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## Economic Effect of Non-Renewable and Renewable Energy on South Korea's Agri-Food Sector: An Input-Output Analysis


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## ABSTRACT

South Korea's Green New Deal highlights ongoing tensions between economic growth and environmental sustainability. This study empirically assesses the economic implications of renewable and non-renewable energy investments for the agri-food sector using the Bank of Korea's input–output framework. The results show that non-renewable energy investments generate stronger short-term economic effects: a 1 million KRW investment produces 22,607 KRW more output, 7,898 KRW more value added, and 2,004 KRW more wages than renewable energy. However, supply-shortage analysis reveals higher systemic vulnerability, with non-renewable energy disruptions causing 53,484 KRW greater production losses per 1 million KRW shortage. These findings indicate a trade-off between short-term economic performance and long-term resilience, underscoring the importance of renewable energy in reducing supply risk and supporting a more stable and sustainable agri-food system.



Keywords: Agri-food sector; Economic effect; I/O model; Non-renewable energy; Renewable energy


## INTRODUCTION

The acceleration of climate change and environmental degradation represents one of the most pressing challenges facing humanity. Environmental degradation has long been recognized as a global concern not only from an ecological perspective but also from an economic standpoint, as it reduces productivity, undermines welfare, and imposes costs on the entire economy. In discussions of climate change and environmental degradation, the energy sector, particularly green or renewable energy, frequently becomes a central focus. From both economic and environmental perspectives, renewable energy is widely viewed as a sustainable source capable of meeting current and future energy demand.

Despite its recognized benefits, the relationship between the expansion of renewable energy and economic development is complex. While the economic contributions of green energy are increasingly acknowledged, renewable energy transitions may also involve economic trade-offs. To some extent, green energy policies may constrain economic expansion during the transition period, particularly if they alter established industrial structures or labour markets. Environmentally friendly policies have sometimes been associated with less favourable short-term labour market outcomes. A report by (Ezalia et al., 2020) suggests that large-scale green


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initiatives such as the Green New Deal could generate significant economic disruption, while (Silva, 2013) argue that it is highly questionable whether government-led green energy campaigns generate net economic benefits. These contrasting perspectives highlight the importance of empirically evaluating the economic implications of renewable energy investments.

The agri-food sector plays a dual role in this context, acting simultaneously as a major energy user and a potential source of renewable energy. On the consumption side, agriculture places a substantial burden on the environment through intensive land use, high input requirements, and extensive reliance on fossil fuels. Modern food production has reached unprecedented scales to meet the demands of a growing global population, resulting in increased use of chemical fertilizers and pesticides and significant fossil fuel consumption during production, processing, and transportation from farm to consumer (Chel, 2010). To mitigate these negative environmental externalities, it is widely argued that agricultural systems should increasingly adopt renewable energy technologies while reducing dependence on non-renewable energy sources (Norse, D. and Tschirley, 2003).

At the same time, agriculture also has considerable potential to contribute to renewable energy supply. Biomass generated from agricultural activities can be used to produce energy, including liquid and gaseous fuels, making it one of the most promising directions for renewable energy development. According to (Sulewski, 2017), large-scale livestock production systems, such as poultry and pig farming operations, can supply substantial quantities of slurry and manure for biogas production, with some systems capable of diverting up to 30 percent of these by-products for energy generation. Considering this potential, the agricultural sector can be regarded as an important contributor to renewable energy production.

Conceptually, renewable energy policies are designed to promote environmentally sustainable practices; however, the transition toward renewable energy can create adjustment challenges for conventional sectors, including fossil fuel-based industries and traditional agricultural systems. Such transitions may involve short-term employment shifts or income adjustments, underscoring the need to carefully evaluate the economic consequences of renewable energy investments relative to non-renewable alternatives. Despite this importance, much of the empirical literature on energy transitions focuses on major industrial or energy-producing sectors, often overlooking the agri-food sector because of its relatively smaller share in total energy consumption. Nevertheless, agriculture and food processing are significant energy users, and even modest changes in energy prices or supply conditions can have substantial implications for production stability, food security, and rural livelihoods.

This study addresses this gap by examining the economic effects of renewable and non-renewable energy investments on South Korea’s agri-food sector using an input–output analysis framework. Rather than evaluating the environmental superiority of specific energy sources, the analysis focuses on comparative economic impacts, including production-inducing effects, value-added creation, wage-inducing effects, and supply-shortage effects. The objective is to assess how equivalent investments in renewable and non-renewable energy propagate through agricultural and food-related industries and to identify differences in economic performance and vulnerability.

To achieve this, the study employs the input–output table from the Bank of Korea to conduct a matrix-based analysis

of energy investment impacts. The input–output approach is particularly suitable because it captures intersectoral linkages, is widely used in national economic accounting, and provides a transparent framework for assessing sectoral effects of energy transitions. All data processing and calculations are carried out using Python-based computational tools.

By doing so, this study contributes to the literature in several important ways. It provides sector-specific empirical evidence on the economic implications of energy investment choices, offers insights for policymakers and industry stakeholders regarding the relative performance of renewable and non-renewable energy investments, and clarifies the economic linkages between energy and agriculture. These contributions support more informed energy transition strategies for South Korea, particularly in relation to the agri-food sector, food system stability, and long-term economic sustainability.

## RESEARCH METHOD

This study uses secondary data, the main dataset consists of South Korea's monetary Input-Output (I/O) table published by the Bank of Korea (2018). These data were not collected directly by the authors through surveys, interviews, or field measurements but were obtained from officially published national accounts. The I/O tables provide comprehensive, standardized, and nationally representative information on inter-sectoral transactions, making them suitable for macro- and sectoral-level economic impact analysis. In this study, the Bank of Korea I/O tables serve as the empirical basis for constructing technical coefficients and conducting production-, value-added-, wage-, and supply-shortage-effect analyses.

Normally there are two kinds of input-output table which are physical input-output tables (PIOTs) and monetary input-output tables (MIOTs). In brief, PIOTs is input-output models based on coefficient matrices derived from input-output tables in physical or mass units while MIOTs is derived from monetary tables. Because our study seeks to track the economic effect of our sector of interest, hence we used MIOTs. Physical input-output models are more appropriate to account for direct and indirect resource requirements in physical unit such as land area, raw materials, energy, or water (Weisz & Duchin, 2006).

The Bank of Korea classifies economic activities into four levels of sectoral detail: large-scale (33 sectors), medium-scale (85 sectors), small-scale (165 sectors), and basic-scale (381 sectors). This study primarily uses the large-scale and basic-scale input–output tables. Given the focus on energy, agriculture, and food sectors, the large-scale table is used for the main analysis, while the basic-scale table is employed to further disaggregate the energy sector.

This study adopts a 33-sector input–output classification based on the Bank of Korea framework. The economy is represented by primary production (agriculture, forestry, and fisheries), mining, manufacturing, utilities, construction, and services. Manufacturing sectors include food processing, textiles, wood and paper products, petroleum and coal products, chemicals, non-metallic and basic metal products, fabricated metals, machinery and equipment, electrical and transport equipment, and other manufactured goods, together with manufacturing repair services.

To enable a detailed assessment of energy impacts, the conventional electricity, gas, and steam supply sector is disaggregated into seven energy types: hydropower, fire (thermal) power, nuclear power, self-generation, city gas, steam, and renewable energy. Service

sectors cover wholesale and retail trade, transportation, accommodation and food services, communications, finance and insurance, real estate, professional and business services, public administration, education, health and social services, arts and other services. This sectoral structure allows for a focused comparison of renewable and non-renewable energy effects on the agri-food system within the broader economy

In the large-scale classification, energy is represented by sector 17 (Electricity, gas, and steam supply), agriculture by sector 1 (Agriculture, forestry, and fishery goods), and food by sector 3 (Food, beverages, and tobacco products). For more detailed analysis, sector 17 is disaggregated at the basic-scale level into seven energy categories: hydropower (17a), fire power (17b), nuclear power (17c), self-generation (17d), city gas (17e), steam and hot water supply (17f), and renewable energy (17g). Sectors 17a through 17f are classified as non-renewable energy, while sector 17g represents renewable energy. These disaggregated energy sectors are then reintegrated into the large-scale framework, producing an expanded input–output table comprising 39 sectors. This disaggregation enables a more precise assessment of the economic effects of different energy sources on the agri-food sectors. Hereafter, sectors are referred to by their assigned sector numbers.

Economic Effect Calculation

Wassily Leontief records the flows of goods and services using the transaction values between industries in the form of table so-called I/O table. The statistical table presents the interrelations among industries with respect to intermediate flows, final demand deliveries, and value-added inputs. The brief framework of Leontief's statistical table can be seen in Table 2. In economic analysis, Input-output (I-O) analysis is useful in estimating the impact of changes in demand for the output of an industry or group of industries. I-O tables provide a "snapshot" of the economy. In any given year, they show the inputs used by each industry, the outputs produced by each industry, and the relationship between industry output and final demand among various users (Garrett-Peltier, 2017).

Let us denote by $x_{ij}$ as the amount of product delivered from industry i to industry j and Xi the total output or total deliveries from industry i. Leontief uses a special production function where the inputs used in producing a product are related by a linear and fixed coefficient production function, i.e., $a_{ij}$is the technical coefficient matrix or input coefficient matrix

$$x_{ij} = a_{ij}X_{ij}$$

$$a_{ij} = \frac{x_{ij}}{x_j}$$ ; for I, j = 1,2,…,n.

Once the matrix of technical coefficients has been derived, it is then possible to compute the solution to the Leontief demand driven model which is specified as;

$$X = AX + Y \; or \; X = (I - A)^{-1}Y$$ ..... Equation. 1

$X$ is an n × 1 output matrix whose element is $X_i$ for $i$ = 1,…,n;

$A$ is an n × n input coefficient matrix.

$Y$ is an n × 1 stimulus matrix whose element is $Y_i$;

$I$ is an n × n identity matrix.

$(I - A)^{-1}$ is usually called a Leontief inverse matrix or input inverse matrix

The basic framework as explained above is expressed as $X = (I - A)^{-1}Y$. However, standard demand-driven IO models are not well suited to directly evaluating the economic effects of new production activities in specific energy industries, as changes in final demand are assumed to originate from forces

external to the model, such as shifts in consumer preferences or government expenditure. To address this limitation, the energy sector of interest is treated as exogenous and incorporated into the final demand vector. The theoretical foundation of this exogenous treatment is well established in the IO literature. Following established practice, this approach is referred to as an electricity-based input–output analysis.

This analytical framework has been widely applied in empirical studies on South Korea's energy sector, all of which adopt an exogenous treatment of specific energy industries to estimate their economy-wide impacts. Consistent with this literature, the present analysis treats sector k as the exogenous sector of interest, allowing for the estimation of production-inducing, value-added-inducing, wage-inducing, and supply-shortage effects. Based on these exogeneous concept we then can continue to analyze the production, wage, value-added, wage, and supply shortage effect. In our analysis, $Q$ is the sector of interest which is treated as exogenous sector.

Production-inducing effects

$\Delta X^e = (I - A^e)^{-1} \ (A_Q^e \, \Delta X_Q)$.....Equation. 2

- $\Delta X^e$ is an (n − 1) × 1 matrix showing changes in the output of other sectors except for Sector $Q$; $I^e$ is an (n − 1) × (n − 1) identity matrix,
- $Q$ = Exogenous sector
- $A^e$ is an (n − 1) × (n − 1) matrix that remains after removing Sector $Q$-related row and column from $A$.
- $A_Q^e$ is an (n − 1) × 1 column vector that is left after eliminating the $Q$-th element from the Sector$Q$-related column vector of $A$ ,
- $\Delta X_Q$ denotes the change in output of Sector $Q$

Value-added creation effects

$\Delta V^e = \overline{A^v}^e (I^e - A^e)^{-1}$

$(A_Q^e \, \Delta X_Q)$.....Equation. 3

- $\Delta V^e$ is a column vector signifying changes in the value-added of other sectors except for Sector $Q$,
- $\overline{A^v}^e$ represents the (n − 1) × (n − 1) matrix that remains after excluding Sector $Q$ -related row and column from $\overline{A^v}$

Wage-inducing effects

$\Delta W^e = \overline{A^w}^e (I^e - A^e)^{-1}$

$(A_Q^e \, \Delta X_Q)$..... Equation. 4

- $\Delta W^e$ is the (n − 1) × 1 matrix, meaning changes in wages in other sectors except for Sector $Q$,
- $\overline{A^w}^e$ indicates the (n − 1)× (n − 1) matrix left after excluding Sector $Q$ -related row and column from $\overline{A^w}$

Supply shortage

$X' = X'R + V' \vee V'(1 - R)^{-1}$.....
..... Equation. 5

- $R$ is the output coefficient matrix and $(1 - R)^{-1}$ is the output inverse matrix of which elements $(q_{ij} = \frac{\partial X_j}{\partial V_i})$ represent the total direct and indirect requirements in Sector $j$ per unit of value-added of Sector $i$.

$\Delta X^{e'} = R_Q^e \Delta X_Q (I^e - R^e)^{-1}$.....
.....Equation 6

- $\Delta X^{e\prime}$ is a 1 × (n − 1) matrix showing changes in the output of other sectors except for Sector $Q$,
- $R^e$ is an (n − 1) × (n − 1) matrix that remains after removing

Sector $Q$ -related row and column from R.

- $R_Q^e$ is the 1 × (n − 1) row vector that is left after eliminating the $Q$ th element from the $Q$-th row vector of R,
- $\Delta X_Q$denotes the change in output of Sector $Q$

In the demand-driven analysis, the row structure of the input–output table is used to derive input coefficients for estimating production-inducing, value-added-inducing, and wage-inducing effects. In contrast, the supply-shortage analysis adopts a supply-driven perspective, utilizing the column structure of the input–output table to construct output coefficients. All data processing and calculations are conducted using Python-based computational tools.

## RESULT

In this section, we present all relevant results in the form of raw data. As outlined in the methodology section, the sector names are expressed according to the numbering system previously established. Additionally, to streamline the structure of the tables, we have excluded self-induced data. For instance, in

Table ***1***

, note that the sector numbers skip from 16 to 18, omitting sector 17. This is because sector 17, representing the energy sector, has been subdivided into seven distinct energy types, each treated as exogenous in our analysis.

### Production-inducing effects

The Production Inducing Effect measures how much a 1 million KRW investment in a particular sector boosts production in other sectors. Essentially, when an investment is made in one sector, it triggers increased production in various interconnected sectors, as reflected in Table 1.

For example, cell (1,1) in the table shows that a 1 million KRW investment in the hydropower sector stimulates an additional 67.4 KRW worth of production in the agriculture sector (sector 1). Similarly, cell (2,1) reveals that investing 1 million KRW in the firepower sector induces a 3,622.5 KRW increase in the production of goods in the agriculture sector. The table continues to demonstrate how investments in different energy sectors affect the production of various industries, highlighting the ripple effects across the economy.

### Value Added creation Effect

The Value-Added Creation Effect quantifies how much a 1 million KRW investment or production in a specific sector generates additional value in other sectors. Essentially, it measures the economic contribution beyond direct output, reflecting the broader impact on overall economic growth. The results of this analysis for each energy sector are detailed in Table , showcasing how investments in different types of energy lead to varying levels of value-added creation across interconnected sectors. This analysis highlights the potential for certain energy investments to generate more significant economic benefits beyond their immediate scope, reinforcing the importance of strategic allocation in the energy sector.

### Wage Inducing effects

The Wage-Inducing Effect measures how a 1 million KRW investment or production in a particular sector increases wages in other sectors of the economy. It reflects the ripple effect of economic activity, showing how investments in one area can indirectly boost income levels across various industries.

**Table 1**
**Production inducing effect of energy sector**

| Sectors | Hydro power | fire power | nuclear power | Self-generation | City gas | Steam | Renewable Energy |
|---|---|---|---|---|---|---|---|
| 1 | 67.4 | 3,622.5 | 998.3 | 247.0 | 3,228.2 | 296.2 | 656.8 |
| 2 | 241.4 | 220,730.1 | 6,256.6 | 14,019.2 | 251,636.6 | 6,336.2 | 3,284.5 |
| 3 | 135.0 | 6,889.6 | 1,881.2 | 480.1 | 6,152.8 | 600.8 | 1,265.4 |
| 4 | 99.7 | 4,358.0 | 1,766.0 | 286.6 | 3,843.1 | 247.3 | 1,087.2 |
| 5 | 132.0 | 8,381.9 | 1,709.0 | 431.7 | 4,398.7 | 347.8 | 1,799.9 |
| 6 | 251.5 | 54,698.4 | 6,758.4 | 2,480.1 | 21,590.5 | 5,027.4 | 3,520.3 |
| 7 | 461.9 | 27,704.5 | 26,139.1 | 1,861.4 | 22,791.9 | 1,533.4 | 13,773.9 |
| 8 | 22.7 | 1,759.4 | 1,054.3 | 110.9 | 1,713.3 | -82.8 | 392.2 |
| 9 | 286.9 | 11,942.0 | 6,110.7 | 560.6 | 8,452.6 | 708.9 | 3,283.0 |
| 10 | 225.0 | 11,292.8 | 4,941.1 | 849.0 | 9,303.2 | 624.0 | 4,958.7 |
| 11 | 518.2 | 12,203.8 | 6,886.4 | 449.5 | 5,777.8 | 873.9 | 3,094.5 |
| 12 | 541.2 | 15,217.6 | 7,542.6 | 568.8 | 5,449.7 | 401.0 | 5,396.3 |
| 13 | 169.8 | 11,561.9 | 3,135.0 | 587.2 | 9,425.7 | 990.0 | 2,223.1 |
| 14 | 88.5 | 9,143.6 | 1,044.0 | 586.7 | 9,462.9 | 375.7 | 881.4 |
| 15 | 37.5 | 1,049.3 | 373.7 | 63.6 | 916.7 | 80.4 | 135.6 |
| 16 | 394.4 | 13,530.8 | 3,605.3 | 1,106.4 | 13,054.3 | 854.6 | 2,101.3 |
| 18 | 185.0 | 2,392.4 | 941.2 | 167.3 | 1,901.2 | 345.0 | 1,080.1 |
| 19 | 89.3 | 2,334.7 | 3,823.4 | 104.9 | 1,573.6 | 208.5 | 250.4 |
| 20 | 342.7 | 17,667.5 | 26,294.7 | 996.6 | 12,516.5 | 1,096.5 | 3,854.3 |
| 21 | 285.0 | 45,340.8 | 48,62.1 | 3,049.8 | 46,312.4 | 1,733.8 | 2,584.3 |
| 22 | 254.9 | 12,594.9 | 3,215.4 | 849.6 | 11,445.7 | 1,255.6 | 2,330.7 |
| 23 | 358.8 | 9,513.2 | 3,527.7 | 531.0 | 7,596.1 | 651.3 | 1,534.5 |
| 24 | 237.5 | 24,816.4 | 4,302.0 | 1,308.1 | 21,064.7 | 1,693.3 | 2,426.0 |
| 25 | 161.8 | 6,279.2 | 1,953.0 | 382.3 | 5,295.8 | 509.2 | 1,713.2 |
| 26 | 1,422.1 | 27,181.2 | 17,009.0 | 1,525.7 | 21,674.7 | 2,278.7 | 3,270.3 |
| 27 | 504.4 | 23,218.0 | 6,337.1 | 1,354.6 | 20,027.1 | 1,242.4 | 2,373.6 |
| 28 | 7.7 | 1,208.2 | 244.0 | 63.4 | 995.3 | 99.5 | 143.1 |
| 29 | 10.0 | 313.3 | 188.6 | 28.7 | 234.5 | 53.6 | 99.6 |
| 30 | 24.7 | 1,440.2 | 420.2 | 75.9 | 1,181.1 | 141.4 | 158.8 |
| 31 | 38.8 | 2,321.4 | 463.5 | 146.3 | 2,251.6 | 153.6 | 312.7 |
| 32 | 50.4 | 3,458.1 | 721.8 | 209.0 | 3,167.4 | 202.6 | 371.0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 33 | 10.5 | 1,669.0 | 365.5 | 82.9 | 1,313.7 | 151.1 | 216.0 |

**Table 2**
**Value added creation effect of energy sector**

| Sectors | Hydro power | fire power | nuclear power | Self-generation | City gas | Steam | Renewable Energy |
|---|---|---|---|---|---|---|---|
| 1 | 35.6 | 1,913.2 | 527.2 | 130.4 | 1,704.9 | 156.5 | 346.9 |
| 2 | 115.3 | 105,471.2 | 2,989.6 | 6,698.8 | 120,239.2 | 3,027.6 | 1,569.4 |
| 3 | 34.3 | 1,749.8 | 477.8 | 121.9 | 1,562.7 | 152.6 | 321.4 |
| 4 | 20.0 | 875.3 | 354.7 | 57.6 | 771.9 | 49.7 | 218.4 |
| 5 | 42.7 | 2,714.8 | 553.5 | 139.8 | 1,424.7 | 112.6 | 583.0 |
| 6 | 63.4 | 13,786.0 | 1,703.4 | 625.1 | 5,441.6 | 1,267.1 | 887.3 |
| 7 | 124.0 | 7,434.7 | 7,014.6 | 499.5 | 6,116.4 | 411.5 | 3,696.3 |
| 8 | 6.9 | 535.3 | 320.7 | 33.7 | 521.2 | -25.2 | 119.3 |
| 9 | 54.5 | 2,266.4 | 1,159.7 | 106.4 | 1,604.2 | 134.5 | 623.1 |
| 10 | 80.4 | 4,034.1 | 1,765.1 | 303.3 | 3,323.4 | 222.9 | 1,771.4 |
| 11 | 221.1 | 5,206.2 | 2,937.8 | 191.8 | 2,464.8 | 372.8 | 1,320.1 |
| 12 | 153.7 | 4,322.4 | 2,142.4 | 161.6 | 1,547.9 | 113.9 | 1,532.8 |
| 13 | 50.3 | 3,424.3 | 928.5 | 173.9 | 2,791.6 | 293.2 | 658.4 |
| 14 | 18.7 | 1,936.1 | 221.1 | 124.2 | 2,003.7 | 79.5 | 186.6 |
| 15 | 10.6 | 295.4 | 105.2 | 17.9 | 258.1 | 22.6 | 38.2 |
| 16 | 189.9 | 6,515.8 | 1,736.1 | 532.8 | 6,286.3 | 411.5 | 1,011.9 |
| 18 | 100.2 | 1,296.0 | 509.9 | 90.6 | 1,030.0 | 186.9 | 585.1 |
| 19 | 39.0 | 1,020.7 | 1,671.5 | 45.9 | 688.0 | 91.1 | 109.5 |
| 20 | 184.3 | 9,503.0 | 14,143.5 | 536.0 | 6,732.4 | 589.8 | 2,073.2 |
| 21 | 101.7 | 16,181.9 | 1,735.3 | 1,088.5 | 16,528.6 | 618.8 | 922.3 |
| 22 | 86.2 | 4,260.6 | 1,087.7 | 287.4 | 3,871.9 | 424.7 | 788.4 |
| 23 | 197.5 | 5,235.5 | 1,941.4 | 292.2 | 4,180.4 | 358.5 | 844.5 |
| 24 | 141.0 | 14,734.1 | 2,554.2 | 776.6 | 12,506.6 | 1,005.3 | 1,440.4 |
| 25 | 119.0 | 4,619.1 | 1,436.7 | 281.2 | 3,895.6 | 374.6 | 1,260.2 |
| 26 | 706.8 | 13,509.3 | 8,453.6 | 758.3 | 10,772.5 | 1,132.5 | 1,625.4 |
| 27 | 346.7 | 15,957.2 | 4,355.3 | 931.0 | 13,764.2 | 853.9 | 1,631.3 |
| 28 | 5.8 | 916.6 | 185.1 | 48.1 | 755.1 | 75.5 | 108.6 |
| 29 | 7.2 | 224.9 | 135.4 | 20.6 | 168.3 | 38.5 | 71.5 |
| 30 | 13.1 | 762.0 | 222.3 | 40.2 | 624.9 | 74.8 | 84.0 |
| 31 | 20.9 | 1,250.6 | 249.7 | 78.8 | 1,213.0 | 82.8 | 168.4 |
| 32 | 22.5 | 1,546.6 | 322.8 | 93.5 | 1,416.6 | 90.6 | 165.9 |
| 33 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

**Table 3**
**Wage inducing effect of energy sector**

| Sectors | Hydro-power | fire power | nuclear power | Self-generation | City gas | Steam | Renewable Energy |
|---|---|---|---|---|---|---|---|
| 1 | 6.4 | 346.1 | 95.4 | 23.6 | 308.5 | 28.3 | 62.8 |
| 2 | 44.3 | 40,486.6 | 1,147.6 | 2,571.4 | 46,155.5 | 1,162.2 | 602.5 |
| 3 | 11.4 | 582.6 | 159.1 | 40.6 | 520.3 | 50.8 | 107.0 |
| 4 | 9.2 | 402.1 | 162.9 | 26.4 | 354.6 | 22.8 | 100.3 |
| 5 | 18.7 | 1,188.2 | 242.3 | 61.2 | 623.5 | 49.3 | 255.1 |
| 6 | 2.7 | 588.3 | 72.7 | 26.7 | 232.2 | 54.1 | 37.9 |
| 7 | 38.7 | 2,323.9 | 2,192.6 | 156.1 | 1,911.8 | 128.6 | 1,155.4 |
| 8 | 2.8 | 218.2 | 130.8 | 13.8 | 212.5 | -10.3 | 48.7 |
| 9 | 19.3 | 805.1 | 411.9 | 37.8 | 569.8 | 47.8 | 221.3 |
| 10 | 37.4 | 1,877.4 | 821.4 | 141.1 | 1,546.6 | 103.7 | 824.4 |
| 11 | 47.0 | 1,107.2 | 624.8 | 40.8 | 524.2 | 79.3 | 280.7 |
| 12 | 58.3 | 1,638.0 | 811.8 | 61.2 | 586.6 | 43.2 | 580.8 |
| 13 | 25.2 | 1,718.4 | 465.9 | 87.3 | 1,400.9 | 147.1 | 330.4 |
| 14 | 8.6 | 884.6 | 101.0 | 56.8 | 915.5 | 36.3 | 85.3 |
| 15 | 5.8 | 161.3 | 57.4 | 9.8 | 140.9 | 12.3 | 20.8 |
| 16 | 126.5 | 4,340.4 | 1,156.5 | 354.9 | 4,187.6 | 274.1 | 674.1 |
| 18 | 0.2 | 14.6 | 74.1 | 20.8 | 244.2 | 106.2 | 47.7 |
| 19 | 0.0 | 0.6 | 0.3 | 0.9 | 10.3 | 4.5 | 2.0 |
| 20 | 0.3 | 877.0 | 10.5 | 38.0 | 0.4 | 0.0 | 0.1 |
| 21 | 0.0 | 2.6 | 0.7 | 0.1 | 1.3 | 78.7 | 4.6 |
| 18 | 0.0 | 1.3 | 0.3 | 0.1 | 0.9 | 0.4 | 0.4 |
| 18 | 45.2 | 584.8 | 230.1 | 40.9 | 464.7 | 84.3 | 264.0 |
| 19 | 27.5 | 719.9 | 1,178.9 | 32.3 | 485.2 | 64.3 | 77.2 |
| 20 | 94.4 | 4,866.1 | 7,242.3 | 274.5 | 3,447.4 | 302.0 | 1,061.6 |
| 21 | 60.7 | 9,653.0 | 1,035.1 | 649.3 | 9,859.8 | 369.1 | 550.2 |
| 22 | 49.7 | 2,454.8 | 626.7 | 165.6 | 2,230.8 | 244.7 | 454.3 |
| 23 | 75.7 | 2,007.4 | 744.4 | 112.0 | 1,602.9 | 137.4 | 323.8 |
| 24 | 54.2 | 5,660.1 | 981.2 | 298.3 | 4,804.4 | 386.2 | 553.3 |
| 25 | 10.7 | 414.3 | 128.9 | 25.2 | 349.4 | 33.6 | 113.0 |
| 26 | 485.4 | 9,277.3 | 5,805.4 | 520.7 | 7,397.9 | 777.7 | 1,116.2 |
| 27 | 196.1 | 9,028.7 | 2,464.3 | 526.7 | 7,787.8 | 483.1 | 923.0 |
| 28 | 3.7 | 580.7 | 117.2 | 30.5 | 478.4 | 47.8 | 68.8 |
| 29 | 6.1 | 190.1 | 114.5 | 17.4 | 142.3 | 32.5 | 60.5 |
| 30 | 9.5 | 556.4 | 162.3 | 29.3 | 456.3 | 54.6 | 61.3 |
| 31 | 8.1 | 483.2 | 96.5 | 30.4 | 468.7 | 32.0 | 65.1 |
| 32 | 14.7 | 1,011.7 | 211.2 | 61.2 | 926.7 | 59.3 | 108.5 |
| 33 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Supply Side – Supply Shortage Effect

**Table 4**
**Supply shortage effect of energy sector**

| Sector | Hydro-power | fire power | nuclear power | Self-generation | City gas | Steam | Renewable Energy |
|---|---|---|---|---|---|---|---|
| 1 | 207.7 | 11,146.1 | 2,309.1 | 163.0 | 1,998.3 | 702.0 | 747.2 |
| 2 | 21.7 | 1,163.8 | 241.2 | 23.4 | 236.8 | 46.0 | 77.6 |
| 3 | 460.8 | 24,550.6 | 5,094.8 | 464.3 | 7,123.3 | 1,669.8 | 1,658.5 |
| 4 | 264.1 | 14,145.3 | 2,956.0 | 298.3 | 4,014.7 | 2,888.7 | 949.6 |
| 5 | 283.0 | 15,334.0 | 3,175.3 | 511.1 | 3,541.1 | 2,993.0 | 1,019.3 |
| 6 | 214.1 | 11,548.4 | 2,399.6 | 1,095.0 | 2,619.7 | 14,785.9 | 771.0 |
| 7 | 1,414.7 | 75,833.8 | 15,867.1 | 4,024.0 | 19,240.4 | 22,814.5 | 5,095.5 |
| 8 | 286.7 | 15,453.5 | 3,205.0 | 603.9 | 6,512.6 | 598.2 | 1,028.3 |
| 9 | 1,187.0 | 62,560.0 | 13,339.5 | 23,979.6 | 22,231.5 | 811.2 | 4,261.6 |
| 10 | 476.6 | 25,473.3 | 5,325.2 | 3,142.8 | 10,474.4 | 910.1 | 1,707.7 |
| 11 | 1,227.3 | 59,614.5 | 12,795.7 | 2,239.1 | 14,592.9 | 3,298.1 | 4,422.2 |
| 12 | 366.2 | 19,499.0 | 4,082.2 | 2,276.0 | 8,443.1 | 1,344.3 | 1,315.7 |
| 13 | 518.0 | 27,592.4 | 5,765.5 | 2,792.1 | 9,793.4 | 1,412.5 | 1,856.1 |
| 14 | 803.8 | 42,630.6 | 8,982.0 | 4,514.2 | 14,007.6 | 2,661.2 | 2,904.6 |
| 15 | 96.7 | 5,189.0 | 1,080.5 | 346.9 | 1,434.6 | 455.5 | 347.0 |
| 16 | 195.0 | 10,412.5 | 2,161.1 | 403.9 | 3,038.9 | 1,566.4 | 696.0 |
| 18 | 195.8 | 10,474.3 | 2,187.1 | 255.3 | 1,717.6 | 176.1 | 716.3 |
| 19 | 745.6 | 39,758.9 | 8,317.5 | 3,974.8 | 13,302.9 | 2,669.0 | 2,677.1 |
| 20 | 842.4 | 45,459.0 | 9,400.7 | 664.0 | 10,205.6 | 3,340.9 | 3,022.8 |
| 21 | 481.5 | 25,972.7 | 5,381.6 | 633.0 | 11,699.5 | 3,327.5 | 1,731.7 |
| 22 | 544.0 | 29,264.6 | 6,060.0 | 432.6 | 16,550.8 | 1,684.9 | 1,954.8 |
| 23 | 383.3 | 20,566.1 | 4,264.2 | 393.2 | 4,517.3 | 695.7 | 1,376.8 |
| 24 | 309.5 | 16,651.9 | 3,438.7 | 267.4 | 4,176.5 | 993.9 | 1,113.1 |
| 25 | 385.6 | 20,757.3 | 4,296.4 | 303.1 | 4,771.2 | 534.6 | 1,381.5 |
| 26 | 1213.5 | 64,446.6 | 13,492.8 | 4,639.8 | 18,770.7 | 2,234.0 | 4,398.7 |
| 27 | 135.4 | 7,442.4 | 1,503.0 | 169.6 | 2,130.6 | 427.2 | 484.3 |
| 28 | 261.0 | 14,306.3 | 2,735.7 | 618.2 | 4,917.9 | 556.2 | 864.0 |
| 29 | 716.2 | 25,372.2 | 3,440.0 | 266.6 | 10,962.0 | 1,281.5 | 1,096.3 |
| 30 | 803.0 | 28,697.0 | 4,520.4 | 599.3 | 17,563.5 | 2,329.8 | 1,584.3 |
| 31 | 212.3 | 11,410.4 | 2,349.7 | 200.5 | 4,409.5 | 325.4 | 754.7 |
| 32 | 178.3 | 9,560.0 | 1,986.2 | 280.6 | 3,466.4 | 1,249.4 | 641.1 |
| 33 | 21.9 | 884.8 | 156.1 | 30.0 | 567.7 | 57.5 | 54.7 |

Table  presents the results of this analysis, highlighting how different types of energy investments influence wage growth in interconnected sectors. This analysis underscores the broader socio-economic impact of energy investments, particularly in terms of job creation and income distribution across the economy. The supply-driven model addresses the direct and indirect effects of natural

resource supply restrictions on the economy. The supply shortage effect measures the impact of a supply disruption in a particular sector on the output of other sectors. In other words, if there is a shortage of 1 million KRW in a specific sector, this model estimates how much production loss will occur in other connected sectors.

For example, in cell (1,1), a supply shortage of 1 million KRW in the Hydropower sector would result in a production failure of 207.7 KRW in the Agriculture sector. The results of this analysis for various sectors are presented in

Table , highlighting the interdependencies within the economy and the potential cascading effects of supply shortages.

## DISCUSSION

The findings of this study contribute to the energy transition and agri-food economics literature by clarifying the economic trade-offs between renewable and non-renewable energy investments from both a demand-side and a supply-risk perspective. From an input–output (IO) theory standpoint, the stronger short-term production, value-added, and wage-inducing effects associated with non-renewable energy investments are consistent with the concept of structural embeddedness in mature industrial systems. Conventional energy sectors, particularly fossil-fuel-based electricity and gas supply, are deeply integrated into existing production networks, resulting in strong backward and forward linkages that amplify multiplier effects. This pattern has been widely documented in previous IO studies, which show that long-established energy technologies tend to generate higher immediate economic spillovers due to capital intensity, extensive intermediate input requirements, and entrenched supplier relationships.

However, when viewed through the lens of economic resilience and vulnerability theory, the supply-shortage analysis reveals a fundamentally different dynamic. The substantially larger negative spillover effects associated with non-renewable energy supply disruptions indicate a higher degree of systemic fragility. This finding aligns with the literature on energy security and shock propagation, which argues that economies heavily dependent on fossil fuels are more exposed to supply interruptions arising from price volatility, geopolitical tensions, and external market dependence. Within an IO framework, such vulnerability reflects the high centrality of non-renewable energy sectors in production networks, where disruptions propagate rapidly across interlinked industries.

In contrast, the lower supply-shortage effects observed for renewable energy sectors suggest a comparatively higher degree of systemic resilience. Although renewable energy currently exhibits weaker short-term multipliers, its decentralized production structure and reduced reliance on imported fuels appear to limit the transmission of supply shocks across the economy. This supports empirical findings from recent energy-transition studies that emphasize renewables' contribution to energy security and risk diversification, even when their immediate economic stimulus effects are smaller. From a theoretical perspective, this reflects a transition from efficiency-driven industrial organization toward robustness-oriented system design, where reduced exposure to shocks becomes a critical performance criterion.

For the agri-food sector, these results underscore a key trade-off between short-term economic performance and long-term stability.

Agriculture and food processing are highly energy-dependent sectors, particularly sensitive to energy price fluctuations and supply reliability. While non-renewable energy investments currently deliver stronger multiplier effects for agri-food production, they also expose the sector to greater disruption risks. Renewable energy, despite generating lower immediate economic gains, may enhance the stability of agri-food systems by reducing vulnerability to energy supply shocks. This finding is consistent with studies highlighting the role of renewable energy in supporting food system resilience, particularly under increasing climate-related and geopolitical uncertainty.

From a policy perspective, the results challenge the adequacy of evaluating energy strategies solely based on short-term economic multipliers. Traditional growth-oriented assessments may systematically undervalue renewable energy by overlooking its contribution to resilience, risk mitigation, and long-term system stability. For sectors critical to food security, such as agriculture and food manufacturing, incorporating supply-risk and vulnerability considerations into energy policy evaluation is essential. Rather than advocating an abrupt substitution of existing energy systems, the findings support a gradual and strategic energy transition, in which renewable energy increasingly complements conventional energy sources while industrial linkages adapt over time. Such an approach allows economies to balance immediate economic performance with longer-term resilience objectives.

The model employed in this study is a fundamental quantitative analysis. Despite its simplicity, the Input-Output (IO) model provides a comprehensive snapshot of the economy by illustrating the interrelationships between sectors within a country. The quantitative results derived from this IO analysis are particularly valuable for initial investigations and for understanding broad economic impacts. In this study, we utilize the IO model to analyse the implications of investing in various energy sectors. This approach allows us to assess the potential economic effects of such investments and provides insights into how different energy sectors influence the broader economy. To summarize the results, we present Table as a concise overview of our findings. This table serves to clearly address our research question, providing a streamlined view of the key outcomes from the analysis for easier interpretation and understanding.

The findings of this study align with and extend the established body of input–output (IO) and energy economics literature by highlighting the structural trade-offs inherent in energy transition pathways. From a conventional IO perspective, the stronger short-term economic impacts associated with non-renewable energy investments are consistent with the theory of industrial embeddedness articulated in foundational IO works (Leontief, 1986; Miller & Blair, 1985). Energy sectors that have evolved over long periods tend to occupy central positions within production networks, generating strong backward and forward linkages that amplify production, value-added, and employment multipliers. Empirical evidence from South Korea supports this interpretation, with previous studies demonstrating that electricity generation and fossil-fuel-based energy sectors produce substantial economy-wide spillover effects (Han et al., 2004; K. Kim et al., 2020).

Recent methodological advances in IO analysis emphasize that high multiplier effects do not necessarily imply systemic robustness. Approaches such as sectoral extraction and supply-shortage analysis explicitly reveal the vulnerability embedded in highly

interconnected sectors (Miller & Lahr, 2001; Dietzenbacher & Lahr, 2013). In this context, the present study's supply-shortage results are consistent with (J. H. Kim et al., 2020), who show that electricity generation sectors in South Korea can transmit significant negative shocks when supply disruptions occur. These findings reinforce the argument that non-renewable energy dependence increases exposure to cascading economic losses, particularly in sectors that rely heavily on stable and affordable energy inputs. The comparatively lower supply-shortage effects associated with renewable energy reflect a different structural role within the economy. While renewable energy investments currently generate smaller short-term multipliers, a result also observed in international studies such as (Lehr et al., n.d.) for Germany and Allan et al. (2014) for the United Kingdom, these sectors tend to reduce systemic risk by diversifying energy sources and limiting dependence on imported fuels. From an energy security perspective, this supports the broader conceptual framework proposed by (Cherp & Jewell, 2014), which argues that resilience and adaptability are critical dimensions of energy systems, alongside affordability and availability.

For the agri-food sector specifically, the findings underscore the importance of evaluating energy investments beyond immediate economic stimulation. Agriculture and food processing are particularly sensitive to energy price volatility and supply interruptions, making them vulnerable to upstream shocks originating in energy markets. The lower vulnerability associated with renewable energy investments suggests a stabilizing effect on agri-food value chains, consistent with studies emphasizing the role of renewable energy in enhancing sectoral resilience and employment sustainability (Rodríguez-Alloza et al., 2015; Kim et al., 2020). This observation also aligns with the temporal perspective on energy transitions articulated by Sovacool (2016), which emphasizes that the benefits of renewable energy often materialize gradually as systems adapt and structural linkages evolve.

Taken together, these findings contribute to the growing literature that reframes energy transition not as a simple substitution of technologies but as a structural transformation of economic systems. While non-renewable energy remains economically dominant in the short term due to its entrenched role in production networks, renewable energy increasingly contributes to long-term stability, risk reduction, and energy security. This duality suggests that policy evaluations based solely on short-term multiplier effects risk underestimating the strategic value of renewable energy, particularly for sectors critical to food security and sustainable development. A balanced and phased transition strategy, in which renewable energy complements existing energy systems while gradually reshaping industrial linkages, is therefore essential for achieving both economic performance and systemic resilience.

The summary table presenting the economic impacts and supply shortages of different energy types across the agriculture, forestry, and fishery sector and the food, beverages, and tobacco products sector, as shown in Table . The results show that both sectors rely heavily on non-renewable energy, which generates the largest production, value-added, and wage-inducing effects. Fire power and city gas contribute the most to economic output and employment but also account for the greatest supply shortages. The food, beverages, and tobacco sector is more energy-intensive overall, showing higher production and labor impacts as well as significantly larger shortages, particularly from fire power. In contrast, renewable energy provides comparatively smaller economic contributions and experiences lower

shortages, indicating a more stable but still limited role. Overall, the table highlights strong dependence on non-renewable energy and the associated vulnerability to supply constraints.

**Table 5**
**Summary of findings**

| Sector | Energy type | Production-inducing | Value-added | Wage-inducing | Supply-shortage |
|---|---|---|---|---|---|
| Agricultural, forestry, and fishery goods | Hydropower | 67.4 | 35.6 | 6.4 | 207.7 |
| | Fire power | 3,622.5 | 1,913.2 | 346.1 | 11,146.1 |
| | Nuclear power | 998.3 | 527.2 | 95.4 | 2,309.1 |
| | Self-generation | 247.0 | 130.4 | 23.6 | 163.0 |
| | City gas | 3,228.2 | 1,704.9 | 308.5 | 1,998.3 |
| | Steam | 296.2 | 156.5 | 28.3 | 702.0 |
| | Total non-renewable energy | 8,459.6 | 4,467.8 | 808.3 | 16,526.2 |
| | Renewable energy | 656.8 | 346.9 | 62.8 | 747.2 |
| Food, beverages, and tobacco products | Hydropower | 135.0 | 34.3 | 11.4 | 460.8 |
| | Fire power | 6,889.6 | 1,749.8 | 582.6 | 24,550.6 |
| | Nuclear power | 1,881.2 | 477.8 | 159.1 | 5,094.8 |
| | Self-generation | 480.1 | 121.9 | 40.6 | 464.3 |
| | City gas | 6,152.8 | 1,562.7 | 520.3 | 7,123.3 |
| | Steam | 600.8 | 152.6 | 50.8 | 1,669.8 |
| | Total non-renewable energy | 16,139.5 | 4,099.1 | 1,364.8 | 39,363.6 |
| | Renewable energy | 1,265.4 | 321.4 | 107.0 | 1,658.5 |

**Non-Renewable Energy**

The non-renewable energy sector includes hydropower, fire power, nuclear power, self-generation, city gas, and steam supply, which together account for approximately 97 percent of South Korea's total energy supply. Non-renewable energy investments generate substantial production-inducing effects in the agri-food sector. For example, a 1 million KRW investment in fire power induces 3,622.49 KRW in the agriculture sector and 6,889.57 KRW in the food sector. Investments in city gas generate 3,228.21 KRW in agriculture and 6,152.83 KRW in food, while nuclear power contributes 998.28 KRW and 1,881.19 KRW to agriculture and food sectors, respectively.

In contrast, steam supply, self-generation, and hydropower exhibit relatively lower production effects. Steam supply contributes 296.25 KRW to agriculture and 600.83 KRW to food, self-generation contributes 246.96 KRW and 480.11 KRW, and hydropower contributes 67.37 KRW and 135.01 KRW, respectively. This ranking pattern is consistent across other economic indicators, including wage-inducing effects, value-added creation, and supply-shortage effects, with fire power, city gas, and nuclear power emerging as the most influential non-renewable

energy contributors to the agri-food sector and the broader economy.

**Renewable Energy**

Renewable energy currently accounts for a relatively small share of South Korea's energy mix, at approximately 3 percent. Despite this limited share, the results indicate that renewable energy performs competitively when compared with several non-renewable energy sectors. Within the agri-food system, renewable energy ranks fourth out of seven energy types in terms of production-inducing effects, value-added creation, and supply-shortage effects. Although its economic impacts are lower than those of fire power, city gas, and nuclear energy, renewable energy generates stronger effects than steam, self-generation, and hydropower.

Importantly, the relatively modest supply-shortage effects associated with renewable energy indicate lower vulnerability to supply disruptions. Renewable energy ranks fourth in the agriculture sector and fifth in the food sector and in the overall economy with respect to supply-shortage impacts. This suggests that disruptions in renewable energy supply have comparatively smaller spillover effects on other sectors than disruptions in non-renewable energy. Such resilience may be related to the more diversified and less input-intensive nature of renewable energy systems, which reduces exposure to upstream supply constraints.

## CONCLUSION

This study demonstrates that renewable and non-renewable energy investments affect South Korea's agri-food sector in fundamentally different ways, reflecting a trade-off between short-term economic performance and long-term system stability. Non-renewable energy remains more deeply embedded in existing production structures and therefore delivers stronger immediate economic gains for the agri-food sector. However, these gains are accompanied by greater exposure to supply-related risks, as disruptions in non-renewable energy propagate more intensively through agricultural and food value chains. In contrast, renewable energy investments generate more moderate economic effects but contribute to greater resilience by limiting the transmission of supply shocks across energy-dependent agri-food systems. These findings indicate that energy investment decisions should not be evaluated solely on short-term economic multipliers, particularly for sectors that are essential to food security and rural livelihoods. A strategic and gradual energy transition, in which renewable energy increasingly complements conventional energy sources, is therefore crucial for balancing economic performance with long-term stability, resilience, and sustainability in the agri-food sector.

The findings imply that energy transition strategies focused solely on short-term economic multipliers may underestimate the strategic value of renewable energy for food-related sectors. Incorporating resilience and supply-risk considerations can improve the design of energy policies that support both economic stability and food security.

This study has several limitations. As with all input–output analyses, the results are based on fixed technical coefficients and do not account for price adjustments or technological change over time. In addition, the analysis reflects the structure of the South Korean economy and may not be directly generalizable to other countries with different energy or agricultural systems. Future research could integrate dynamic or computable general equilibrium models to capture longer-term adjustment effects.

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