.80	0.80	0.81	0.81	0.81
28	0.61	0.62	0.63	0.59	0.60	0.62	0.59	0.62	0.64	0.66	0.65
29	1.26	1.31	1.41	1.35	1.40	1.35	1.33	1.33	1.31	1.30	1.38
30	0.63	0.62	0.63	0.59	0.60	0.60	0.56	0.57	0.58	0.60	0.60
31	1.50	1.54	1.58	1.57	1.66	1.59	1.51	1.58	1.62	1.70	1.79
32	0.51	0.50	0.50	0.48	0.48	0.46	0.48	0.47	0.48	0.46	0.49
33	0.50	0.50	0.50	0.48	0.48	0.47	0.45	0.45	0.45	0.46	0.47
34	0.61	0.62	0.65	0.64	0.68	0.70	0.68	0.68	0.67	0.72	0.76
35	0.54	0.53	0.54	0.52	0.53	0.53	0.52	0.53	0.53	0.55	0.56
36	0.44	0.43	0.43	0.40	0.41	0.40	0.39	0.39	0.39	0.40	0.42

Note: Industry definitions: (1) Agriculture, forestry and fishing; (2) Mining and extraction of energy producing products; (3) Mining and quarrying of non-energy producing products; (4) Mining support service activities; (5) Food products, beverages and tobacco; (6) Textiles, wearing apparel, leather, and related products; (7) Wood and products of wood and cork; (8) Paper products and printing; (9) Coke and refined petroleum products; (10) Chemicals and pharmaceutical products; (11) Rubber and plastic products; (12) Other non-metallic mineral products; (13) Basic metals; (14) Fabricated metal products; (15) Computer, electronic and optical products; (16) Electrical equipment; (17) Machinery and equipment, nec; (18) Motor vehicles, trailers and semi-trailers; (19) Other transport equipment; (20) Other manufacturing; repair and installation of machinery, and equipment; (21) Electricity, gas, water supply, sewerage, waste, and remediation services; (22) Construction; (23) Wholesale and retail trade; repair of motor vehicles; (24) Transportation and storage; (25) Accommodation and food services; (26) Publishing, audiovisual, and broadcasting activities; (27) Telecommunications; (28) IT and other information services; (29) Financial and insurance activities; (30) Real estate activities; (31) Other business sector services; (32) Public admin. and defense; compulsory social security; (33) Education; (34) Human health and social work; (35) Arts, entertainment, recreation and other service activities; (36) Private households with employed persons.

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