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A GREEN ECONOMY TRANSITION PROGRAM FOR SOUTH KOREA

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ABSTRACT

This study outlines a workable climate stabilization framework for South Korea, building from the government's own Green New Deal program as well as a number of related research studies, written by both government agencies and a range of independent researchers.

Achieving the Green New Deal's Objectives. The program's most important objectives are to reduce the country's carbon dioxide (CO_2) emissions by more than 40 percent by 2030 and to achieve zero emissions by 2050. Korea will be able to achieve these emissions reduction objectives while also maintaining a healthy overall economic growth trajectory and, critically, producing a major expansion in overall employment opportunities.

Phasing Out Fossil Fuels. The primary way through which South Korea will reach its CO_2 emissions reduction targets will be through phasing out the consumption of oil, coal, and natural gas to produce energy. Burning oil, coal, and natural gas accounts at present for about 84 percent of the Korean economy's overall energy consumption. Virtually all of this fossil fuel energy is imported into the Korean economy. These imports will be phased out.

Building a Clean Energy Infrastructure. South Korea's Green New Deal project will need to build a new energy infrastructure. Its centerpieces will be investments in energy efficiency and clean renewable energy sources. Investments should be in the range of 3.6 percent of GDP between 2022 – 2030 and 1.4 percent of GDP between 2031 – 2050.

Large-Scale Job Creation. Investments in energy efficiency and renewable energy, along with substituting domestically-produced clean energy for imported fossil fuels, will generate an average of between 810,000 and 860,000 more jobs between 2022 – 2030 and between 900,000 and 1.2 million more jobs between 2031 – 2050 throughout South Korea, equal to between about 3 – 4 percent of Korea's current workforce. New job opportunities will emerge in all sectors of Korea's labor force at a wide range of pay levels and educational credentials. This major expansion in job opportunities will also create supportive conditions for improving wages, benefits, and working conditions.

Modest Job Losses through Fossil Fuel Phase-Out. This phase-out of fossil fuel consumption will mean job losses for workers now employed in the range of fossil fuel-based activities, such as natural gas distribution and operating oil and gas stations. Job losses will also result as Korea transitions its robust auto manufacturing sector from producing internal combustion engine vehicles, powered by oil, to zero-emissions vehicles, including electric and hydrogen fuel cell-powered autos. Korea also plans to incrementally phase out its nuclear power industry, which will also produce some job losses. But the number of workers whose jobs will be phased out and will need reemployment—i.e. displaced workers—will average only about 9,000 per year after accounting for workers who leave the work force voluntarily through retirement during 2022 – 2030. Displacements are likely to peak to roughly 15,000 per year between 2031 – 2035 as internal combustion engine auto manufacturing closes down, but then decline to around 3,000 per year between 2036 – 2050 for workers in the fossil fuel and nuclear industries only.

Generous Transition Support for Displaced Workers. The workers who will face displacement through Korea's fossil fuel phase-out should all be provided with generous government transition support. The economy's rapidly expanding clean energy sectors will provide one major new pool of job opportunities available to these displaced workers.

Financing Korea's Green Economy Transition. The South Korean government has been actively advancing a range of financing initiatives to promote large-scale clean energy investments. To scale up these programs, we consider, for purposes of illustration, three new public revenue sources: 1) converting the government's existing fossil fuel subsidies into clean energy investment subsidies; 2) transferring a share of Korea's military budget into clean energy investments; and 3) enacting a carbon tax. Most of the revenue generated by the tax would be rebated directly to Korean citizens. But significant funds would still be available to support clean energy investments. These public funding sources would be supplemented with strong incentives for private investors, including through subsidized green bonds, carbon pricing, and regulatory measures.

SUMMARY OF STUDY

This study outlines a workable climate stabilization framework for South Korea, building from the government's own Green New Deal program as well as a number of related research studies, written by both government agencies and a range of independent researchers. Under the program we outline, Korea will be able to achieve the government's two most important objectives within its Green New Deal program. These are to reduce the country's carbon dioxide (CO_2) emissions by more than 40 percent by 2030 and to achieve zero emissions by 2050. CO_2 emissions account for about 93 percent of overall greenhouse gas emissions in South Korea.[1] By 2050, Korea will have become a carbon-neutral economy. Moreover, Korea will be able to achieve these emissions reduction targets while also maintaining a healthy overall economic growth trajectory and, critically, producing a major expansion in overall employment opportunities.

South Korea's Clean Energy Transition Project

The primary way through which South Korea will reach its CO_2 emissions reduction targets will be through phasing out the consumption of oil, coal, and natural gas to produce energy. On a global basis, the combusting of fossil fuels to produce energy is responsible for producing about 75 – 80 percent of all greenhouse gas emissions, including CO_2 emissions as well as methane and nitrous oxide.[2] Within South Korea, burning oil, coal and natural gas accounts at present for about 84 percent of the economy's overall energy consumption. Virtually all of this fossil fuel energy is imported into the Korean economy.[3]

In conjunction with the phasing out of its current fossil fuel-dominant energy infrastructure, South Korea's Green New Deal project will need to advance a large-scale investment program through 2050 to create a new energy infrastructure. The centerpieces of this investment program will be high efficiency and clean renewable energy sources.

Large-Scale Job Creation through Clean Energy Investments

Our study estimates that the investments in energy efficiency and renewable energy that will be required to transform Korea into a carbon-neutral economy will generate an average of between 810,000 and 860,000 more jobs between 2022 – 2030 and between 900,000 and 1.2 million more jobs between 2031 – 2050 throughout South Korea. This represents an expansion of job opportunities of between about 3 – 4 percent relative to the 28.4 million people who are currently in the South Korean labor force, including those with jobs as well as the unemployed and underemployed workers. The phasing out of fossil fuel imports and the substitution of renewable energy generated within Korea's own domestic economy for these imports will be a major contributor to the overall expansion of job opportunities. This expansion of job opportunities will cover all sectors of Korea's labor force at a wide range of pay levels and educational credentials. It will also create supportive conditions for improving wages, benefits, and working conditions throughout Korea's economy.

Modest Job Losses through Fossil Fuel Phase-Out

This phase-out of fossil fuel consumption within Korea will mean job losses for workers now employed in the range of fossil fuel-based activities, such as natural gas distribution and operating oil and gas stations. Job losses will also result as Korea transitions its robust auto manufacturing sector from producing internal combustion engine vehicles, powered by oil, to zero-emissions vehicles, including electric and hydrogen fuel cell-powered autos. This will result because the number of workers needed to manufacture zero-emissions vehicles is lower than what is required for internal combustion engine vehicles.

But these job losses will be relatively small, in the range of 9,000 workers per year on average between 2022 – 2030, after we take account of the share of workers in fossil fuel-based industries and auto manufacturing workers who will leave the work force voluntarily through retirement. There will be a spike in auto manufacturing job displacements between 2031 – 2035 of about 11,500 workers per year, as the manufacturing of internal combustion engine powered autos is completely shut down by 2035. About 3,000 fossil fuel and nuclear industry workers will also be displaced annually between 2031 – 2035, bringing total displacements for those five years to a high annual figure of about 14,500. But this also means that, from 2036 – 2050, further job displacements will be in the fossil fuel and nuclear industries only, at about 3,000 workers per year. The workers who will face displacement through Korea's phase-out—those employed in the fossil fuel and nuclear industries as well as those in auto manufacturing—should all be provided with generous government support in transitioning into new employment areas. The economy's rapidly expanding clean energy sectors will provide one major new pool of job opportunities available to these displaced workers.

Tables S.1 and S.2 summarize our job creation and job displacement estimates for the initial 2022 – 2030 phase of the clean energy transition.

TABLE S.1
Average Annual Job Creation through Combined Channels, 2022 – 2030

- *Energy efficiency and renewable energy investments*
- *Reforestation*
- *Phasing out fossil fuel energy imports*

	Job creation with fixed employment/output ratios	Job creation with 1.5% annual labor productivity growth *(figures are for midpoint year 2026)*
Energy efficiency and renewable energy investments: *KRW 78 trillion/year*	789,780	743,450
Reforestation investments: *KRW 631 billion/year*	11,930	11,230
Phase-out of fossil fuel energy imports: *KRW 6.3 trillion/year in net energy import substitution*	59,454	55,970
Total job creation	861,164	810,650
Total job creation as share of 2020 South Korea labor force *(labor force at 28.4 million)*	3.0%	2.9%

Sources: Tables 3.5, 3.9, 3.11.

TABLE S.2
Average Annual Job Displacements, 2022 – 2030

- *Fossil fuel energy phase-out*
- *Auto manufacturing transition from internal combustion to zero-emissions vehicles*
- *Zero displacements for nuclear industry workforce*

All fossil fuel industry workers displaced	3,354
- Gas station workers	1,298
- All other fossil fuel industry workers	2,056
Auto manufacturing industry workers displaced	5,222
Total average workers displaced	8,576
Total job displacement as share of 2020 South Korea labor force *(labor force at 28.4 million)*	**0.03%**

Sources: Tables 4.4, 4.6.

The Government's Carbon Neutrality Commitment

The specific features of the framework we develop can be understood more clearly within the context of the government's stated Green New Deal project and the range of related research work both by the government and independent researchers. The starting point here is the government's series of announcements and reports in 2020 and 2021, through which it committed South Korea to reduce the country's greenhouse gas emissions by more than 40 percent as of 2030 and to become carbon neutral by 2050.[4]

Thus, in its December 2020 report titled *2050 Carbon Neutral Strategy of the Republic of Korea: Towards a Sustainable and Green Society* the government set out what it termed "Korea's 2050 vision" as follows[5]:

> The Republic of Korea moves towards the goal of carbon neutrality by 2050. The Korean New Deal will serve as a steppingstone to reach carbon neutrality by 2050. Korea will harness green innovations and advanced digital technologies to create synergies between the Green New Deal and the Digital New Deal, the two pillars of the Korean New Deal. Korea will also take decisive action especially in supporting and investing in the development of innovative climate technologies to achieve carbon neutrality by 2050. Tackling climate change requires global efforts and collective engagement. Korea will lead by example to help the international community jointly make efforts to reach carbon neutrality by 2050.

At the November 2021 United Nations Climate Change Conference of the Parties (COP26) in Glasgow, Scotland, South Korean President Moon Jae-in affirmed his government's ambitious climate stabilization commitments, including to cut the country's greenhouse gas emissions by more than 40 percent by 2030 and to achieve carbon neutrality by 2050. In his November 1 address to the COP26 conference, President Moon stated that "It is not easy, but the Korean people have decided that now is the time for action. Korea has legislated 2050 Carbon Neutrality and announced relevant scenarios."[6]

The South Korean program to reduce CO_2 emissions by more than 40 percent by 2030 and to achieve carbon neutrality is outlined in the December 2020 report *2050 Carbon Neutral Strategy of the Republic of Korea*. The program is further developed in work that the Korean Ministry of Trade, Industry and Energy (MOTIE), and the Korea Energy Economics Institute (KEEI) produced in conjunction with the International Energy Agency (IEA). This includes the November 2020 study, *Korea 2020: Energy Policy Review* and the December 2021 study *Reforming Korea's Electricity Market for Net Zero.*[7]

Recent Research on Korea's Carbon Neutrality Project

The range of recent studies by independent researchers and non-governmental organizations provides further perspectives and details on how South Korea can successfully transition to a zero emissions economy by 2050.[8] Of course, these various studies differ in their respective approaches and detailed analyses. But their main findings and recommendations are in broad agreement. They are also in broad alignment with the recent government reports.

As a first overarching target, all of these studies recognize that South Korea, as with the rest of the world, will need to phase out consumption of oil, coal, and natural gas to produce energy. These studies then all recognize that South Korea will need to build an alternative clean energy infrastructure in conjunction with phasing out its fossil fuel-dominant system. This will entail large-scale investments to dramatically raise energy efficiency standards at all levels of the economy, including in the operations of buildings, transportation systems, information technologies and industrial equipment. It will equally require large-scale investments in clean renewable energy. Solar energy is expected to be the economy's primary renewable energy source within the economy's new energy infrastructure, followed by wind power, as well as, to a lesser extent, hydro, tidal, geothermal and low-emissions bioenergy. High-emissions bioenergy sources, such as wood-burning or corn ethanol, provide no benefit in emissions reduction relative to burning fossil fuels. Increasing the Korean economy's reliance on clean renewable energy sources also entails correspondingly raising the share of energy that will be delivered in the form of electricity. This is because electrification is the most efficient way to deliver most clean renewable energy supplies.

Korea's Renewable Energy Potential

In assessing the viability of Korea's capacity to develop this alternative clean energy infrastructure, it is especially notable that the Korean Energy Agency (KEA), in the 2020 edition of its *New and Renewable Energy White Paper*, concluded that the economy's "technical potential" for expanding its renewable energy supply is *12 times greater* than Korea's total primary energy consumption as of 2020. The KEA also estimates what it terms the "market potential" for renewable energy, which takes account of the level of supply that can be provided on a cost-competitive basis after incorporating both technical potential and realistic levels of government support. The KEA's market potential estimate is much lower, with overall renewable energy supply at only about 7 percent of its technical potential. Nevertheless, the KEA's market potential figure for renewable supply should still be sufficient to provide fully 100 percent of Korea's total energy demand as of 2050, after also allowing for significant improvements in energy efficiency between now and 2050. The KEA estimates that solar energy will provide about 74 percent of Korea's overall renewable energy market potential.

Wind power contributes another 18 percent. According to the KEA, all other renewable energy sources add up to the remaining 8 percent of Korea's renewable market potential.

Energy Efficiency and Renewable Energy Investment Costs

The framework we develop here enables us to generate estimates as to the levels of investments in both energy efficiency and renewable energy sources that will be required to build a clean energy infrastructure capable of supporting the Korean economy. Our framework assumes that the Korean economy will grow at a healthy average rate of 2.5 percent per year over the full period until 2050—that is, Korea's Gross Domestic Product (GDP) will grow at an average rate of 2.5 percent per year over the full period 2022 – 2050. The Korean economy will therefore not have to experience sacrifices in terms of improving average living standards in order to achieve carbon neutrality. In fact, the transition from a fossil fuel-dominant energy infrastructure to a clean energy infrastructure will entail lower costs for all Korean energy consumers. This is first of all because investments to raise energy efficiency standards will, by definition, lower the amount of energy that people will need to purchase in order to, for example, heat, cool and light their homes or drive their cars a given distance. In addition, as we will review, it is already the case that the costs of generating electricity from renewable energy sources are lower, on average, than those for producing electricity by burning coal or natural gas.

We examine the energy efficiency and renewable energy investment programs within two separate time periods. The first period is between 2022 – 2030. We show how Korea can succeed in reducing CO_2 emissions by 45 percent during this period. We set this 45 percent emissions reduction target by assumption, to be consistent with and give specificity to the government's stated goal of bringing down emissions by "more than 40 percent" by 2030. The second period covers 2031 – 2050. We show how Korea can achieve carbon neutrality by 2050.

For both of these time periods, we provide rough estimates as to the costs of building a clean energy infrastructure. Incorporating both energy efficiency and renewable energy investments, we estimate that overall costs between 2022 – 2030 will average about 3.6 percent of the economy's overall GDP, equal to about KRW 78 trillion per year. Over the second 2031 – 2050 period, we estimate that overall investment costs will fall sharply as a share of GDP, to an average of about 1.4 percent of GDP per year. This would equal an average of KRW 44 trillion between 2031 – 2050.

There are two reasons why average investment costs per year will fall in the second period. The first factor is that between 2022 – 2030, Korea has targeted emissions reduction at "greater than 40 percent"—which, again, we have interpreted as a 45 percent decline—to be achieved within 9 years only. This specifically means that emissions in Korea will fall from its 2018 level of 631 million tons to 350 million tons over the 9-year period to 2030.[9] By contrast, the Korean economy will have 20 years between 2031 – 2050 to drive down emissions to zero from the 2030 level of 350 million tons. The transition out of fossil fuels can therefore advance at a somewhat more deliberate pace over 2031 – 2050. In addition, we assume that the costs of building a clean energy infrastructure will fall incrementally between now and 2050. In fact, on the global market, average solar energy costs have fallen by more than 80 percent since 2010. We assume, conservatively, a much more moderate 1.5 percent average annual decline in overall renewable energy costs for South Korea through the full 2022 – 2050 investment period.

Reforestation

We also take into account two other features of the government's Green New Deal project. One is the government's reforestation program, through which Korea would expand its CO_2 absorption capacity by planting approximately 2.7 billion trees within South Korea by 2050. President Moon emphasized the importance of this project in his November 2021 address at the COP26 conference, stating that "Trees are living greenhouse gas sinks. Growing trees and reviving forests are important solutions to the climate crisis." The Korean Forest Service has provided some preliminary descriptions as to how this program may develop. As we will discuss, this reforestation program as described thus far by the Forest Service, or any comparable measure mounted on a similar scale, will have the potential to make only a relatively modest contribution towards bringing Korea's emissions down to zero by 2050. As such, virtually all of the gains in emissions reduction will result through building a clean energy infrastructure in South Korea to replace its existing fossil fuel-dominant infrastructure.

Phasing Out Nuclear Energy

We also consider the Moon government's proposal to phase out nuclear energy. Currently, nuclear energy provides about 16 percent of Korea's overall primary energy supply. Although President Moon committed to phasing out nuclear power when he took office in 2017, in fact, nuclear energy consumption in South Korea has not declined since 2017. Despite this, several of the recent studies that we have reviewed do assume that nuclear energy will still be phased out by 2050. In the framework that we develop, we assume that nuclear energy will be phased out within the timeline currently set out by the government. Under this timeline, nuclear supply will be reduced by about 15 percent as of 2030 and by about 55 percent as of 2050 relative to current production levels. Under the government's current plan, nuclear electricity generation will be fully phased out by 2085. Of course, this phase-out of nuclear energy that is scheduled to occur between now and 2050 will produce job losses and some workers will face displacement. But these nuclear industry displacements will be small. In fact, between 2022 – 2030, we estimate no displacements after accounting for voluntary retirements. For 2031 – 2050, we estimate displacements per year at less than 400 nuclear industry workers.

Raising Job Quality Standards as Employment Opportunities Expand

To generate our estimates of job creation through the clean energy investment program, we work with the government's statistical resources that document the employment requirements for all activities within the Korean economy. Specifically, we use the government's official input-output (I-O) tables. With these I-O tables, we are able to estimate the number of jobs that will be generated through spending, for example, KRW 1 billion to increase the availability of public transportation services or to install solar energy at a community, commercial or utility scale. We use this same methodology to estimate job creation through the government's reforestation program. We then also incorporate the prospects for expanding jobs through phasing out fossil fuel imports and substituting domestically produced renewable energy for the fossil fuel imports.

We utilize the government's labor force statistical resources to estimate the wage and benefit levels for the full range of jobs that will be generated through the clean energy transition. These same data sources enable us to estimate the characteristics of workers who are currently employed in these jobs, including both their average educational credentials as well as the share of workers in these sectors who are women. As we will review, at present, the share of female workers is low in all of the sectors connected with Korea's clean energy transition, equal to no more than 20 percent of the workforce in most sectors. But the large-scale employment expansion associated with Korea's clean energy transition should also create conditions for both improving the wages and benefits of all workers in these industries and to significantly expand the share of women who will be holding these newly-created jobs.

Financing Korea's Green Economy Transition

The South Korean government has been actively advancing a range of financing initiatives to promote large-scale clean energy investments, including both green bond and carbon pricing programs. The specific approach to carbon pricing that the government has adopted thus far has been its Emissions Trading Scheme (ETS). As a complementary measure, the government is also considering implementing a direct tax on the use of fossil fuels, i.e. a "carbon tax." It would also eliminate its existing fossil fuel subsidy programs. All three of these measures—the ETS, a carbon tax, and eliminating existing fossil fuel subsidies—will generate revenue that the government can channel into financing clean energy investments. The funds that become available through these measures could be used both to finance direct public investments in clean energy projects and to subsidize private investments. But the scale of financing required will need to be significantly larger than what the government has proposed thus far.

For purposes of illustration, we consider a combination of measures through which the government can realistically mobilize an average of KRW 78 trillion per year between 2022 – 2030, i.e. 3.6 percent of average GDP over these years, as well as KRW 44 trillion per year, 1.4 percent of GDP, between 2031 – 2050. For 2022 – 2030, the three new revenue sources include: 1) transferring KRW 1.6 trillion out of fossil fuel subsidies; 2) transferring KRW 5.5 trillion out of military spending; and 3) generating KRW 27.2 trillion in carbon tax revenues, with 6.8 trillion channeled into clean energy investments. The remaining KRW 20.4 trillion would be rebated directly back to Korean citizens in equal shares.

The total revenues received through these three sources would amount to KRW 13.9 trillion per year, equal to about 18 percent of the KRW 78 trillion needed on average per year to finance the 2022 – 2030 program. The remaining roughly KRW 64 trillion in required investment funds would need to come from private investors. The private investors can be incentivized through a combination of measures. These would include the existing green bond subsidy program, the carbon pricing measures as well as regulations that promote high efficiency and renewable energy and discourage fossil fuel consumption.

Overall, we conclude that the goal of South Korea's Green New Deal program to achieve carbon neutrality by 2050 is realistic. Achieving carbon neutrality by 2050 is also fully compatible with the Korean economy maintaining a healthy economic growth trajectory, thereby creating conditions under which average living standards in the country can continue rising. In particular, the Green New Deal program will generate in the range of 800,000 or more jobs over 2022 – 2030 and about 1 million jobs over 2031 – 2050 as long as the clean energy investment program is sustained.

STUDY HIGHLIGHTS

1. SOUTH KOREA'S 2050 GREEN NEW DEAL PROJECT FOR CARBON NEUTRALITY

The South Korean government is committed to reducing the country's greenhouse gas emissions by more than 40 percent as of 2030 and to becoming carbon neutral by 2050.

- The five "Key Elements" of the government's 2050 Vision "to achieve a green transition" project include:
  - Expanding the use of clean energy and hydrogen across all sectors
  - Improving energy efficiency to a significant level
  - Commercial deployment of carbon removal and other future technologies
  - Scaling up the circular economy to improve industrial sustainability
  - Enhancing carbon sinks
- In a November 2020 study produced in conjunction with the International Energy Agency, the Korean Ministry of Trade, Industry and Energy (MOTIE) set out three policy targets:
  - Implement a Green Transition for Cities, Spaces, and Infrastructure
  - Expand Low-Carbon and Distributed Energy
  - Create an Innovative Ecosystem for Green Industries
- The government's program aligns broadly with a range of independent studies developing proposals for Korea to reach carbon neutrality by 2050.
- This range of research and proposals establishes the framework for the models and estimates developed in this study.

2. CLEAN ENERGY INVESTMENT PROGRAM FOR 2022 – 2030

Energy efficiency and clean renewable energy are the major investment areas for reducing CO_2 emissions by 45 percent by 2030.

- **Energy Efficiency**
  - Building retrofits, electrical grid upgrades, industrial machinery, public transportation, expanding zero-emissions auto fleet
- **Renewable Energy**
  - Solar and wind as primary renewable sources
  - Low-emissions bioenergy, tidal, small-scale hydro and geothermal as supplemental sources
  - Electrification is most efficient way to deliver renewable energy
- **Reforestation to Expand Carbon Sinks as Supplemental Investment Project**

- **Prospects for Energy Efficiency**
  - Reduce energy intensity in Korean economy—i.e. energy consumption/GDP—by 31 percent as of 2030
  - Cost estimate for raising energy efficiency in Korea:
    - *High-end estimate*: KRW 35 trillion per quadrillion British Thermal Units (Q-BTUs) of energy savings
    - "Rebound effect"
      - Assume overall energy consumption rises by 10 percent due to higher efficiency/lower costs
      - Rebound effect is concentrated in industrial sector, with lower production costs increasing export competitiveness

- **Prospects for Renewable Energy**
  - Korean Energy Agency (KEA) estimates Korea's "technical" and "market" potential for Korean renewable energy supply.
    - "Technical potential" is 12 times greater than Korea's 2020 primary energy consumption.
    - "Market potential" is nearly equal to 2020 primary energy consumption.
  - KEA estimates solar and wind to provide 92 percent of Korea's "market potential" renewable supply
  - Current global average costs for renewable-powered electricity are at parity or lower than for fossil fuel-powered electricity.
  - Cost estimate for expanding renewable energy supply in Korea:
    - *High-end estimate:* KRW 213 trillion per Q-BTU of energy

- **Achieving 45 Percent CO_2 Emissions Reduction by 2030**
  - Assume South Korea GDP grows at 2.5 percent per year.
  - KRW 14 trillion per year in energy efficiency investments for 31 percent reduction in energy intensity as of 2030
  - KRW 64 trillion per year in renewable energy investments to expand supply by 2.7 Q-BTUs as of 2030
  - Overall clean energy investment program:
    - KRW 78 trillion per year
    - 3.6 percent of average GDP per year
    - CO_2 emissions fall by 45 percent, to 350 million tons by 2030 from 631 million tons in 2018.
  - Korea reduces nuclear energy production by 15 percent through 2030.

3. CLEAN ENERGY INVESTMENTS, REFORESTATION AND JOB CREATION, 2022 – 2030

Job Creation Estimates

- Job creation through energy efficiency and renewable energy investments:
  - Roughly 790,000 jobs created through KRW 78 trillion per year in investments over 2022 – 2030.
- Job creation through reforestation investments:
  - 2.7 billion trees to be planted by 2050
    - 93 million trees per year on average
  - KRW 631 billion per year in reforestation investment spending
  - Roughly 12,000 jobs created through reforestation investment program over 2022 – 2030.
- Job creation through phasing out fossil fuel imports
  - KRW 6.3 trillion per year in average net import reduction through energy import substitution
  - Roughly 60,000 jobs created per year over 2022 – 2030.
- Total job creation through clean energy and reforestation investments and phasing out fossil fuel imports, 2022 – 2030
  - Roughly 860,000 jobs created over 2022 – 2030.
    - Job creation estimates vary according to whether we assume constant or increasing labor productivity.

Job Quality and Worker Characteristics

Energy Efficiency and Renewable Energy Sectors

- Wages and benefits for energy efficiency and renewable energy sector workers range between KRW 31.1 million in bioenergy and KRW 43.6 million in manufacturing zero-emissions vehicles.
- The share of workers with "regular jobs" ranges from 30 percent in building retrofits to 91 percent in manufacturing zero-emissions vehicles.
- Education credentials of workers:
  - The share with high school degrees or less ranges from 34 percent in industrial efficiency to 65 percent in building retrofits.
  - The share with Bachelor's degrees or higher range from 26 percent in building retrofits to 53 percent in industrial efficiency.
- The share of female workers ranges from 8 percent in building retrofits to 25 percent in electric grid upgrades and bioenergy.

Forestry Sector

- Average pay is KRW 29.3 million
- 43 percent of workers hold "regular jobs"

- Educational credentials of workers:
  - 59 percent of workers have high school degrees or less.
  - 28 percent have Bachelor's degrees or higher
- Women are 24 percent of workforce.

Expansion of job opportunities will support efforts to improve wages, benefits and female employment share.

4. CONTRACTION OF FOSSIL FUEL-BASED INDUSTRIES, NUCLEAR POWER, AND INTERNAL COMBUSTION ENGINE AUTO MANUFACTURING, 2022 – 2030

Fossil Fuel Energy and Related Sectors Employment

- Roughly 140,000 workers are employed in South Korea's fossil fuel-based industries.
- Largest employment sectors include:
  - Gas and oil stations: 45 percent
  - Fossil fuel electricity supply: 23 percent
  - Wholesale distribution of liquid fuels: 10 percent
  - Gas distribution: 10 percent

Job Quality and Worker Characteristics for Fossil Fuel and Related Sectors

- Gas and oil station workers:
  - Average pay is KRW 25.4 million; 41 percent with regular jobs.
  - 63 percent with high school degrees or less; 22 percent with Bachelor's degrees or higher
  - 19 percent are women.
- Other fossil fuel sectors:
  - Average pay is KRW 47.8 million; 85 percent have regular jobs.
  - 35 percent have high school degrees or less; 49 percent have Bachelor's degrees or higher.
  - 14 percent are women.

Job Displacement for Fossil Fuel and Related Sector Workers, 2022 – 2030

- Roughly 3,400 workers per year will be displaced, after accounting for voluntary retirements.

Job Displacement for Nuclear Power Workers, 2022 – 2030

- Nuclear power sector will contract by about 15 percent.
- No workers will be displaced, after accounting for voluntary retirements.

Auto Manufacturing Employment

- Auto manufacturing labor force is roughly 370,000 workers.
- Transition from manufacturing internal combustion engine (ICEV) to zero-emissions vehicles (ZEV) will generate job losses.

- We assume ICEV manufacturing falls by 60 percent by 2030 and is fully phased out by 2035.
- ICEV job displacements will be about 5,200 workers per year between 2022 – 2030.

Overall Job Displacement through Fossil Fuel and Nuclear Phase-Out, 2022 – 2030

- Roughly 8,600 workers per year will be displaced, after accounting for voluntary retirements.
- Just transition policies for all displaced workers per year:
  - Employment guarantees
  - Wage insurance
  - Retraining support
  - Relocation support
  - Pension guarantees

5. REACHING ZERO EMISSIONS, 2031 – 2050

Investment Program to Reduce Emissions to Zero by 2050

- Assume South Korea GDP grows at 2.5 percent per year
- KRW 10 trillion per year in energy efficiency investments for 45 percent reduction in energy intensity as of 2050
- KRW 35 trillion per year in renewable energy investments to expand supply by 3.9 Q-BTUs as of 2050
- Overall clean energy investment program:
  - KRW 44 trillion per year; 1.4 percent of GDP
  - CO_2 emissions fall from 350 million tons in 2030 to zero in 2050.
- South Korea reduces nuclear energy by 55 percent relative to the current level between 2031 – 2050.

Job Creation

- Job creation through clean energy and reforestation investments:
  - Roughly 360,000 – 480,000 jobs created over 2031 – 2050.
- Job creation through phasing out fossil fuel imports:
  - Roughly 510,000 – 670,000 average job creation over 2031 – 2050.
- Overall job creation:
  - An average of roughly 900,000 – 1.2 million jobs created over 2031 – 2050.

Job Displacement through Fossil Fuel Industry Phase-Out

- Roughly 3,000 workers per year displaced in fossil fuel-based and nuclear energy sectors, 2031 – 2050.
- Roughly 11,500 workers per year displaced in manufacturing transition from internal combustion engine vehicles (ICEV) to zero emission vehicles between 2031 – 2035. No further job displacements will occur for ICEV workers between 2036 – 2050.
- Just transition policies needed for all displaced workers.

An Illustrative Financing Framework for Clean Energy Investments, 2022 – 2030

- KRW 78 trillion per year in public and private investment funds needed for 2022 – 2030.
- Public Sources of Investment Funds: KRW 13.9 trillion
    - Converting existing fossil fuel subsidies: KRW 1.6 trillion
    - Transferring 10 percent of military budget: KRW 5.5 trillion
    - Carbon revenue tax revenues: KRW 6.8 trillion
        - Carbon tax revenue rebates to Korean citizens: KRW 20.4 trillion in equal shares
- Private Sources of Investment Funds: KRW 64.1 trillion
    - Policies for incentivizing private investors
        - Subsidized green bond lending
        - Eliminating fossil fuel subsidies
        - Carbon tax
        - Renewable portfolio standards

Green New Deal Project Can Achieve Carbon Neutrality by 2050

- Project fully compatible with:
    - Maintaining healthy economic growth trajectory
    - Expanding job opportunities for workers in wide range of economic sectors and employment categories and for women across categories.

1. SOUTH KOREA'S 2050 CARBON-NEUTRALITY PROJECT

In a series of announcements and reports in 2020 and 2021, the government of the Republic of Korea committed to reduce the country's greenhouse gas emissions by more than 40 percent as of 2030 and to become carbon neutral by 2050. Carbon dioxide accounts for 93 percent of overall greenhouse gas emissions in South Korea. The other two significant sources are methane at 4 percent and nitrous oxide at 2 percent.[10]

In its December 2020 report titled *2050 Carbon Neutral Strategy of the Republic of Korea: Towards a Sustainable and Green Society* the government set out what it termed "Korea's 2050 vision" as follows[11]:

> The Republic of Korea moves towards the goal of carbon neutrality by 2050. The Korean New Deal will serve as a steppingstone to reach carbon neutrality by 2050. Korea will harness green innovations and advanced digital technologies to create synergies between the Green New Deal and the Digital New Deal, the two pillars of the Korean New Deal. Korea will also take decisive action especially in supporting and investing in the development of innovative climate technologies to achieve carbon neutrality by 2050. Tackling climate change requires global efforts and collective engagement. Korea will lead by example to help the international community jointly make efforts to reach carbon neutrality by 2050.

This December 2020 report lists five "Key Elements" of its 2050 Vision "to achieve a green transition." These include:

1. Expanding the use of clean power and hydrogen across all sectors
2. Improving energy efficiency to a significant level
3. Commercial deployment of carbon removal and other future technologies
4. Scaling up the circular economy to improve industrial sustainability
5. Enhancing carbon sinks

These overall green transition goals are also summarized in materials that the Ministry of Trade, Industry and Energy (MOTIE) provided to the International Energy Agency (IEA) for the IEA's November 2020 study, *Korea 2020: Energy Policy Review.*[12] The IEA summarized MOTIE's New Deal project as including these main features:

1. Implement a Green Transition for Cities, Spaces and Infrastructure

- Facilitate zero-energy in public facilities
- Restore the green ecosystem of land, ocean and cities
- Build a clean and safe water management system

2. Expand Low-Carbon and Distributed Energy

- Build smart grids for efficient energy management
- Create a foundation for renewable energy deployment and support a fair transition
- Promote green mobility, such as electric and hydrogen vehicles

3. Create an Innovative Ecosystem for Green Industries

- Develop promising green enterprises and establish low-carbon and green industrial complexes
- Create a foundation for green innovation in the R&D and financial sectors

Subsequent to these late-2020 publications, the Korean government announced in October 2021 that it was raising its emissions-reduction target for 2030 to at least 40 percent relative to its 2018 emissions level. They made this announcement just prior to the opening of the UN Climate Change Conference of the Parties (COP26) in Glasgow, Scotland. Previous to this pre-COP26 announcement, Korea had committed to reducing emissions by 26.3 percent as of 2030. The government also reiterated in its October 2021 announcement its commitment to reach net zero emissions by 2050.[13]

At the COP26 conference itself, President Moon Jae-in affirmed his government's more ambitious emissions reduction targets in his November 1 address to the conference. Moon stated in this address that: "Korea…will cut greenhouse gas emissions by more than 40 percent relative to the level of 2018." Moon also stated that "Korea…will lead connective forest restoration efforts. Trees are living greenhouse gas sinks. Growing trees and reviving forests are important solutions to the climate crisis." Overall, Moon stated that "It is not easy, but the Korean people have decided that now is the time for action. Korea has legislated 2050 Carbon Neutrality and announced relevant scenarios." [14]

The Global Climate Crisis at Present

The Korean government's commitments are in alignment with the current scientific understanding on the state of the global climate and the imperative to advance aggressive climate stabilization projects in all regions of the world. Thus, in August 2021, the Intergovernmental Panel on Climate Change (IPCC), the most authoritative global organization advancing climate change research, published its *Sixth Assessment Report*. Some of the findings documented in this 4,000-page study include the following conclusions:

- The scale of recent changes across the climate system as a whole and the present state of many aspects of the climate system are unprecedented over many centuries to many thousands of years.
- Human-induced climate change is already affecting many weather and climate extremes in every region across the globe. Evidence of observed changes in extremes such as heatwaves, heavy precipitation, droughts, and tropical cyclones, and, in particular, their attribution to human influence, has strengthened since the Fifth Assessment Report.
- Many changes in the climate system become larger in direct relation to increasing global warming. They include increases in the frequency and intensity of hot extremes, marine heatwaves, and heavy precipitation, agricultural and ecological droughts in some regions, and proportion of intense tropical cyclones, as well as reductions in Arctic sea ice, snow cover and permafrost.

The IPCC's Sixth Assessment Report affirmed the conclusions of the alarming report they had published in 2018 titled *Global Warming of 1.5^0*. This report emphasized the imperative of limiting the increase in global mean temperatures to 1.5 degrees above pre-industrial levels as opposed to what had been its previous goal of limiting global warming to 2.0 degrees above pre-industrial levels. The IPCC concluded in 2018 that limiting the global mean temperature increase to 1.5 rather than 2.0 degrees by 2100 will dramatically lower the likely negative consequences of climate change. These include the risks of heat extremes, heavy precipitation, droughts, sea level rise, biodiversity losses, and corresponding impacts on health, livelihoods, food security, water supply, and human security.

The IPCC estimates that to achieve the 1.5 degrees maximum global mean temperature increase target as of 2100, global net CO_2 emissions will have to fall by about 45 percent as of 2030 and reach net zero emissions by 2050. That is, the IPCC's targets for reducing CO_2 emissions are basically the same as those that the Korean government have most recently set—i.e. to cut emissions in Korea by more than 40 percent by 2030 and to achieve carbon neutrality by 2050.

The impacts of climate change have clearly already become increasingly severe in recent years. Thus, the 2019 *State of the Global Climate Report* by the World Meteorological Organization reported that "the physical signs and socio-economic impacts of climate change are accelerating as record greenhouse gas concentrations drive global temperatures towards increasingly dangerous levels." In its 2021 report, some of the evidence presented by the WMO includes the following:

> Exceptional heatwaves affected western North America on several occasions during June and July. Lytton, in south-central British Columbia, reached 49.6 °C on 29 June, breaking the previous Canadian national record by 4.6 °C. 569 heat-related deaths were reported in British Columbia alone between 20 June and 29 July. Death Valley, California reached 54.4 °C on 9 July, equaling a similar 2020 value as the highest recorded in the world since at least the 1930s.
>
> Western Europe experienced some of its most severe flooding on record in mid-July. The worst-affected area was western Germany and eastern Belgium, where 100 to 150 mm fell over a wide area on 14-15 July over wet ground. The highest daily rainfall was 162.4 mm at Wipperfürth-Gardenau (Germany). Numerous rivers experienced extreme flooding, with several towns inundated, and there were also several landslides. 179 deaths were reported in Germany and 36 in Belgium, with economic losses in Germany exceeding US$20 billion.
>
> Extreme rainfall hit Henan Province of China from 17 to 21 July. On 20 July, the city of Zhengzhou received 201.9 mm of rainfall in one hour (a Chinese national record), 382 mm in 6 hours, and 720 mm for the event as a whole, more than its annual average. The city experienced extreme flash flooding with many buildings, roads and subways inundated. 302 deaths were attributed to the flooding, and economic losses of US$17.7 billion were reported.

Similar impacts have emerged in South Korea as well. The 2021 study by Moon et al., "Analyzing climate change impacts on health, energy, water resources, and biodiversity sectors for effective climate change policy in South Korea," summarizes recent developments in Korea as follows:

> The impact of climate change in Korea is growing rapidly, mainly due to typhoons, heavy rains, droughts, cold waves and abnormal temperatures. According to the *2020 Abnormal Climate Report* published by the Korean Meteorological Administration, the number of property damage and casualties was 1.2685 trillion won and 46 lives due to typhoons and heavy rains in 2020,

tripled from the average annual damage…in the past decade. In addition, 6,175 landslides … occurred, the third largest number in history since 1976….Typhoon Maisak caused a power outage in 294,818 houses, nearly double the number of Typhoon Lingling (161,646 homes) in 2019. Winter abnormal temperatures occurred nationwide, and winter temperatures in January were the warmest since 1973, caused many summer insects…and 6,183 hectares of forest damage nationwide (p. 2).

Independent Climate Stabilization Proposals for Korea

The Korean government's Green New Deal plan is in broad alignment with recent studies by independent researchers and non-governmental organizations on Korea's climate stabilization project. The World Wildlife Fund (WWF) published one such study in 2017.[15] This study presents four alternative energy scenarios for Korea through 2050. They include "business as usual," "moderate transition," "advanced transition," and "visionary transition." Under its "visionary transition," Korea reduces its emissions by more than 90 percent as of 2050. By contrast, emissions would decline by roughly 10 percent under business as usual, while the moderate and advanced transitions would reduce emissions by 51 and 69 percent respectively.

The World Wildlife Fund's "visionary transition" includes three major components: 1) To improve energy efficiency, such that Korea's absolute level of energy consumption falls by about 20 percent by 2050 even while the economy's GDP continues to grow; 2) To expand the country's supply of clean renewable energy, achieving 100 percent reliance on renewable energy throughout the economy by 2050; and 3) To electrify the country's transportation system, so that high-efficiency vehicles are powered fully by clean renewable energy.

Similar to the World Wildlife Fund's 2017 study, a 2019 research paper by Professor Jong Ho Hong of Seoul National University and co-authors also develops three alternatives to a business as usual scenario for Korea's energy system, which the authors term as "moderate," "advanced," and "visionary" transition scenarios. Of these three alternatives, Hong et al.'s "visionary scenario" is the only one through which Korea would become a net zero emissions economy by 2050. Similar to the WWF framework, the Hong et al. "visionary" scenario assumes that Korea's absolute level of energy consumption falls by roughly 20 percent as of 2050, even while the economy grows at an average rate of 2.4 percent per year. Again, similar to the WWF framework, 100 percent of the economy's energy consumption is provided by renewable energy sources as of 2050, with nuclear energy as well as all fossil fuel sources having been phased out by 2050.

In February 2021, the Green Energy Strategy Institute published a study by Pilseok Kwon et al. titled, *Deep Decarbonization of Korea's Energy System*.[16] As with the two previously cited publications, this study develops three alternative pathways for dramatically lowering CO_2 emissions in Korea by 2050.[17] The main features of all three scenarios include dramatic increases in energy efficiency and the expansion of Korea's renewable energy capacity. Some specifics of the scenarios are as follows:

Energy Efficiency. All three scenarios assume major gains in energy efficiency through electrification, increases in building efficiency, and gains in transportation efficiency through expanding the supply of electric and fuel cell-powered vehicles and increasing access to public transportation.

CO_2 pricing scenario. This is their reference scenario, developed on the basis of "minimizing policy interventions." The policy changes introduced in this scenario are a) CO_2 pricing; and b) technological cost reductions through innovation. The objective of this scenario is to estimate how much emissions can be reduced with these two basic measures.

Hydrogen plus scenario. This scenario assesses the impact of hydrogen energy expansion on the energy system. The authors write that "The government announced the Hydrogen Economy Roadmap which targets a significant amount of hydrogen production by 2040. In addition to the two reduction measures assumed in the CO_2 pricing scenario, the Hydrogen Plus scenario adopts more hydrogen demands according to the Hydrogen Economy Roadmap rather than direct electrification," (p. 10).

Absolute Zero scenario. This scenario achieves zero emissions through expanding solar and wind capacity at what the authors estimate is a maximum expansion rate of 22 GW per year, while hydrogen and electricity are utilized increasingly in Korea's industrial sector.

According to Kwon et al., their Absolute Zero scenario is the only one in which Korea does reach zero emissions by 2050. But under the other two scenarios, they estimate that emissions will still fall by at least 90 percent by 2050.

Overall, the range of policy proposals, scenarios, and research findings that we have briefly reviewed in this section will establish the framework for the models and estimates that we present in the next sections of this study.

2. A CLEAN ENERGY INVESTMENT PROGRAM FOR 2022 – 2030

The program we develop for this study will enable South Korea to achieve its primary climate stabilization goals—i.e. to reduce CO_2 emissions by at least 40 percent as of 2030 and to become a carbon neutral economy by 2050. Our proposal builds from the main features of the Korean government's reports over the past two years as well as the various studies that we reviewed in the previous section. As of this writing, the most current published figures for CO_2 emissions in South Korea are those for 2018. As of these 2018 figures, Korea's total CO_2 emissions were at 631 million tons.[18] Reducing emissions by more than 40 percent will mean that emissions need to be less than 379 million tons by 2030.

All versions of a climate stabilization program for Korea, or any other country, necessarily begin with a plan for phasing out the country's reliance on oil, coal, and natural gas to generate energy. At present, Korea depends on fossil fuel energy sources to provide about 84 percent of its total energy supply.[19] Korea also consumes large supplies of both coking coal for steel production and oil in the petrochemical industry. However, the consumption of fossil fuel as raw material inputs in steel and plastics production generates relatively small amounts of CO_2 emissions in comparison with those generated through fossil fuel combustion.[20] Our study therefore focuses only on phasing out Korea's consumption of fossil fuels for the purpose of producing energy.

Following from the government emissions reduction goals and the studies reviewed above, the zero emissions program we develop is incorporated into a macroeconomic framework in which the Korean economy proceeds along a healthy long-run growth trajectory over the full period through 2050, when the economy reaches the zero emissions target. Specifically, we assume that the South Korean economy grows between 2022 – 2050 with an average GDP growth rate of 2.5 percent per year.[21]

Our program has two major areas of focus. The first is to dramatically increase investments that will raise energy efficiency levels in all areas of economic activity, i.e. the operations of buildings, transportation systems and industrial equipment. Specific efficiency investment targets include building retrofits, electrical grid upgrades, industrial machinery, including combined heat and power systems, public transportation expansions and upgrades, and expanding the zero-emissions automobile fleet. The second area of focus is to dramatically increase the supply of clean renewable energy sources, including especially solar and wind power but also low-emissions bioenergy, tidal energy, small-scale hydro and geothermal power. Increasing the Korean economy's reliance on renewable energy sources also entails correspondingly raising the share of energy that is delivered in the form of electricity. This is because electrification is the most efficient way to deliver most renewable energy supplies. We do also examine the potential for lowering emissions through increasing the country's carbon sinks, in particular through investments in reforestation as described in recent government proposals.

We also incorporate a role for hydrogen in our framework. We do not assume it will be able to scale up as soon as, or at a rate comparable to, investments in renewable energy. This is because, at present, unlike renewables, hydrogen fuel technology is not close to achieving cost competitiveness relative to fossil fuel energy. Nevertheless, the Korean government and some private firms are investing in developing cost-competitive hydrogen energy capacity. There is also significant interest, especially from Hyundai Motors, in manufacturing hydrogen fuel cell vehicles. The Korean government is projecting that hydrogen will account for 5 percent of the economy's power supply by 2040 and grow thereafter. Within the program we develop for reaching zero emissions by 2050, we assume that hydrogen will contribute, though not at a scale comparable to those for investments in energy efficiency, clean renewable energy or electricity-powered vehicles. In any case, to produce "green hydrogen" still requires clean renewable energy as an input, which then is converted into hydrogen fuel through an electrolyzer. "Gray hydrogen" will still produce CO_2, and therefore cannot be incorporated into a zero emissions program. Through reviewing the recent literature and news reports, we assume that Korea's advances in this area, at least through 2050, will be primarily through the downstream manufacturing of hydrogen fuel cell vehicles rather than the upstream production of hydrogen energy itself.[22]

At present, the major energy source for the South Korean economy other than fossil fuels is nuclear power. As of 2020, nuclear was providing about 16 percent of Korea's overall primary energy supply. On taking office in 2017, President Moon committed to phasing out nuclear power. However, nuclear capacity has not declined during the Moon presidency. It is also not clear that Moon's commitment to phase out nuclear will maintain sufficient political support over the coming decades.[23]

For the purposes of our study, we assume that Korea will reduce its current level of nuclear energy consumption of about 1.3 Q-BTUs to 1.1 Q-BTUs by 2030, in accordance with the timeline currently set out by the government. We then assume that Korea's nuclear energy consumption will reduce further to 0.6 Q-BTUs over 2031 – 2050.[24] In terms of Korea becoming a zero-emissions economy by 2050, nuclear energy, has the benefit of generating no CO_2 emissions in producing energy. At the same time, nuclear energy creates a separate set of serious environmental and public safety problems. These problems are associated with radioactive waste, storage of spent reactor fuel, nuclear reactor meltdowns and the political risks resulting from nuclear proliferation.[25] The Moon government's plan to phase out nuclear energy reflects this range of environmental and public safety concerns.

The emissions reduction program that we develop is relatively simple and transparent, building from the literature that we have reviewed in Section 1 above. Working with this relatively simple energy transition and economic growth model facilitates our work in examining the second major set of issues on which we focus. These are the impacts on employment of both the sustained large-scale investments in energy efficiency and clean renewable energy as well as the phase-out of the fossil fuel industries.

One main source of employment expansion will be through the investment spending undertaken in energy efficiency and renewable energy projects. The additional significant channel for employment expansion is through reducing South Korea's heavy reliance on imported energy. Employment in Korea will increase as the country shifts increasingly from spending on imported energy into spending on domestically produced renewable energy. Investments in reforestation will also create new job opportunities. But the levels of spending being discussed thus far for this program, by the government and more generally, have been small. The impact on job creation would therefore be similarly modest.

Even though Korea imports virtually all of the energy it consumes, the phase out of fossil fuels will nevertheless produce job losses within its domestic labor market, in sectors such as fossil fuel electricity generation and distribution, crude oil refining, and the operation of gasoline filling stations. The contraction of nuclear power production will also produce job losses within this industry. We will also examine the extent of job losses that will result in South Korea's large auto manufacturing sector through transitioning away from internal combustion engine vehicle production in favor of building electric and fuel cell-powered vehicles. Korea fully intends to remain as a major automobile manufacturer, as the industry transitions from internal combustion engine vehicles towards zero emission vehicles, including both electric and hydrogen-powered cars. But manufacturing zero emissions vehicles requires about 11 percent fewer workers per vehicle than manufacturing internal combustion engine vehicles. In addition, the specific features of the work to build zero emission vehicles are, in some areas, distinct from those for internal combustion engine vehicle manufacturing.

The estimates that we provide for both job creation and job losses will then establish a framework for the Korean society to develop just transition policies for the workers who will be negatively impacted as the economy advances towards achieving its zero emissions goal.

Prospects for Energy Efficiency

Energy efficiency entails using less energy to achieve the same, or even higher, levels of energy services from the adoption of improved technologies and practices. Examples include insulating buildings much more effectively to stabilize indoor temperatures; driving more fuel-efficient cars or expanding well-functioning public transportation systems; and reducing the amount of energy that is wasted through operating industrial machinery and transmitting electricity over the grid. Expanding energy efficiency investments supports rising living standards because raising energy efficiency standards, by definition, saves money for energy consumers.

In 2*050 Carbon Neutral Strategy of the Republic of Korea*, the government highlighted the centrality of energy efficiency investments as one of five "key elements" for achieving its 2050 carbon neutral goal. The report states:

> "Energy efficiency" is by far the most eco-friendly and economical energy resource. Improving energy efficiency saves costs for businesses, making them more competitive in the market. With this enhanced competitiveness, companies could produce highly efficient products, which ultimately contributes to the overall industrial growth. It is a highly economical strategy that could also help reduce energy consumption. In the absence of natural resources, improving energy efficiency is one of the most essential strategies for Korea, especially in relation to its energy security. Once energy efficiency is improved, it will ultimately lead to a decreased energy supply. Compared with the huge upfront cost of developing ESS [energy storage] and hydrogen technologies, improving energy efficiency is the most cost-effective option that should be considered as a policy instrument. There are a number of time-tested solutions that are effective in improving energy efficiency: enhancing vehicle fuel efficiency, strengthening building insulation, using highly-efficient appliances and deploying a smart energy management system. These solutions are already in use or readily available for all sectors from the government to industry to the public. The Government's clear policy vision for improved energy efficiency along with balanced regulations and incentives will encourage active engagement and efforts from all sectors and ultimately help achieve a significantly improved energy efficiency (p 49).

The government's Energy Efficiency Innovation Strategy, developed in 2019 by the Ministry of Trade, Industry and Energy (MOTIE) describes major policy initiatives in the three areas—buildings, transportation, and industry—in which energy is consumed.[26] These initiatives include:

Buildings

- Subsidize top energy efficient appliances.
- Launch Energy Rebuilding.
- Benchmark Energy STAR building efficiency standards:
  - public buildings by 2022;
  - commercial buildings by 2024.
- Phase out fluorescent lamps by 2027.

Transportation

- Roll out Cooperative-Intelligent Transport Systems.
- Deploy Mobility as a Service, with a pilot project.
- Reinforce the fuel economy standard:
  - 28.1 km/L for passenger vehicles by 2020;
  - Adopt a standard for heavy vehicles by 2022.

Industry

- Install 1,500 Factory Energy Management Systems by 2030.
- Build 20 smart energy industrial complexes and 40 energy efficient local communities by 2030.
- Voluntary Energy Intensity Reduction Agreement: 1 percent annual improvement for companies above 2,000 tons of energy consumption per year.

Through these and related measures, the government has targeted reductions gains in energy efficiency (i.e. reductions in the energy intensity of economic activity, measured as energy consumption per unit of GDP) by 27 percent as of 2030, with further significant gains continuing until 2050.

This trajectory for efficiency gains in the Korean economy are fully consistent with the projections of the International Energy Agency for global efficiency gains through 2050. According to the IEA's "Zero Emissions by 2050 Scenario," global energy consumption falls at an average annual rate of -0.6 percent per year between 2020 – 2050 while GDP grows at 3.0 percent, (IEA 2021, p.310).

Estimating Costs of Efficiency Gains

How much will it cost to achieve such major efficiency gains in South Korea? Recent studies focused on efficiency investments in the East Asia region and Korea specifically do not break out cost estimates for efficiency investments explicitly.[27] Earlier studies considering the U.S. and global economies vary widely in their estimates. For example, a 2010 study by the National Academy of Sciences estimated average costs for building, transportation and industrial efficiency improvements in the United States at KRW 34.2 trillion won ($29 billion) per Q-BTU of energy savings (hereafter we refer to the Korean currency interchangeably as "won" or more often "KRW").[28] More recent studies in 2014 and 2016, focused on the U.S. building sector alone, report similar cost estimates.[29] By contrast, a 2008 World Bank study by Taylor et al. puts average costs at KRW 2.2 trillion ($1.9 billion) per Q-BTU of energy savings, based on a study of 455 projects in both industrial and developing economies, a figure that is only 7 percent of the U.S. National Academy of Sciences estimate. A 2010 study by the McKinsey consulting firm estimates costs for a wide range of non-OECD economies at KRW 13.0 trillion ($11 billion) per Q-BTU of energy savings.

It is not surprising that average costs to raise energy efficiency standards should be significantly higher in industrialized economies. A high proportion of overall energy efficiency investments are labor costs, especially projects to retrofit buildings and industrial equipment. However, these wide differences in cost estimates between the various studies do not simply result from variations in labor and other input costs by region and levels of development. For example, the World Bank estimate of KRW 2.2 trillion ($1.9 billion) per Q-BTU includes efficiency investment projects in both industrialized and developing countries.

These alternative studies do not provide sufficiently detailed methodological discussions that would enable us to identify the main factors generating these major differences in cost estimates. But it is at least reasonable to conclude from these figures that, with on the ground real-world projects, there are likely to be large variations in costs down to the project-by-project level. Thus, the costs for energy efficiency investments that will apply in any given situation will necessarily be specific to that situation, and must always be analyzed on a case-by-case basis. At the same time, for our present purposes, we need to proceed with some general rules-of-thumb for estimating the level of savings that are attainable through a typical set of efficiency investments in South Korea.

A conservative approach is to use the high-end U.S. National Academy of Sciences estimate as a baseline figure for Korea, at KRW 34.2 trillion per Q-BTU of energy savings through efficiency investments. Korea will certainly be able to achieve efficiency gains at lower per-unit costs through their initiatives in digitization of energy systems and related innovations. At the same time, the costs of efficiency gains will necessarily increase after an initial period of replacing the most inefficient equipment and practices has been completed. Given that, if anything, we would want to err by overestimating rather than underestimating costs for the purposes of our analysis. Therefore, we will assume here that the average costs through 2050 will be KRW 35 trillion to achieve one Q-BTU of energy savings in Korea.

Rebound Effects

Raising energy efficiency levels will generate "rebound effects"—i.e. energy consumption increases resulting from lower energy costs. An example of a rebound effect is when people travel more frequently and/or greater distances in their automobiles because the energy costs of operating their cars will have fallen through efficiency gains. Similarly, people could heat, light, or cool their homes to a greater extent because of the reduced costs resulting from efficiency gains. Another example would be manufacturers operating their equipment more extensively because of the reduced costs of doing so.

Because South Korea is advancing a comprehensive efficiency project within their broader Green New Deal framework, it is unlikely that a large economywide rebound effect will emerge as the efficiency gains are achieved.[30] For example, gains in automobile efficiency could encourage more driving. But the government's transportation efficiency program also includes increasing the availability of high-quality public transportation. This should offset any increases in private automobile traveling by private vehicle owners. In the case of residential energy consumption, it is unlikely that most Koreans will choose to heat, light or cool homes, or make use of computers or home appliances to a significantly greater extent due to reduced energy costs, since these uses of energy are, in most cases, close to saturation points.

The situation should be different in the case of industrial energy efficiency gains. Lower energy costs in industry could enhance the competitiveness of Korean firms. This could, in turn, increase demand for Korea's industrial products. Of course, it is also possible that other countries will be increasing their levels of industrial efficiency to an extent comparable with Korea. If so, this would offset Korea's industrial efficiency advantage, and correspondingly weaken or eliminate altogether the potential for an industrial rebound effect in Korea. However, to work with high-end assumptions as to Korea's overall energy demand level during its clean energy transition, we will allow that Korea's industrial efficiency gains do increase the economy's export competitiveness, and thereby generates a rebound effect in the economy's overall energy demand.

Consumption of energy in Korea's industrial sectors amounts to about one-third of total energy consumption in Korea.[31] This industrial demand for energy is distinct from the industrial consumption of fossil fuels *as non-energy inputs*, including oil as a petrochemical feedstock and coal as a coal production feedstock. For our purposes, again as a high-end assumption, we allow for a large rebound effect, of 30 percent, in industrial energy consumption resulting from energy efficiency gains in the sector. This industrial sector rebound effect would then generate an overall rebound effect of approximately 10 percent for the overall Korean economy (i.e. 0.33 x 0.3 = 0.099). That is, after taking account of the gains in energy efficiency in the Korean economy resulting through efficiency investments, we will assume that economywide energy consumption will rise by 10 percent resulting from this industrial sector rebound effect.[32]

Prospects for Clean Renewable Energy

Building a renewable-dominant energy infrastructure in Korea is central to the country's program to reach carbon neutrality by 2050. The government's December 2020 report *2050 Carbon Neutral Strategy of the Republic of Korea* states this view explicitly:

> In achieving the 2050 Vision, the most important key element is an accelerated energy transition towards carbon neutrality. Solar, wind, hydro, and other types of renewable energy should be the central sources of energy supply (2020, p. 48).

In support of this vision, the most recent estimates of the Korea Energy Agency (KEA) as to the potential for building a renewable-dominant energy infrastructure are highly favorable. Table 2.1 shows the KEA's estimates of both the "technical potential" and "market potential" for renewables as a *primary energy* supply as of 2020. Technical potential refers to what the KEA estimates is feasible relative to engineering considerations and geographic constraints in Korea. Market potential takes account of the level of renewable energy that can be produced on a cost-competitive basis, after incorporating what the KEA considers to be realistic levels of government policy support for renewables. For example, the KEA esti-

TABLE 2.1
South Korea's Estimated Renewable Energy Potential
Technical and Market Potential for Primary Energy
2020 Estimate by Korea Energy Agency

Shares of potential energy by energy source	Technical potential = 109.8 Q-BTUs	Market potential = 7.7 Q-BTUs
Solar	70.8%	73.6%
Wind	14.9%	18.5%
Geothermal	7.2%	3.1%
Ocean	5.9%	0%
Bioenergy	0.5%	0.3%
Waste	0.2%	3.5%

Note: "Technical potential" is the amount of energy available when reflecting geographic and technical influencing factors among theoretical potentials. "Market potential" is the amount of energy practically available when applying economic and policy factors (subsidies, regulations) on the technical potential.
Source: Korea Energy Agency (2021).

mates that the technical potential for all renewable energy sources from the ocean—including tidal currents, tidal power, waves, ocean thermal energy conversion (OTEC) and seawater air conditioning—is 6.5 Q-BTUs. Yet the KEA concludes that none of these ocean sources of renewable energy have reached a stage of development where they have market potential. The KEA also gives estimates for renewables as *final energy* sources. The results on final energy are comparable to those shown in Table 2.1 for primary energy.[33]

As Table 2.1 shows, the KEA's estimate for renewables' technical potential as a source of primary energy supply is 109.8 Q-BTUs. This figure is *12 times greater* than Korea's total primary energy consumption as of 2020, at 8.7 Q-BTUs. The KEA's estimates of the market potential for renewables is much lower than the technical potential figure, at 7.7 Q-BTUs, precisely because it incorporates the KEA's assessment of competitive market considerations as well as engineering and geographic factors in developing renewables in Korea. This market potential figure amounts to only about 7 percent of technical potential. Yet, as we show below, the 7.7 Q-BTU figure is still equal to nearly 90 percent of our estimate of total primary energy consumption as of 2030 under the zero-emissions-by-2050 scenario, and is modestly greater than our estimate of total primary energy consumption in Korea as of 2050 under the zero emissions scenario. In short, we can see from this most recent KEA estimate that Korea does clearly have the potential to develop a 100 percent clean renewable energy infrastructure by 2050.

As Table 2.1 shows, the KEA estimates that most of the country's renewable energy supply will be provided by solar and wind power. Solar power accounts for about 74 percent of market potential while wind is at 19 percent. Therefore, according to the KEA, solar and wind combine to provide about 93 percent of the renewable energy supply after taking account of expected market conditions and the government's policy priorities.

The strong market potential that the KEA anticipates for renewables in Korea, especially solar and wind power, is consistent with the pattern of declining costs on a global basis for renewables over the past decade. These cost declines have brought most renewable sources to cost parity or lower than fossil fuel energy sources for generating electricity.

Table 2.2 shows the most recent figures reported by the International Renewable Energy Agency (IRENA), for 2010 and 2020, on the "levelized costs" of supplying electricity through alternative energy sources. Levelized costs take account of *all costs* of producing and delivering a kilowatt of electricity to a final consumer. The cost calculations begin with the upfront capital expenditures needed to build the generating capacity, including both fixed and variable operations and maintenance costs, and continue through to the transmission and delivery of electricity. These costs include the energy that is lost during the electricity-generation process.

As we see in Table 2.2, the levelized costs for fossil-fuel generated electricity ranged between KRW 65 and KRW 175 per kilowatt hour as of 2020 in the G-20 countries. The average figures for the seven clean renewable sources are all within this range for fossil fuels as of 2020 or lower. As we see, solar PV is at KRW 67, concentrated solar power is at KRW 128, onshore wind is at KRW 46, offshore wind is at KRW 99, bioenergy is at KRW 90, hydro is at KRW 52 and geothermal is at KRW 84. Moreover, the costs of solar and wind power fell sharply between 2010 – 2020, led by the massive 85 percent decline in solar PV. These average cost figures for solar and wind should continue to decline still further as advances in technology and economies of scale proceed along with the rapid global expansion of these sectors. By contrast, the costs of bioenergy remained flat between 2010 – 2020, at KRW 90. The costs of hydro and geothermal actually rose between 2010 – 2020, though their 2020 costs are still low, at KRW 52 and KRW 84 respectively, relative to the fossil fuel range.

We emphasize that these cost figures from the IRENA are global and annual averages. They do not show differences in costs due to regional or seasonally-specific factors.[34] In

TABLE 2.2
Average Global Levelized Costs of Electricity from Utility-Scale Renewable Energy Sources vs. Fossil Fuel Sources, 2010 – 2020

Average levelized costs in 2020 for fossil-fuel generated electricity in G-20 countries: KRW 65 to 175 per kilowatt hour

	2010	2020	Percent change, 2010 – 2020
Solar PV	KRW 438	KRW 67	-85%
Concentrated solar power	KRW 402	KRW 128	-68%
Onshore wind	KRW 105	KRW 46	-56%
Offshore wind	KRW 191	KRW 99	-48%
Bioenergy	KRW 90	KRW 90	0
Hydro	KRW 45	KRW 52	+16%
Geothermal	KRW 58	KRW 84	+45%

Source: International Renewable Energy Agency (2021).

particular, solar and wind energy costs will vary significantly by region and season. Moreover, both solar and wind energy are intermittent sources—i.e. they only generate energy, respectively, when the sun is shining or the wind is blowing. The issues of energy storage will become significant as Korea approaches the net zero emissions goal by 2050. Over the decade 2021 – 2030, these issues will not be pressing. This is because fossil fuels and nuclear energy will be supplying over 90 percent of Korea's total energy supply as of 2021, with that figure still maintained at over 60 percent as of 2030, even as Korea achieves a major expansion in renewable supply along with major gains in efficiency. Thus, the economy's baseload energy sources will continue to be fossil fuels and nuclear through 2030 and several years beyond.

Keeping all such considerations in mind, we can still roughly conclude from these figures that, for the most part, clean renewable energy sources are rapidly emerging into a position at which they can produce electricity at comparable or lower costs than non-renewable sources in Korea. As such, assuming that solar and wind, along with other supplemental renewable sources, can be scaled up to meet all the economy's energy demand by 2050, then the costs to consumers of purchasing this energy should be *lower* than what they would have been from fossil fuel sources, probably significantly lower. It is critical to also emphasize that this is *without* factoring in the environmental costs—starting with global warming—of burning oil, coal, and natural gas to produce energy.

Costs of Expanding Renewable Capacity

With most clean renewable technologies, the largest share of overall costs in generating electricity is capital costs—i.e. the costs of producing new productive equipment, as opposed to the costs of operating and maintaining that productive equipment once it has been built and is generating energy. These capital costs are between 71 – 75 percent for solar, wind, and hydro power. They are somewhat lower, at 54 percent for geothermal power, and lower still, at 42 percent for low-emissions bioenergy.[35] But even with bioenergy, capital costs are still the largest cost component.[36] From these figures on levelized costs, we can also estimate the capital costs of installing renewable energy capacity as a lump sum—i.e. how much investors need to spend *upfront* to put this capital equipment into place and in running order.

Estimates of capital costs vary by source, with widely-cited sources including the International Energy Agency (IEA), IRENA and the U.S. Energy Information Agency. Estimates can also vary significantly by region. For example, the most recent IEA estimates of capital costs for solar PV installations in the U.S. are 70 – 80 percent higher than those in China and India.[37] We are not aware of estimates on capital costs for renewables that are specifically focused on South Korea. Thus, for our purposes of estimating likely capital costs in South Korea, it will be prudent to work with the higher-end figures for the U.S. case. We work here, again, with the same principle as with our energy efficiency cost estimates—that, if anything, we will want to err by over- rather than underestimating capital costs of expanding renewable capacity.

In Table 2.3, we report the most recent 2021 figures from the U.S. Energy Information Agency on lump sum capital costs. Specifically, these figures represent the present values of total lump-sum capital expenditures needed to produce one Q-BTU of electricity from these various utility-scale clean renewable sources.[38] As we see, these cost figures are KRW 115 trillion for solar PV, KRW 130 trillion for onshore wind, KRW 175 trillion for low-emissions bioenergy, KRW 90 trillion for geothermal, and KRW 163 trillion for small-scale hydro.

TABLE 2.3

Capital Expenditure Costs for Building Renewable Electricity Productive Equipment

Present values of total lump-sum capital costs per Q-BTU of electricity

Solar PV	KRW 115 trillion
Onshore wind	KRW 130 trillion
Low-emissions bioenergy	KRW 175 trillion
Geothermal	KRW 90 trillion
Small-scale hydro	KRW 163 trillion
Weighted average costs *Assuming investments are 65% solar, 30% wind and 5% for all other sources combined*	**KRW 121 trillion**

Sources: U.S. Energy Information Administration (2021, February). See Pollin et al. (2014) pp. 136 – 37 for methodology in converting levelized costs per Q-BTU into lump-sum capital costs.

As an initial approximation at generating a weighted average of these respective capital costs, we work from assumptions based on consultations with Dr. Pil Seok Kwon, Director of the Green Energy Strategy Institute. Following from these consultations, we assume that over 2022 – 2030, Korea's renewable energy infrastructure will develop along roughly these proportions: 65 percent solar energy, 30 percent wind energy, and 5 percent for all other renewable sources. With these relative proportions, a weighted average of the capital costs for expanding the clean renewable energy supply by 1 Q-BTU would be KRW 121 trillion, as we show in Table 2.3.

This KRW 121 trillion figure can serve as a benchmark for estimating the average costs of expanding the supply of clean renewable energy in Korea. At the same time, we recognize that Korea is actively advancing investment prospects in a wider range of more specific renewable energy sources.[39] These include the following:

- Solar, onshore, community, commercial, residential
- Solar, onshore utility scale
- Solar, offshore utility scale
- Wind, offshore
- Wind, onshore
- Low-emissions bioenergy
- Tidal
- Small-scale hydro
- Geothermal

The capital costs for the smaller-scale or less well-developed renewable sources will be higher than the averages we report in Table 2.3. In particular, the figures for solar and wind energy in Table 2.3 are for utility-scale projects only. But, still focusing on U.S.-based data, the National Renewable Energy Lab estimates that in 2020, the total levelized costs of residential solar PV are 2.5 times higher than those for utility scale PV, and commercial rooftop PV costs are about 70 percent more expensive than utility scale PV.[40] We clearly need to take account of these large cost differences in capital costs between the specific renewable energy technologies.

Thus, still working from consultations with Dr. Kwon of the Green Energy Strategy Institute, we assume that the more detailed breakdown of Korea's renewable energy infrastructure over 2022 – 2030 will be in the proportions we show in Table 2.4.

That is, we assume that of the 65 percent of overall investments in solar, 35 percent of the 65 percent will be in onshore community, commercial and residential projects; 25 percent will be in onshore utility scale projects; and 5 percent will be in offshore utility scale operations. With the 30 percent total in wind energy projects, we assume that 14 percent will be in offshore platforms and 16 percent will be onshore. We then assume that the remaining 5 percent of overall renewable energy supply will be provided, in equal 1.25 percent proportions, between low-emissions bioenergy, tidal, small-scale hydro and geothermal.

Because Korea is committed to an innovative program that incorporates this wider range of renewable platforms, we should assume that the upfront capital costs will be greater than our KRW 121 trillion benchmark figure. We also need to take account of other factors influencing costs as Korea builds out its renewable capacity. One consideration is that, with the build-out of the clean energy supply proceeding rapidly throughout the global economy, over the next decade and beyond, the average costs are likely to rise as production bottlenecks emerge. In addition, our benchmark figure does not include the costs of storing energy from the intermittent energy sources, i.e. solar and wind power. In turn, solar and wind will be the two most significant renewable energy sources for Korea. The additional storage costs of delivering solar and wind power therefore need to be incorporated into the overall cost estimates.

For this combination of reasons, we work with the assumption that the average costs of expanding the supply of clean renewable energy in South Korea will initially be at KRW 236 trillion ($200 billion) per Q-BTU, i.e. about 95 percent higher than our KRW 121 trillion average benchmark figure. From this initial average figure, we will then incorporate assumptions on an average rate of cost reductions, both through the initial investment phase through 2030, then over 2031 – 2050. Specifically, we will work with a conservative assump-

TABLE 2.4
Assumptions for South Korea Clean Renewable Investment Proportions

Solar investments	**65%**
Solar, onshore, community, commercial, residential	35%
Solar, onshore utility scale	25%
Solar, offshore utility scale	5%
Wind investments	**30%**
Wind, offshore	14%
Wind, onshore	16%
Additional renewable investments	**5%**
Low-emissions bioenergy	1.25%
Tidal	1.25%
Small-scale hydro	1.25%
Geothermal	1.25%

tion again, that, starting with the KRW 236 trillion per Q-BTU capital cost figure, costs will decline at an average rate of 1.5 percent per year through the full period 2022 – 2050. The midpoint cost figure for the 2022 – 2030 period will therefore be KRW 213 trillion ($180 billion). This is the figure we show in Table 2.7.[41]

Achieving a 45 Percent CO_2 Emissions Reduction by 2030

The 9-year clean energy investment initiative that we describe in this section is designed to achieve, again, two interrelated goals supported by both the government itself and a range of NGOs and research studies. The first is to bring total CO_2 emissions in South Korea down by at least 40 percent by 2030. So as not to underestimate the investment requirements necessary to achieve the 40 percent emissions reduction goal, we have targeted a 45 percent reduction relative to the 2018 emissions level. In absolute figures, this means reducing CO_2 emissions from the 2018 level of 631 million tons to 350 million tons.[42]

The second goal is to advance this climate stabilization program while the South Korean economy grows at a healthy rate between now and 2030, so that existing jobs are protected, job opportunities expand, and average well-being rises throughout the country. In this section of the study, we describe the clean energy investment initiatives that will be needed to bring together these two goals.

To explore the prospects for achieving the 2030 emissions reduction goal within the context of a growing Korean economy, we must, of course, work with some assumptions as to the country's real economic growth trajectory between 2022 – 2030. Thus, we assume that the South Korean economy will grow in real (i.e. inflation-adjusted) terms between 2022 and 2030 at an average rate of 2.5 percent per year. This figure is close to the 2.4 percent growth assumption in the KEEI's energy growth model.[43]

In Table 2.5, we first report on South Korea's real GDP as of 2020 (expressed in 2020 KRW) and the projected level in 2030, assuming the economy's average real growth rate is maintained at 2.5 percent through 2030. We see that, under this growth assumption, Korea's real GDP will be KRW 2,419 trillion in 2030. The midpoint year between 2022 – 2030 will be 2026. Korea's real GDP will be at KRW 2,192 trillion at that midpoint, assuming a 2.5 percent average GDP growth rate.

Within this framework, we can then project an energy and CO_2 emissions profile for South Korea for 2030. We consider two distinct scenarios, which we present in Table 2.6.

TABLE 2.5
GDP Level for 2020 and Projections for 2026 and 2030
Figures are in 2020 KRW

2020 GDP	KRW 1,890 trillion
Projected average growth rate through 2030	2.5%
Projected 2030 GDP	KRW 2,419 trillion
Projected midpoint GDP in 2026	KRW 2,192 trillion

Source: KEEI and authors' calculations.

TABLE 2.6
South Korea Energy Consumption and Emissions:
2018/2020 Actuals and 2030 Alternative Projections

	1) 2018/2020 actuals	2) 2030 with Business-as-Usual energy infrastructure *(= categories grow at 2.5% average annual rate)*	3) 2030 through Clean Energy Investment Program
1) Real GDP 2020	KRW 1,890 trillion	KRW 2,419 trillion	KRW 2,419 trillion
2) Energy intensity ratio *(Q-BTUs consumption/KRW 1,000 trillion of GDP)*	4.6	4.6	3.1
3) Energy consumption in 2019 *(Q-BTUs)*	8.7	11.1	7.9 *(7.6 with efficiency gain; 10% rebound effect)*
Energy Mix for Supply			
4) Non-renewables and bioenergy *(Q-BTUs—rows 5-9)*	*8.6*	*11.0*	*5.1*
5) Petroleum	2.6	3.3	1.4
6) Coal	2.6	3.3	1.4
7) Natural gas	2.1	2.7	1.2
8) Nuclear	1.3	1.7	1.1
9) High-emissions bioenergy	0.03	0.04	0.02
10) Clean renewables *(Q-BTUs = row 3 – row 4)*	*0.1*	*0.1*	*2.8*
11) Solar	0.04	0.05	1.8
12) Wind	0.01	0.01	0.8
13) Hydro	0.01	0.01	.05
14) Tidal	0.01	0.01	.05
15) Low-emissions bioenergy	0	0	.05
16) Geothermal	0	0	.05
Emissions			
17) Total CO_2 emissions *(million metric tons)*	631	808	350
18) Emissions intensity ratio *(CO_2 emissions per consumed Q-BTUs = row 17 / row 3)*	72.6	72.6	44.3

Note: Assumes 3.1 energy intensity ratio plus 10 percent overall rebound effect, with most of the rebound coming from industry. Rebound effect calculated as: (11.1 Q-BTUs - 7.6 Q-BTUs) x 0.10. See endnote 32.

Sources: For non-renewables and nuclear: KEEI (2021), see "Total Primary Energy Supply" table. For renewables: U.S. EIA (n.d.), "International -- South Korea."

Specifically, in column 1 of Table 2.6, we first show the actual breakdown of energy consumption and emissions as of 2018/2020. In column 2, we then present projected figures, assuming the Korean economy grows at an average annual rate of 2.5 percent through 2030 and the economy's energy infrastructure remains basically intact. We term this the "Business-as-Usual" (BAU) energy infrastructure trajectory for Korea. In this scenario, Korea's existing energy sources all grow at exactly the economy's overall 2.5 percent annual GDP growth rate. In column 3, we then present figures through which Korea reduces emissions by 45 percent as of 2030 while maintaining its average annual GDP growth rate of 2.5 percent.

Within this overall set of assumptions, it follows that, under the BAU scenario, Korea's energy intensity ratio remains at its 2018 level of 4.6 Q-BTU's per KRW 1,000 trillion in GDP. The country's emissions intensity ratio also remains unchanged, at 72.6, as shown in row 18, columns 1 and 2. Given the BAU assumption of a stable energy infrastructure between 2018 and 2030 while the economy grows at 2.5 percent per year, we then see the impact on Korea's CO_2 emissions in row 17 of Table 2.6. That is, total CO_2 emissions increases from 631 to 808 million tons, an increase of 28 percent.

In column 3 of Table 2.6, we then show the impact on the energy mix and emissions levels of a clean energy program focused on bringing down CO_2 emissions to 350 million tons by 2030. The first component of this program is energy efficiency investments. As noted above, we assume energy efficiency investments will span across the building, transportation and industrial sectors of the Korean economy. Specifically, we assume that, by 2030, Korea is capable of reducing its energy intensity ratio from the 2018 level of 4.6 to 3.1 Q-BTUs per KRW 1,000 trillion of GDP. This would be a 31 percent gain in overall energy efficiency, achieved over 2022 – 2030, at an average rate of efficiency gain of 4.1 percent per year. Once we achieve this level of efficiency gains, we then factor in the 10 percent rebound effect. That would bring aggregate energy consumption in Korea to 7.9 Q-BTUs as of 2030, a fall of about 9 percent relative to Korea's actual energy consumption level of 8.7 Q-BTUs in 2019.[44]

Working from this energy intensity level and incorporating the 10 percent rebound effect, we then consider the energy mix that will be necessary to allow for 7.9 Q-BTUs total energy consumption while still maintaining emissions at no more than 350 million tons. In fact, this emissions reduction goal can be achieved through several combinations of phase-out rates for oil, coal, and natural gas consumption. For simplicity, we assume a scenario in which oil, coal, and natural gas consumption each decline, respectively, by the same 45 percent as of 2030. Thus, as of 2030, oil and coal consumption will have fallen from 2.6 to 1.4 Q-BTUs and natural gas will have fallen from 2.1 to 1.2 Q-BTUs. The 45 precent consumption decline for all three fossil fuel energy sources will correspondingly generate a comparable 45 percent reduction in overall CO_2 emissions as of 2030. This is how, within this scenario, emissions fall to 350 million tons as of 2030.

Following the government's current timeline, we assume in this scenario that nuclear energy supply declines by about 15 percent as of 2030, to 1.1 Q-BTUs. Under this scenario, the full phase out of nuclear energy proceeds until 2085. In Appendix 3, we show the planned phase-out program for South Korea's nuclear power plants. This phase-out trajectory for nuclear energy in Korea will be incorporated into our emissions reduction scenario for 2031 – 2050 as well.

Overall then, by 2030, total energy provided by non-renewable sources will amount to 5.1 Q-BTUs, including the 4.0 Q-BTUs of energy supplied by fossil fuels and the 1.1 Q-BTUs supplied by nuclear. Given that, under this scenario, we have estimated total energy demand in 2030 to be 7.9 Q-BTUs, it follows that Korea will need an additional 2.8 Q-BTUs of energy supplied by clean renewable sources—i.e. some combination of solar, wind, hydro, tidal, low-emissions bioenergy and geothermal energy.

As of 2020, all clean renewable sources—solar, wind, low-emissions bioenergy, geothermal, tidal and hydro—combined to supply only 0.1 Q-BTUs of energy to Korea. Effectively then, 2.7 Q-BTUs of *new supply* needs to be provided by clean renewable sources in order to bring Korea's total energy supply to 7.9 Q-BTUs as of 2030, with 5.1 Q-BTUs coming from fossil fuels and nuclear along with the 2.8 Q-BTUs supplied by clean renewables.

As discussed above, we assume, as a high-end estimate, that the average lump-sum capital expenditures needed to raise aggregate energy efficiency in South Korea will be KRW 35 trillion per Q-BTU. We also assume, as a similarly high-end estimate, that the average lump-sum cost of expanding clean renewable energy supply by 1 Q-BTU will be KRW 213 trillion. Working from these assumptions, in Table 2.7, panels A-C, we summarize the main features of the 2030 clean energy investment program. These include the following:

- ***Efficiency.*** KRW 14 trillion per year in energy efficiency investments between 2022 – 2030, amounting to about 0.6 percent of Korea's projected midpoint GDP between 2022 – 2030. These efficiency investments will generate 3.5 Q-BTUs of energy savings relative to the business as usual growth path for Korea through 2030. This, again, is a 31 percent improvement in energy efficiency throughout Korea's economy relative to 2019 energy use levels.
- ***Rebound effect.*** As discussed above we assume that the 31 percent gain in energy efficiency will generate a 10 percent rebound effect. The 31 percent gain in energy efficiency would bring energy consumption down to 7.6 Q-BTUs as of 2030. The 10 percent rebound effect raises energy consumption in 2030 to 7.9 Q-BTUs.
- ***Clean renewables.*** KRW 64 trillion per year for investments in solar, wind, low-emissions bioenergy, tidal, geothermal, and small-scale hydro power. This will amount to about 2.9 percent of Korea's projected midpoint GDP between 2022 – 2030. It will generate an increase of 2.7 Q-BTUs of clean renewable supply by 2030.
- ***Overall program and emissions reduction.*** Combining the efficiency gains, rebound effect, and clean renewable investments, the program will therefore cost about KRW 78 trillion per year, or 3.6 percent of Korea's projected midpoint GDP between 2022 – 2030. Overall, this program will generate 5.9 Q-BTUs in the combination of energy savings through efficiency investments or expansion of renewable supply relative to the BAU scenario. The end result of this program will be that overall CO_2 emissions in Korea in 2030 will be 350 million tons, 45 percent less than the 631 million ton level for 2019. Korea will have achieved this 45 percent emissions reduction while the economy also will have grown at an average rate of 2.5 percent per year through 2030. That is, the Korean economy will not have to experience sacrifices in terms of improving average living standards in order to achieve carbon neutrality.

Moreover, the transition from a fossil fuel-dominant energy infrastructure to a clean energy infrastructure will entail lower costs for all Korean energy consumers. This is first of all because investments to raise energy efficiency standards will, by definition, lower the amount of energy that people will need to purchase in order to, for example, heat, cool and light their homes or drive their cars a given distance. In addition, as we have seen, it is already the case that the costs of generating electricity from renewable energy sources are lower, on average, than those for producing electricity by burning coal, oil, or natural gas.[45]

TABLE 2.7
South Korea Clean Energy Investment Program for 2022 – 2030

A) Energy Efficiency Investments

1. 2030 Energy intensity ratio	3.1 Q-BTUs per KRW 1,000 trillion GDP *(31% improvement over 4.6 Q-BTU per KRW 1,000 trillion GDP steady state figure)*
2. Total energy consumption	7.9 Q-BTUs *(= KRW 2,419 trillion GDP x 3.1 intensity ratio + 0.3 Q-BTUs for 10% rebound effect)*
3. Efficiency gains relative to BAU before rebound effect	3.5 Q-BTUs *(=11.1 Q-BTUs – 7.6 Q-BTUs in consumption before rebound effect)*
4. Energy saving relative to BAU after rebound effect	3.2 Q-BTUs *(=11.1 Q-BTUs – (7.6 Q-BTUs in consumption before rebound effect + 0.3 Q-BTU rebound effect))*
5. Average investment costs per Q-BTU in efficiency gains	KRW 35 trillion per Q-BTU
6. Costs of efficiency gains	KRW 123 trillion *(= KRW 35 trillion x 3.5 Q-BTUs in pre-rebound savings)*
7. Average annual costs over 2021 – 2030	KRW 14 trillion *(= KRW 123 trillion/9 years)*
8. Average annual costs of efficiency gains as % of midpoint GDP	0.6% *(= KRW 14 trillion/KRW 2,192 trillion)*

B) Clean Renewable Energy Investments

1. Total renewable supply necessary	2.8 Q-BTUs *(=7.9 Q-BTUs in total consumption – 5.1 Q-BTUs in non-renewable supply)*
2. Expansion of renewable supply relative to 2019/2020 level	2.7 Q-BTUs *(=2.8 Q-BTUs – 0.1 Q-BTUS of existing clean renewable energy supply)*
3. Average investment costs per Q-BTU for expanding renewable supply	KRW 213 trillion per Q-BTU
4. Costs of expanding renewable supply	KRW 575 trillion *(=2.7 Q-BTUs x KRW 213 trillion)*
5. Average annual costs over 2021 – 2030	KRW 64 trillion *(= KRW 575 trillion/9 years)*
6. Average annual costs of renewable supply expansion as % of midpoint GDP	2.9% *(= KRW 64 trillion/KRW 2,192 trillion)*

C) Overall Clean Energy Investments: Efficiency + Clean Renewables

1. Total clean energy investments	KRW 698 trillion *(= KRW 123 trillion for energy efficiency + KRW 575 trillion for renewables)*
2. Average annual investments	KRW 78 trillion *(= KRW 698 trillion/9 years)*
3. Average annual investments as share of midpoint GDP	3.6% *(= KRW 78 trillion/KRW 2,192 trillion)*
4. Total energy savings or clean renewable capacity expansion	5.9 Q-BTUs *(= 3.2 Q-BTUs in energy saving after rebound effect + 2.7 Q-BTUs in clean renewable supply expansion)*

Sources: Tables 2.5 – 2.6.

3. CLEAN ENERGY INVESTMENTS, REFORESTATION AND JOB CREATION

In Tables 3.1 and 3.2, we present our estimates as to the job creation effects of investing in energy efficiency in South Korea. Tables 3.3 and 3.4 then present comparable estimates for investments in clean renewable energy in Korea's economy. In both cases, we report two sets of figures—first, job creation per KRW 1 billion in expenditure, then, job creation given the average annual level of investment spending we have proposed for between 2021 – 2030, i.e. KRW 14 trillion in energy efficiency and KRW 64 trillion in clean renewable energy.

Direct, Indirect and Induced Job Creation

Before reviewing the actual data on job creation in Tables 3.1 – 3.4, we need to briefly describe the three channels through which jobs will be generated through clean energy investments. In fact, these three sources of job creation will be associated with any expansion of spending in any area of the economy, including clean energy investments. They are: direct, indirect, and induced employment effects. For purposes of illustration, consider these categories in terms of investments in home retrofitting or installing solar panels:

1. *Direct effects*—the jobs created, for example, by retrofitting buildings to make them more energy efficient or installing solar panels;
2. *Indirect effects*—the jobs associated with industries that supply intermediate goods for the building retrofits or solar panels, such as glass, steel, and transportation. In other words, indirect effects measure job creation along the clean energy investment supply chain;
3. *Induced effects*—the expansion of employment that results when people who are paid in the construction or steel industries spend the money they have earned on other products in the economy. These are the multiplier effects within a standard macroeconomic model.

In Tables 3.1 – 3.4, we first report figures for direct and indirect jobs, along with the totals for these main job categories. We then include the figures on induced jobs, and show total job creation when induced jobs are added to that total.

As we discuss in detail in Appendix 1, our estimates for direct and indirect job creation are derived from the input-output (I-O) tables for the South Korean economy. We use the most recent I-O tables available from the Bank of Korea, which are for 2018. From these I-O tables, we are able to generate figures for employment creation per level of spending on all activities in the South Korean economy—what are known as *employment/output ratios*. The figures we report on induced job creation are based on standard macroeconomic models which estimate the impact on overall spending and employment in the economy when more workers in the economy are employed and, as a result, spend a significant share of the increased income they are receiving from their new jobs. These impacts are known as *spending and employment multipliers*. As we describe in Appendix 1, we are deliberately reporting here low-end figures on the induced employment effects from South Korea's zero emissions project. Our low-end estimate is that induced job creation will amount to 40 percent of the combined direct plus indirect job expansion generated by any specific clean energy investment project.

After presenting results on overall job creation through clean energy investments, we then review later in this section data on quality indicators for the newly-created jobs, including figures on compensation levels and the percentage of workers with regular jobs. We next provide figures on the demographic profile of the existing workforce in the clean energy sectors, including the levels of educational attainment, and the proportion of jobs in each sector held by women.

Time Dimension in Measuring Job Creation: Jobs-per-Year vs. Job Years

Any type of spending activity creates employment over a given amount of time. To understand the impact on jobs of a given spending activity, one must therefore incorporate a time dimension into the measurement of employment creation. For example, a program that creates 100 jobs that last for only one year needs to be distinguished from another program that creates 100 jobs that continue for 10 years each. It is important to keep this time dimension in mind in assessing the impact on job creation of any clean energy investment activity.

There are two straightforward ways in which one can express the time dimensions in these job creation estimates. One is through measuring *job years*. This measures cumulative job creation over the total number of years that jobs have been created. Thus, an activity that generates 100 jobs for 1 year would create 100 job years. By contrast, the activity that produces 100 jobs for 10 years would generate 1,000 job years.

The other way to report the same figures would be in terms of *jobs-per-year*. Through this measure, we are able to provide detail on the year-to-year breakdown of the overall level of job creation. Thus, with the 10-year investment programs in our example, we could express the effects of these investment programs as creating 100 jobs per year over 10 years.

This jobs-per-year measure is most appropriate for the purposes of this study. The reason that jobs-per-year is a better metric than job years is because the impact of any new investment, whether on clean energy or anything else, will be felt within a given set of labor market conditions at a point in time. Reporting cumulative job creation figures over multiple years prevents us from scaling the impact of investments on job markets at a given point in time, e.g. within a given year. As we will see, we estimate that the combined investment programs that we develop in this section will create, as an average, about 860,000 jobs within South Korea per year between 2022 – 2030. We are able to scale this job creation estimate to the size of the Korean labor market. Thus, as of 2020, Korea's overall labor force included 28.4 million people. Providing 860,000 jobs to this overall labor force pool would, all else equal, therefore increase the proportion of employed people in the labor force by about 3 percent. However, if we measure this employment impact in terms of cumulative job creation, the 9 years' worth of investment would, by this measure, amount to over 7.7 million jobs over the full 9-year period. It is misleading to compare that 7.7 million cumulative job creation figure to the 28.4 million people in the Korean labor market as of 2020. If we did want to scale the cumulative job creation figure of 7.7 million over 2022 – 2030, the appropriate comparison would be with the cumulative job figures for the whole Korean economy over 9 years. But this cumulative jobs figure is not a clear or useful way to understand labor market conditions at any given point in time.

Job Creation through Energy Efficiency Investments

In Table 3.1, we show the job creation figures per KRW 1 billion in spending for our five categories of efficiency investments: building retrofits; industrial efficiency; electrical grid upgrades; public transportation expansion and upgrades; and expanding the high efficiency auto fleet, including electric and hydrogen fuel cell vehicles. As Table 3.1 shows, direct plus indirect job creation per KRW 1 billion in spending ranges between 6.9 jobs for expanding the zero-emissions automobile fleet to 11.9 jobs for public transportation expansion and upgrades.

In Table 3.2, we show the level of job creation through spending an average of KRW 14 trillion per year on these efficiency projects in South Korea between 2022 – 2030. We have assumed that the overall level of funding is channeled into the various energy efficiency areas in equal 20 percent shares. Working with this assumption, the overall result of KRW 14 trillion per year in efficiency investments in Korea will be the creation of 68,320 direct jobs and 62,720 indirect jobs, for a total of 131,040 direct plus indirect jobs created through this energy efficiency investment program. Including induced jobs adds another 52,360 jobs to the total figure. This brings the total job creation figure for efficiency investments, including induced jobs, to 183,400 jobs.

TABLE 3.1
Job Creation in South Korea through Energy Efficiency Investments
Job creation per KRW 1 billion in efficiency investments

	Direct jobs	Indirect jobs	Direct + indirect jobs	Induced jobs *(=40% of direct+indirect)*	Direct, indirect + induced jobs
Building retrofits	6.0	5.6	11.6	4.6	16.2
Industrial efficiency	4.7	4.1	8.8	3.5	12.3
Electrical grid upgrades	3.5	4.1	7.6	3.0	10.6
Public transportation expansion/upgrades, including rail	8.1	3.8	11.9	4.8	16.7
Expanding zero emissions automobile fleet *(electric and hydrogen fuel cell vehicles)*	2.1	4.8	6.9	2.8	9.7

Source: See Appendix 1.

TABLE 3.2
Annual Job Creation in South Korea through Energy Efficiency Investments, 2022 – 2030
Job creation through average annual spending of KRW 14 trillion in efficiency investments

ASSUMPTIONS FOR ENERGY EFFICIENCY INVESTMENTS
- 20% on building retrofits
- 20% on industrial efficiency
- 20% on electrical grid upgrades
- 20% on public transportation expansion/upgrades
- 20% on expanding zero-emissions auto fleet

	Spending amounts	Direct jobs	Indirect jobs	Direct + in-direct jobs	Induced jobs *(=40% of direct + indirect)*	Direct, indirect + induced jobs
Building retrofits	KRW 2.8 trillion	16,800	15,680	32,480	12,880	45,360
Industrial efficiency	KRW 2.8 trillion	13,160	11,480	24,640	9,800	34,440
Electrical grid upgrades	KRW 2.8 trillion	9,800	11,480	21,280	8,400	29,680
Public transportation expansion/upgrades, including rail	KRW 2.8 trillion	22,680	10,640	33,320	13,440	46,760
Expanding high efficiency automobile fleet	KRW 2.8 trillion	5,880	13,440	19,320	7,840	27,160
TOTALS	**KRW 14 trillion**	**68,320**	**62,720**	**131,040**	**52,360**	**183,400**

Sources: See Tables 2.7 and 3.1.

Job Creation through Clean Renewable Energy Investments

In Table 3.3, we show the job creation figures for our 9 clean renewable energy categories—onshore community, commercial and residential scale solar; onshore utility scale solar; offshore utility scale solar; offshore wind; onshore wind; low-emissions bioenergy; tidal; small-scale hydro; and geothermal. As we see, the extent of direct plus indirect jobs ranges from 5.3 direct plus indirect jobs per KRW 1 billion in expenditure for offshore utility-scale solar to 16.2 jobs for investing KRW 1 billion in low-emissions bioenergy. Adding induced jobs brings the range to 7.4 jobs for offshore utility-scale solar to 22.7 jobs for bioenergy.

Based on these employment/output ratios, we see in Table 3.4 the levels of job creation in South Korea generated by spending an average of KRW 64 trillion per year between 2022 – 2030 in these areas of clean renewable energy. As we see in Table 3.4, we have divided total spending levels as follows: 35 percent for onshore community, commercial and residential solar; 25 percent for onshore utility-scale solar; 5 percent for offshore utility-scale solar; 14 percent and 16 percent for offshore and onshore wind respectively; and 1.25 percent respectively for low-emissions bioenergy, tidal, small-scale hydro and geothermal.

Following from these budgetary assumptions, we see in Table 3.4 that total direct plus indirect job creation generated in South Korea by this large-scale expansion in the country's clean renewable energy supply will be 432,380 jobs. If we include induced jobs, then the total rises to 606,380 jobs.

TABLE 3.3

Job Creation in South Korea through Clean Renewable Energy Investments

Job creation per KRW 1 billion in clean renewable investments

	Direct jobs	Indirect jobs	Direct + indirect jobs	Induced jobs (=40% of direct + indirect)	Direct, indirect + induced jobs
Solar: onshore community, commercial, and residential scales	2.9	3.3	6.2	2.5	8.7
Solar: onshore utility scale	2.8	3.1	5.9	2.4	8.3
Solar: offshore utility scale	2.5	2.8	5.3	2.1	7.4
Wind: offshore	3.6	4.1	7.7	3.1	10.8
Wind: onshore	3.6	4.2	7.8	3.1	10.9
Low-emissions bioenergy	12.6	3.6	16.2	6.5	22.7
Tidal	3.3	3.6	6.9	2.8	9.7
Small-scale hydro	4.9	4.1	9.0	3.6	12.6
Geothermal	5.1	4.4	9.5	3.8	13.3

Source: See Appendix 1.

TABLE 3.4

Annual Job Creation in South Korea through Clean Renewable Energy Investments, 2022 – 2030

Job creation through average annual spending of KRW 64 trillion in clean renewable investments

ASSUMPTIONS FOR CLEAN RENEWABLE INVESTMENTS

- 35% on solar, onshore, community, commercial, residential
- 25% on solar, onshore utility scale
- 5% on solar, offshore utility scale
- 14% on wind, offshore
- 16% on wind, onshore
- 1.25% on low-emissions bioenergy
- 1.25% on tidal
- 1.25% on small-scale hydro
- 1.25% on geothermal energy

	Spending amounts	Direct jobs	Indirect jobs	Direct + indirect jobs	Induced jobs (=40% of direct + indirect)	Direct, indirect + induced jobs
Solar: onshore community, commercial, and residential scales	KRW 22.4 trillion	64,960	73,920	138,880	56,000	194,880
Solar: onshore utility scale	KRW 16.0 trillion	44,800	49,600	94,400	38,400	132,800
Solar: offshore utility scale	KRW 3.2 trillion	8,000	8,960	16,960	6,720	23,680
Wind: offshore	KRW 9.0 trillion	32,400	36,900	69,300	27,900	97,200
Wind: onshore	KRW 10.2 trillion	36,720	42,840	79,560	31,620	111,180
Low-emissions bioenergy	KRW 0.8 trillion	10,080	2,880	12,960	5,200	18,160
Tidal	KRW 0.8 trillion	2,640	2,880	5,520	2,240	7,760
Small-scale hydro	KRW 0.8 trillion	3,920	3,280	7,200	2,880	10,080
Geothermal	KRW 0.8 trillion	4,080	3,520	7,600	3,040	10,640
TOTALS	**KRW 64 trillion**	**207,600**	**224,780**	**432,380**	**174,000**	**606,380**

Sources: See Tables 2.7 and 3.3.

Table 3.5 brings together our job estimates for both energy efficiency and clean renewable energy through spending about KRW 78 trillion per year on this project in Korea between 2022 – 2030. We first show total figures for direct plus indirect jobs only, then we also show the total when induced jobs are included.

We see in row 14 of Table 3.5 that total average direct and indirect job creation for 2022 – 2030 is 563,420 jobs and 789,780 jobs when we add induced jobs to the total. As we see in row 15, this level of job creation amounts to between 2.0 and 2.8 percent of the total workforce in South Korea as of 2020, the range depending on whether we include induced jobs in the total.[46]

TABLE 3.5
Annual Job Creation in South Korea through Combined Energy Efficiency and Clean Renewable Energy Investment Program
Average annual figures for 2022 – 2030

Investment	Number of direct and indirect jobs created	Number of direct, indirect, and induced jobs created
KRW 14 trillion in energy efficiency		
1) Building retrofits	32,480	45,360
2) Industrial efficiency	24,640	34,440
3) Electrical grid upgrades	21,280	29,680
4) Public transportation expansion/upgrades	33,320	46,760
5) Expanding zero-emissions automobile fleet	19,320	27,160
6) Total energy efficiency job creation	*131,040*	*183,400*
KRW 64 trillion in clean renewables		
7) All solar investment areas	250,240	351,360
8) All wind investment areas	148,860	208,380
9) Low-emissions bioenergy	12,960	18,160
10) Tidal	5,520	7,760
11) Small-scale hydro	7,200	10,080
12) Geothermal	7,600	10,640
13) Total job creation from clean renewables	*432,380*	*606,380*
14) TOTALS *(=rows 6+13)*	**563,420**	**789,780**
15) TOTAL AS SHARE OF 2020 South Korea labor force *(labor force at 28.4 million)*	**2.0%**	**2.8%**

Indicators of Job Quality and Worker Characteristics

Job Quality: Wages and Benefits

In Table 3.6, we provide some basic measures of job quality for the jobs that will be generated through energy efficiency and clean renewable energy investments in South Korea. These basic indicators include: 1) average total compensation (including wages plus benefits) and 2) the percentage of workers with "regular jobs." "Regular jobs" are those that have either fixed contracts of over one year or have open-ended contracts. Most workers with regular contracts have social insurance benefits, including unemployment insurance, industrial accident insurance, national medical care, a national pension and severance pay. By contrast, workers with "non-regular jobs" include those with temporary jobs, daily or on-call jobs, subcontract workers, independent contractors and the self-employed, among others.[47]

All of the figures we report here describe *existing conditions* for workers currently employed in the various energy efficiency and clean renewable sectors. Of course, these currently existing conditions are subject to change. This will be true especially as the large-scale expansion in energy efficiency and renewable energy investments significantly expand the number of job opportunities in the range of impacted economic sectors. In particular, the large- scale expansion in employment in energy efficiency and renewables resulting from investment in these areas can help foster conditions in which compensation and benefits for workers can improve.

We focus here on the *direct* jobs that will be created through energy efficiency and renewable investments in South Korea. By definition, the direct jobs, such as workers mounting solar panels on rooftops, are the ones that are fully integrated within the economy's energy transformation project. By contrast, an indirect, supply-chain worker, such as a truck driver delivering solar panels to an onshore project, could, for example, within the same week, be delivering furniture to retail outlets, i.e. working in areas of the economy unconnected to its clean energy transformation. Generally then, the characteristics associated with these directly-created jobs will most fully reflect the specific range of opportunities that will result through building a clean energy economy in South Korea. The jobs created through the indirect and induced channels will be more diffuse in their characteristics. Indeed, the characteristics of the induced jobs created through economy-wide multiplier effects will simply reflect the overall characteristics of Korea's present-day workforce.

Focusing on the direct employment category, we report combined figures that incorporated our three solar energy categories—i.e. onshore community, commercial and residential; onshore utility scale and offshore utility scale. We also show combined figures for offshore and onshore wind. Both the job quality and worker characteristic figures are very similar among the three solar energy subsectors and the two wind energy subsectors.

Considering the full set of 11 investment activities—5 efficiency investment and 6 renewable energy areas—compensation figures are broadly similar for 9 of the activities, at between KRW 36.9 million and KRW 43.6 million in wages and benefits per year. The two outliers are building retrofits and bioenergy, where compensation is significantly lower, at KRW 31.1 million in bioenergy and KRW 32.4 million in retrofits. Not surprisingly, the workers in these two areas are also most likely to be employed in non-regular arrangements. Only about 30 percent of workers in building retrofits and 46 percent of workers in bioenergy have regular jobs. With the other 9 investment activities, the percent of regular jobs

TABLE 3.6
Job Quality Indicators:
South Korea's Energy Efficiency and Renewable Energy Sectors and Overall Economy
Figures are for direct jobs only

	Average annual pay: wages and benefits	Percent of workers with regular jobs
Energy efficiency sectors		
Building retrofits *(16,800 workers)*	KRW 32.4 million	30.3%
Industrial efficiency *(13,160 workers)*	KRW 42.6 million	82.6%
Electrical grid upgrades *(9,800 workers)*	KRW 38.1 million	80.7%
Public transportation *(22,680 workers)*	KRW 40.0 million	68.0%
Zero-emissions vehicles *(5,880 workers)*	KRW 43.6 million	90.7%
Clean renewable energy sectors		
Solar—all subsectors *(117,760 workers)*	KRW 40.8 million	79.1%
Wind—all subsectors *(69,120 workers)*	KRW 36.9 million	70.9%
Low-emissions bioenergy *(10,080 workers)*	KRW 31.1 million	45.9%
Tidal *(2,640 workers)*	KRW 40.4 million	77.3%
Small-scale hydro *(3,920 workers)*	KRW 41.8 million	73.6%
Geothermal *(4,080 workers)*	KRW 41.7 million	67.5%
Overall South Korea economy	**KRW 32.1 million**	**51.8%**

Note: Regular workers are those with a fixed contract of at least one year or an open-ended contract. Most workers with regular jobs have social insurance benefits, including unemployment insurance, industrial accident insurance, and severance pay.

Source: Figures for overall workforce are based on the Local Area Labor Force Survey (LLFS), 2019. Sector specific figures are based on LLFS 2019; 2015 Economic Census; and Bank of Korea Economic Statistics System. See Appendix 1 for details.

ranges between 68 percent for the geothermal sector to 91 percent in automobile manufacturing.

It is useful to compare these indicators of job quality with economywide averages for the Korean labor force overall. As we see, the average annual pay for the overall Korean labor force, at KRW 32.1 million, is basically in line with the lower-paying clean energy jobs in retrofits and bioenergy. The overall share of Korean workers with regular contracts is 52 percent. This is in line with the figure for bioenergy, but higher than the 30 percent figure in building retrofits. But more generally, workers employed at present in Korea's energy efficiency and renewable energy sectors have significantly higher pay and better contract terms—including benefits—than the average throughout the Korean labor force.

Worker Characteristics: Educational Credentials and Gender

Table 3.7 presents figures on educational credentials and gender for workers in the various energy efficiency and renewable energy sectors. In terms of educational credentials in the 11 specific investment areas, again the retrofit and bioenergy sectors are relative outliers. In both sectors, as high-end figures relative to the other 9 sectors, over 60 percent of the currently employed workers have high school degrees or less. As low-end figures, between 25 – 30 percent hold Bachelor's degrees. In the other 9 sectors, between 34 – 50 percent of workers have high school degrees or less while between 33 – 53 percent have at least Bachelor's degrees. The economy-wide figures on educational credentials fall in between these alternative distributions in the clean energy sectors, with about 48 percent of all Korean

TABLE 3.7
Worker Characteristics:
South Korea's Energy Efficiency and Renewable Energy Sectors and Overall Economy
Figures are for direct jobs only

	Educational credentials			Share of women in workforce
	High school degree or less	Some college or Associate degree	Bachelor's degree or higher	
Energy efficiency sectors				
Building retrofits *(16,800 workers)*	65.2%	9.1%	25.7%	8.0%
Industrial efficiency *(13,160 workers)*	33.6%	13.9%	52.5%	22.1%
Electrical grid upgrades *(9,800 workers)*	44.4%	18.3%	37.3%	24.5%
Public transportation *(22,680 workers)*	46.5%	13.1%	40.4%	13.1%
Zero-emissions vehicles *(5,880 workers)*	43.7%	19.9%	36.3%	20.3%
Clean renewable energy sectors				
Solar—all subsectors *(117,760 workers)*	44.3%	18.3%	37.4%	21.5%
Wind—all subsectors *(69,120 workers)*	50.5%	16.4%	33.1%	20.1%
Low-emissions bioenergy *(10,080 workers)*	61.1%	8.6%	30.2%	24.5%
Tidal *(2,640 workers)*	44.0%	15.3%	40.6%	19.8%
Small-scale hydro *(3,920 workers)*	37.9%	10.7%	51.4%	21.5%
Geothermal *(4,080 workers)*	47.1%	11.5%	41.3%	15.2%
Overall South Korea economy	**47.7%**	**14.2%**	**38.1%**	**43.0%**

Source: Figures for overall workforce are based on LLFS 2019. Sector specific figures are based on LLFS 2019; 2015 Economic Census; and Bank of Korea Economic Statistics System. See Appendix 1 for details.

workers having high school degrees or less and 38 percent having Bachelor's degrees or higher. This range of educational credentials among currently employed workers in energy efficiency and renewable energy suggests that the large-scale expansion of these activities will open job opportunities for workers at all educational credentials.

With respect to gender composition, employment in all 11 energy efficiency and renewable energy sectors is dominated by men. The sectors with the highest shares of female employment are grid upgrades and bioenergy. But the share of female employment in these sectors is only about 25 percent. The lowest figure for female employment share is in retrofits, with women representing only about 8 percent of the workforce. All of these figures fall well below that for the Korean economy overall, in which women account for 43 percent of all employment.

On balance then, the positive features of the current workforce composition in energy efficiency and renewable energy in South Korea is that people with a wide range of educational credentials are currently employed in the 11 sectors. The far less favorable situation is that the share of women currently employed is very low across-the-board.

Reforestation and Job Creation

As noted above in Section 1, President Moon has emphasized reforestation as a major component of his government's overall program to reach carbon neutrality by 2050. Quoting Moon again from his November 1, 2021 speech, just prior to the COP26 conference, he said that "Korea…will cut greenhouse gas emissions by more than 40 percent relative to the level of 2018." Moon also stated that "Korea…will lead connective forest restoration efforts. Trees are living greenhouse gas sinks. Growing trees and reviving forests are important solutions to the climate crisis."

Moon himself did not provide details of this reforestation program. But the Korea Forest Service has developed some specifics, initially presenting them in January 2021. Details on the proposed program that we discuss here, along with critical responses to the proposals, are based on a 5/17/21 news story in *Korea JoongAng Daily,* unless specifically cited otherwise.[48]

In June 2021, after facing criticism of the initial program proposal, the Forestry Service decided to undertake a series of public consultations on the program before proceeding further.[49] To our knowledge, the Service has not provided updated estimates beyond the January proposal. It will nevertheless be useful to review here some of the main features of the January proposal. They include the following.

In the January 2021 proposal, the project aims to plant 3 billion trees within a 30-year time frame. Of this total, about 2.6 billion will be planted in existing South Korean forests. Another 100 million will be planted in South Korea's urban areas. The remaining 300 million will be planted in North Korea and other countries.

Some background is useful for assessing the scope of this proposal. South Korea undertook an earlier major reforestation project between 1955 – 1980. During this period, the country's share of forest cover rose dramatically, from 35 percent to 65 percent of the country's total land mass. The country's current forest cover area, at 63 percent of total land area, is slightly below the 1980 peak.[50]

Under the current proposal, South Korea would not increase its forest cover share of total land mass any further. Rather, the project entails two components: first increasing the rate at which mature trees are logged, then planting new trees in the areas that will have been cleared through logging. Korea would aim to increase its carbon sink through the combination of these two measures. This rests on the following logic. According to the Forest Service, the stock of mature trees will have reached its capacity to absorb CO_2, since the trees were planted, for the most part, during the earlier reforestation project that ended in the 1980s. At the same time, the newly-planted trees will be absorbing CO_2 at a high rate during their initial 30 – 40 years of relatively rapid growth. The logged trees will then be used for building materials and similar purposes as opposed to having these logs burned to provide heat and energy.

However, this premise that the Forest Service has proposed, that Korea's more mature trees will have lost most of their CO_2 absorption capacity after they have grown for 40 years, is not broadly supported within the research literature. For instance, the U.S. Forest Service has found that carbon absorption between years 45 – 95 is roughly equal to years 0 to 45, and perhaps even greater after accounting for the impact of understory and down dead wood. Recent studies have estimated that even forests 200 years and older were still absorbing carbon at rates between 1.6 – 2.4 tons of carbon per hectare per year. Absorption rates do vary, depending on tree species and geography, and Korean forests are distinct from those in the U.S. However, none of these differences in tree species and geography would suggest that, for South Korea, it is likely that trees no longer are significant carbon sinks after they have grown for more than 40 years.[51] It is also the case that, to the extent that the felled logs are used to produce heat and energy, this will produce an increase in CO_2 emissions at a level comparable to burning coal.[52]

If the Forest Service were to proceed with such a program, it estimates that the program will be able to absorb 20.7 million tons of CO_2 at the end of the 30-year project.[53] If their estimate is accurate, it implies that, if the project were to have started in 2021 and then end 30 years later in 2050, the reforestation program would have the capacity to absorb CO_2 at the modest rate of about 3 percent relative to Korea's 2019 emissions level of 631 million tons. For the present discussion, we have made a slight adjustment given that 2021 has ended. We still assume the program will be completed in 2050. But we assume that it begins in 2022 and therefore runs in full for 29 years as opposed to a 30-year program beginning in 2021 and ending in 2050.

Of course, the reforestation program will not only absorb CO_2 in 2050, the final year of the 29-year program. Rather, newly-planted trees will begin absorbing CO_2 as soon as they begin growing. Thus, if we assume that the total of 2.7 billion trees are planted within South Korea at a steady rate over a 29-year period, that will mean that 93 million new trees would be planted every year. As we show in Table 3.8, the level of CO_2 absorption would then increase every year, as the total number of new tree plantings increases from 93 million in 2022 to 186 million in 2023, to 279 million in year 2024, and so on. If, by 2050, total absorption is at 20.7 million tons, as estimated by government researchers, this implies that the increases in CO_2 absorption would start at about 700,000 tons in 2023, then rises to 1.5 million tons in 2024, to 2.2 million tons in 2025 and so forth. Over the full 29-year period, cumulative CO_2 absorption would total to 300 million tons. The average rate of absorption would be 10.4 million tons per year.

TABLE 3.8

Tree Plantings and CO_2 Absorption Rate through South Korea's Proposed 2022 – 2050 Reforestation Project

- *2.7 billion trees to be planted within South Korea over 29 years*
- *93 million trees planted per year*

Year	Cumulative trees planted	Annual net CO_2 absorption *(millions of tons)*	Cumulative CO_2 absorption *(millions of tons)*
2022	93 million	0	0
2023	186 million	0.7	0.7
2024	279 million	1.5	2.2
2025	372 million	2.2	4.4
2026	465 million	3.0	7.4
2027	558 million	3.7	11.1
2028	651 million	4.4	15.5
2029	744 million	5.2	20.7
2030	837 million	5.9	26.6
2031	930 million	6.7	33.3
2032	1.0 billion	7.4	40.7
2033	1.1 billion	8.1	48.8
2034	1.2 billion	8.9	57.7
2035	1.3 billion	9.6	67.3
2036	1.4 billion	10.4	77.6
2037	1.5 billion	11.1	88.7
2038	1.6 billion	11.8	100.5
2039	1.7 billion	12.6	113.1
2040	1.8 billion	13.3	126.4
2041	1.9 billion	14.0	140.5
2042	2.0 billion	14.8	155.3
2043	2.05 billion	15.5	170.8
2044	2.1 billion	16.3	187.0
2045	2.2 billion	17.0	204.0
2046	2.3 billion	17.7	221.8
2047	2.4 billion	18.5	240.3
2048	2.5 billion	19.2	259.5
2049	2.6 billion	20.0	279.5
2050	2.7 billion	20.7	300.2
Averages per year	----	10.4	----
Cumulative for 30-year program	2.7 billion	----	300.2

Source: Korea Forest Service (2021) for background information from which this framework is developed.

In short, after taking account of both the total level of absorption and the average rate of absorption per year over 29 years, the impact of this reforestation program on CO_2 emissions reductions in South Korea will remain quite modest. The cumulative level of absorption over 30 years, at 300 million tons, is less than half of South Korea's current CO_2 emissions level for *one year only*. The average annual rate of emissions absorption of 10.4 million tons amounts to about 1.6 percent of Korea's current emissions level.[54]

Estimating Program Costs

To our knowledge, the government has not yet provided any official cost estimates of the program. The May news story in *Korea JoonAng Daily* reported a government estimate at KRW 6 trillion ($5.3 billion) for overall costs.[55] Averaged over 29 years, this overall cost figure would amount to about KRW 215 billion per year. But there were no details provided in this story, or elsewhere to our knowledge, as to how this cost estimate was derived.

We can derive some alternative cost estimates working from the relevant research literature which, for all regions of the globe, estimates costs of expanding carbon sinks through reforestation. Thus, according to a 2018 paper by Fuss et al., the costs of such a program in South Korea would likely be in the range of KRW 47,240 – 59,050 ($40 – $50) per ton of CO_2 that is absorbed through reforestation. Based on this cost estimate, the total cost of the reforestation program over the full period in which 2.7 billion trees are planted in South Korea itself would be between KRW 14.6 trillion and KRW 18.3 trillion.[56] These figures are between 2.4 and 3 times higher than the KRW 6 trillion figure reported in the press. This higher range of figures imply that the average costs per year over the full 29 years of the program would be between KRW 505 billion[57] (i.e. KRW 14.6 trillion/29) and KRW 631 billion (KRW 18.3 trillion/29).

We do not have any further information for assessing which of the cost estimates are more reliable. But we can conclude that, even with the highest estimate of KRW 631 billion per year, the costs would be less than 0.01 percent of South Korea's average GDP between 2021 – 2050. Thus, by any measure, the program is very modest relative to the size of the Korean economy as well as, correspondingly, to the country's ambitions to reach carbon neutrality emissions by 2050.

Employment Creation

Based on our figures for the reforestation program's likely costs, we are able to also estimate its impact with respect to job creation. We work here with the same input-output tables for South Korea that we have used above in estimating employment impacts for energy efficiency and renewable energy investments. We report our results in Table 3.9.

As we see in Table 3.9, reforestation is a relatively labor-intensive activity. Direct plus indirect job creation amounts to 13.5 jobs per KRW 1 billion. Including induced jobs brings total job creation to 18.9 jobs per KRW 1 billion. This level of job creation for a given amount of spending is, for example, higher than investments in public transportation, which, at 16.9 jobs per KRW 1 billion, is the most labor-intensive sector among all energy efficiency investments. The level of labor intensity for reforestation is also more than twice as high as the roughly 8 jobs per KRW 1 billion figure for the various onshore solar energy sectors.

TABLE 3.9
Job Creation in South Korea through Reforestation Investment Program
Job creation through average annual spending of KRW 631 billion in reforestation program, 2022 – 2050

	Direct jobs	Indirect jobs	Direct + indirect jobs	Induced jobs *(=40% of direct + indirect)*	Direct, indirect + induced jobs
Job creation per KRW 1 billion in spending	9.4	4.1	13.5	5.4	18.9
Job creation through KRW 631 billion in annual spending	5,930	2,590	8,520	3,410	11,930

Source: See Appendix 1.

If South Korea's reforestation program is budgeted at our highest-end figure of KRW 631 billion per year, the result would then be to create 8,520 direct plus indirect jobs and 11,930 jobs in total, including induced jobs.

Of course, these job creation figures for reforestation are very small relative to the nearly 790,000 jobs that we estimate would be generated by the investment program in energy efficiency and renewable energy between 2021 – 2030 that we have described above. The huge disparity in these relative job creation figures results from the fact that our estimated budget for energy efficiency and renewable energy is about KRW 78 trillion per year between 2021 – 2030 while our estimate for even a high-end reforestation budget is KRW 631 billion —about 0.7 percent of the clean energy investment budget.

Job Quality and Worker Characteristics

Table 3.10 reports data on job quality and worker characteristics in Korea's forestry industry under its current conditions. As we can see, these jobs are relatively low paying. The average annual pay and benefits are at KRW 29.3 million, about 9 percent below Korea's economywide average figure of KRW 32.1 million. Moreover, only about 42 percent of forestry workers have regular job arrangements with their employers. Part of the reason why pay is relatively low in this sector is that a high proportion of these jobs are filled on a temporary basis, with short weekly hours, frequently by elderly workers.

Nearly 60 percent of forestry workers have relatively low educational credentials while only 28 percent have Bachelor's degrees. About one-quarter of the workers in this sector are women. This percentage for female employment is higher than most of the employment areas in the energy efficiency and renewable energy sectors. But it remains well below the national average of 43 percent female employment.

Even at its relatively modest scale, the government's proposed reforestation program could nevertheless create an opportunity to raise wages, benefits and working conditions in this sector, and to open opportunities for women.

TABLE 3.10
Job Quality Indicators and Worker Characteristics for South Korea's Forestry Sectors
Figures are for direct jobs only

A) Job Quality Indicators

	Average annual pay: wages and benefits	Percent regular workers
Forestry workers (5,930 jobs)	KRW 29.3 million	42.5%
Overall South Korea economy	KRW 32.1 million	51.8%

Note: Regular workers are those with a fixed contract of at least one year or an open-ended contract. Most workers with regular jobs have social insurance benefits, including unemployment insurance, industrial accident insurance, and severance pay.

Source: Figures for overall workforce are based on the Local Area Labor Force Survey (LLFS), 2019. Sector specific figures are based on LLFS 2019; 2015 Economic Census; and Bank of Korea Economic Statistics System. See Appendix 1 for details.

B) Worker Characteristics

	Educational credentials			Share of women in workforce
	High school degree or less	Some college or Associate degree	Bachelor's degree or higher	
Forestry workers (5,930 jobs)	58.6%	13.2%	28.2%	24.3%
Overall South Korea economy	47.7%	14.2%	38.1%	43.0%

Source: Figures for overall workforce are based on the Local Area Labor Force Survey (LLFS), 2019. Sector specific figures are based on LLFS 2019; 2015 Economic Census; and Bank of Korea Economic Statistics System. See Appendix 1 for details.

Job Creation through Phasing Out Fossil Fuel Energy Imports

As noted above, South Korea imports virtually all of its oil, coal and natural gas supplies. For example, in 2019, Korea imported about KRW 67 trillion in fossil fuels that were consumed to produce energy. This was equal to 3.5 percent of Korea's 2019 GDP. Between the years 2002 – 2019, the median figure for fossil fuel energy imports as a share of GDP was even higher, at 3.8 percent of GDP.[58]

The project for South Korea to phase out fossil fuel consumption and generate domestically-produced renewable energy to substitute for fossil fuels will have a significant impact on employment in Korea. This will result through reducing the economy's overall spending on imports and correspondingly increasing the level of spending within the domestic economy. Generally speaking, every won of spending that remains within the domestic Korean economy as opposed to being spent on imported goods—fossil fuels or otherwise—will have a positive impact on employment in Korea. The average level of job creation for all types of spending in South Korea is 9.5 jobs per KRW 1 billion. This implies that when Korea retains KRW 1 billion in spending within its domestic economy rather than spending the KRW 1 billion on fossil fuel imports, the impact will be to expand employment in Korea by 9.5 jobs.

Working from this framework, we estimate the impact on employment of South Korea reducing its average energy import bill from 3.8 percent of GDP down to zero by 2050. If South Korea is going to succeed in becoming a zero-emissions economy by 2050, it follows that its fossil fuel energy import bill will also fall to zero by 2050.

We focus here on the employment impacts of the fossil fuel import phase-out as it proceeds between 2022 – 2030, the period in which Korea would be reducing its CO_2 emissions by 45 percent. In Section 5, we then consider the equivalent scenario between 2031 – 2050, as Korea advances towards its goal of reaching zero emissions by 2050.

To estimate the overall effects of Korea's energy transition on the economy's import purchases, we need to introduce one additional factor. This is the extent to which the country's investments in energy efficiency and clean renewable energy will themselves entail an increase in imports. In Section 2, we estimated that energy efficiency and clean renewable energy investments will need to average 3.6 percent of South Korea's GDP per year between 2022 – 2030 in order to reduce CO_2 emissions by 45 percent as of 2030. Of that total level of investment spending, we estimate, as a high-end figure, that 15 percent of this total clean energy investment spending will be on imports.[59] Thus, as an approximate average, the import share of energy efficiency and renewable energy investments will amount to about 0.6 percent of Korea's GDP per year from 2022 – 2030 (i.e. 3.6 percent of GDP x 0.15 = 0.54 percent).

Table 3.11 presents the series of calculations through which we can estimate the net employment impact of Korea reducing its fossil fuel energy import bill by 45 percent as of 2030. Our calculations proceed as follows:

- Column 2 shows Korea's GDP every year between 2022 – 2030, following from the assumption we presented in Section 2 that the growth of Korea's economy will average 2.5 percent per year between 2020 – 2030.
- Column 3 shows what Korea's energy import bill would be every year between 2022 – 2030 under the Business as Usual scenario. Under this BAU scenario, we assume that Korea's fossil fuel energy imports will remain over 2022 – 2030 at what had been its median value of 3.8 percent between 2002 – 2019.
- Column 4 shows how the decline in South Korea's energy imports will proceed over 2022 – 2030 under the assumption that fossil fuel energy consumption and imports in Korea will have fallen by 45 percent as of 2030. That implies that fossil fuel imports will fall from 3.8 percent of GDP in 2022 to 2.1 percent of GDP as of 2030.
- Column 5 reports figures on the extent of fossil fuel energy imports under the assumption, as shown in column 4, that fossil fuel imports as a share of GDP will fall from 3.8 to 2.1 percent between 2022 – 2030.
- Column 6 shows the reduction in Korea's energy import bill, i.e. column 3 – column 5.
- Column 7 shows the level of import spending resulting from Korea's investments in energy efficiency and clean renewable energy. These figures are based on our assumption that this level of imported investment spending will average 0.6 percent of GDP between 2022 – 2030.
- Column 8 shows the net change in Korea's overall imports after accounting for both a) the reduction in fossil fuel imports; and b) the increase in import purchases resulting from the country's efficiency and renewables investments.

- Column 9 shows the job impacts generated by this net change in Korea's imports—the fall of fossil fuel energy imports and the steady purchases of imports tied to the clean energy investment program.

As we see in column 9, as of 2022, with Korea's purchasing of fossil fuel energy imports at 3.8 percent of GDP, and with clean energy imports at KRW 11.9 trillion, the net impact will be to reduce employment by 113,000 jobs. But these net job losses will fall to about 75,000 jobs by 2023, as fossil fuel energy imports falls to 3.6 percent of GDP while the imports from clean energy investments remains at 0.6 percent of GDP. By 2025, the overall impact on jobs turns modestly positive due to fossil fuel energy imports falling to 3.2 percent of GDP. Then from 2026 – 2030, the gains in employment grow every year as the economy's fossil fuel import bill declines. By 2030, the employment gain from Korea having reduced its fossil fuel energy imports to 2.1 percent of GDP amounts to more than 250,000 jobs.

TABLE 3.11
Employment Impact of Phasing Out Fossil Fuel Imports, 2022 – 2030

1) Year	2) GDP *(KRW trillions)*	3) Energy imports under BAU *(in KRW trillions; = 3.8% of GDP)*	4) Energy import share under Clean Energy Program	5) Energy imports under Clean Energy Program *(in KRW trillions; = 45% reduction by 2030)*	6) Annual reduction in energy imports under Clean Energy Program *(in KRW trillions; = column 3-5)*	7) Clean energy imports *(in KRW trillions; = 0.6% of GDP)*	8) Net import substitution *(in KRW trillions; = column 6-7)*	9) Annual job creation through net import substitution *(= column 8 x 9.5 jobs per KRW 1 billion)*
2022	1,986	75.5	3.8%	75.5	-	11.9	(11.9)	-113,184
2023	2,035	77.3	3.6%	73.0	4.3	12.2	(7.9)	-74,925
2024	2,086	79.3	3.4%	70.4	8.9	12.5	(3.7)	-34,683
2025	2,138	81.3	3.2%	67.6	13.6	12.8	0.8	7,618
2026	2,192	83.3	3.0%	64.7	18.6	13.2	5.5	52,056
2027	2,247	85.4	2.7%	61.5	23.9	13.5	10.4	98,711
2028	2,303	87.5	2.5%	58.1	29.4	13.8	15.5	147,666
2029	2,360	89.7	2.3%	54.6	35.1	14.2	20.9	199,007
2030	2,419	91.9	2.1%	50.8	41.1	14.5	26.6	252,823
Total	----	----	----	----	----	----	----	**535,088**
Average	----	----	----	----	19.4	13.2	6.3	59,454

Overall 2022 – 2030 Job Creation through Investment Programs and Fossil Fuel Import Reductions

We now bring together our estimates for 2022 – 2030 of the combined impacts through the three employment-generating channels we have described above, i.e:

- Energy efficiency and clean renewable investments, averaging KRW 78 trillion per year
- Reforestation investments, averaging KRW 631 billion per year
- Phasing-out fossil fuel energy imports, which will reduce South Korea's average energy import bill by nearly KRW 19 trillion per year.

We present these summary figures in Table 3.12. As we see in column 1 of Table 3.12, our estimate of total job creation through these three channels is 861,164.

But as we note in the table, this estimate assumes that the employment/output ratios that we have presented in Tables 3.1, 3.3 and 3.9 above will remain fixed over the full 2022 – 2030 period. In fact, it is more likely that the major increase in investment spending in the relevant range of activities will itself create opportunities for improvements in production methods. These improvements will likely entail reducing the employment requirements for a given level of production—i.e. labor productivity will improve over this 9-year period.

To reflect this prospect of improving labor productivity, we report a second set of job creation estimates in column 2. These figures assume that labor productivity improves at an

TABLE 3.12
Average Annual Job Creation through Combined Channels, 2022 – 2030

- *Energy efficiency and renewable energy investments*
- *Reforestation*
- *Phasing out fossil fuel energy imports*

	Job creation with fixed employment/output ratios	Job creation with 1.5% annual labor productivity growth *(figures are for midpoint year 2026)*
Energy efficiency and renewable energy investments: *KRW 78 trillion/year*	789,780	743,450
Reforestation investments: *KRW 631 billion/year*	11,930	11,230
Phase-out of fossil fuel energy imports: *KRW 6.3 trillion/year in net energy import substitution*	59,454	55,970
Total job creation	861,164	810,650
Total job creation as share of 2020 South Korea labor force *(labor force at 28.4 million)*	3.0%	2.9%

Sources: Tables 3.5, 3.9, 3.11.

average rate of 1.5 percent per year over 2022 – 2030.[60] As a result of this assumption, we see that our total for average job creation estimates fall modestly, to 810,650.

Taking a broader view, it is nevertheless clear that under either assumption—either that labor productivity remains fixed or improves at 1.5 percent per year—our overall estimate is that South Korea will gain in the range of 800,000 – 850,000 jobs through pursuing a climate stabilization program, targeted at reducing CO_2 emissions by 45 percent as of 2030. This increase in the country's overall employment level will be in the range of 3.0 percent of the country's total workforce in 2020. The most likely result will then be to draw more Koreans into the workforce, as opportunities expand for them to obtain jobs and improve their incomes.

4. EMPLOYMENT CONTRACTION AND JUST TRANSITION FOR DISPLACED WORKERS

Even though Korea imports all of its fossil fuel energy, a significant amount of fossil fuel-based economic activity still takes place within its domestic economy. These activities are in the areas of distribution, marketing, refining, and electricity generation. The largest source of employment in Korea's fossil-fuel related economic sectors is the operation of gas and oil stations. We assume in this section that overall economic activity and employment in the full set of fossil fuel-based sectors will all contract by 45 percent as of 2030. This rate of contraction aligns with the 45 percent reduction in the consumption of oil, coal, and natural gas that we described in Section 2. This is the rate of fossil fuel consumption reduction necessary to bring CO_2 emissions in Korea down by the same 45 percent as of 2030.

South Korea will also experience job losses in the area of automobile manufacturing, as this sector transitions out of producing gasoline and diesel-powered vehicles and into producing zero-emissions electric and hydrogen-powered cars. Hereafter, we will interchangeably refer to both gasoline and diesel-powered vehicles as "internal combustion engine powered vehicles", or ICEVs and zero-emissions electric and hydrogen-powered vehicles as ZEVs. The job losses from phasing out ICEV manufacturing will be offset by the jobs that are created as Korea advances with its project to become a global leader in manufacturing ZEVs. We therefore estimate the *net impacts* of Korea's transition in auto manufacturing separately, as distinct from the job losses resulting from phasing out fossil fuel consumption. Finally, we also estimate the impact on employment resulting from the 15 percent reduction in nuclear energy production in South Korea between 2022 – 2030. We will then provide an overall estimate of potential job losses resulting through all three of these channels.

Our estimates of potential employment contractions and layoffs in Korea's fossil fuel-based industries as well as its auto manufacturing and nuclear power industries can then provide a framework for designing just transition policies to support the workers experiencing layoffs. We conclude this section of the study by briefly reviewing what might serve as effective just transition policies for these workers.

Focus on Direct Job Losses

Our primary focus in this section is on the *direct* jobs that will be lost in Korea through the contraction of the economy's fossil fuel-based industries and nuclear energy production as well as the transition from ICEV to ZEV manufacturing. Our reasoning for focusing on the contraction of direct jobs is the same as we discussed above with respect to the job quality issues regarding clean energy investments. That is, the direct jobs that will be lost in Korea through the cuts in CO_2-generating energy sources or nuclear power production are the jobs that are, at present, most closely associated with the economy's fossil fuel-based industry and nuclear power activities. The workers currently employed in these jobs will therefore be the ones that will be most in need of just transition support as Korea phases out these activities.

The jobs that will be lost through the indirect and induced channels will be more diffuse in their characteristics. A high proportion of the jobs lost through the indirect channels are likely to match up reasonably well with those in the clean energy economy, including in areas such as administration, clerical, professional services, and transportation services. The characteristics of the induced jobs created will simply reflect the overall characteristics of Korea's present-day workforce. The job losses that will result through the indirect and induced channels can therefore be appropriately managed through the same set of policies that are available to all workers in Korea who experience unemployment.

Measuring Direct Employment Levels for Fossil Fuel-Based Industries

In Table 4.1, we show employment levels for the 9 fossil-fuel and ancillary industries in South Korea as of 2018. This includes employment in managing oil and gas stations, which, as the table shows, is the largest source of employment among all fossil fuel-based activities.

TABLE 4.1
Number of Workers in South Korea Employed in Producing Fossil Fuel-Based Energy and Related Commodities, 2018

Commodity	2018 Employment levels	Share of total fossil fuel-based employment
Gas and oil stations	63,000	44.5%
Fossil fuel electric supply	32,280	22.8%
Wholesale distribution of liquid fuels and related products	14,740	10.4%
Gas manufacturing; distribution of gaseous fuel through mains	14,654	10.4%
Refinery products of crude oil	8,367	5.9%
Coal	4,227	3.0%
Manufacturing of machinery and equipment, mining, oil and gas fields	3,490	2.5%
Pipeline transportation	420	0.3%
Crude petroleum and natural gas	284	0.2%
Total employment in fossil fuel-based energy and related commodities	***141,462***	***100.0%***
TOTAL FOSSIL FUEL EMPLOYMENT AS SHARE OF SOUTH KOREA EMPLOYMENT *(South Korea 2018 employment = 24.5 million)*	**0.6%**	

Note: The jobs figure for gas and oil stations are extrapolated from the number of workers reported for this sector in the 2015 Economic Census. See Appendix 1 for details.

Source: Sector specific figures are based on LLFS 2019; 2015 Economic Census; and Bank of Korea Economic Statistics System. Employment figure for total employment is based on Bank of Korea Economic Statistics System. See Appendix 1 for details.

As we see, as of 2018, the level of employment in the fossil fuel and ancillary industries in Korea is 141,462 jobs.[61] This level of employment in South Korea's fossil fuel-based industries accounts for only 0.6 percent—a bit more than one-half of one percent—of all employment in the country.

Of this total, 63,000, amounting to 45 percent, are employed in oil and gas stations. Of the remaining 55 percent, 32,280, or 23 percent, are employed in supplying fossil fuels to generate electricity. There are two other sub-sectors which, respectively, employ over 10 percent of the fossil fuel-based workforce each. These are wholesale distribution of liquid fuels and related products; and gas manufacturing. These four largest sources thus account for nearly 90 percent of all fossil fuel-based employment in South Korea.

Characteristics of Fossil Fuel-Based Industry Jobs

Table 4.2 provides basic figures on the characteristics of the direct jobs in South Korea for workers in fossil fuel-based sectors. The first key point here is the sharp disparity between the pay and benefits for workers employed in the oil and gas stations versus the other fossil fuel-based industries. The average pay and benefits received by gas station workers is KRW 25.4 million and only about 41 percent are "regular jobs." As we discussed in Section 3, "regular jobs" are those that have either fixed contracts of over one year or have open-ended contracts. Workers with regular jobs also have access to better social insurance benefits, including unemployment insurance, industrial accident insurance, national medical care, national pensions, and severance pay. By contrast, workers with "non-regular jobs" include those with temporary jobs, daily or on-call jobs, as well as subcontract workers, independent contractors and the self-employed, among others.

Workers in the other fossil fuel-based industries receive nearly twice the pay level, at KRW 47.8 million and more than twice as many—i.e. nearly 85 percent—have regular jobs. One factor contributing to the high quality standards in these jobs is there is a high proportion of public enterprises operating in these sectors. Workers employed in public enterprises have relatively high union membership rates and are guaranteed retirement at age 60.

TABLE 4.2
Job Quality Indicators for South Korea's Fossil Fuel-Based Energy Sectors
Figures are for direct jobs only

	Average annual pay: wages and benefits	Percent regular workers
Gas and oil stations *(63,000 jobs)*	KRW 25.4 million	40.9%
All other fossil fuel-based energy sectors *(78,462 jobs)*	KRW 47.8 million	84.7%
Overall South Korea economy	**KRW 32.1 million**	**51.8%**

Note: Regular workers are those with a fixed contract of at least one year or an open-ended contract. Most workers with regular jobs have social insurance benefits, including unemployment insurance, industrial accident insurance, and severance pay.

Source: Figures for overall workforce are based on the Local Area Labor Force Survey (LLFS), 2019. Sector specific figures are based on LLFS 2019; 2015 Economic Census; and Bank of Korea Economic Statistics System. See Appendix 1 for details.

Relative to the economywide averages, gas station workers receive about 20 percent lower pay than the average, while workers in the other fossil fuel-based industries are paid about 50 percent more than the average. The differences are similar in terms of the share of regular jobs—i.e. the share of gasoline station workers is about 10 percentage points lower than average while the share for the other fossil fuel-based industries is about 30 percentage points higher.

The sharp differences between gas station workers and those in other fossil fuel-based industries is also evident through comparing their respective levels of educational credentials. As we show in Table 4.3, nearly two-thirds of gas station workers have high school degrees or less while 22 percent have Bachelor's degrees or higher. By contrast, for those in the other fossil fuel-based industries, only about one-third have high school degrees or less while nearly half have Bachelor's degrees or higher.

The one area in which the employment patterns are similar between the gas station workers and those in the other fossil fuel-based industries is the gender composition of the respective workforces. That is, only about 19 percent of gas station workers are women. The share is even lower, at 14 percent, for the other fossil fuel-based activities.

Overall, we can conclude that, on average, employment in the fossil fuel-based industries other than gas stations provides relatively high-quality jobs for workers who have relatively high educational credentials. By contrast, working in gas stations are relatively low-quality jobs. Finally, these conditions—both the high-quality and low-quality jobs—apply across-the-board, for the most part, to men.

These figures provide background for considering what might be an appropriate set of policy responses in light of the fact that all these areas of employment will be contracting as Korea phases out fossil fuel consumption. It will nevertheless still be critical to examine more specific data on how the phasing out of these fossil fuel industries will impact workers. We therefore next provide estimates as to the pattern in which jobs are likely to be lost during the phase out period, initially through 2030.

TABLE 4.3
Worker Characteristics for South Korea's Fossil Fuel-Based Energy Sectors
Figures are for direct jobs only

	Educational credentials			Share of women in workforce
	High school degree or less	Some college or Associate degree	Bachelor's degree or higher	
Gas and oil stations *(63,000 jobs)*	62.9%	14.6%	22.4%	18.5%
All other fossil fuel-based energy sectors *(78,462 jobs)*	34.9%	16.1%	49.0%	14.0%
Overall South Korea economy	**47.7%**	**14.2%**	**38.1%**	**43.0%**

Note: "All Other Fossil Fuel-Based Energy Sectors" includes workers engaged in the production of the following commodities: Fossil fuel electric supply; Wholesale of liquid fuels and related products; Gas manufacturing, distribution of gaseous fuel through mains; Refinery products of crude oil; Coal; Manufacturing of machinery and equipment, mining, oil and gas fields; Pipeline transportation; Crude petroleum and natural gas.

Source: Figures for overall workforce are based on the Local Area Labor Force Survey (LLFS), 2019. Sector specific figures are based on LLFS 2019; 2015 Economic Census; and Bank of Korea Economic Statistics System. See Appendix 1 for details.

Steady versus Episodic Industry Contraction

Before presenting the actual estimates on employment losses, we first need to highlight a crucial distinction between a steady versus an episodic contraction pattern for Korea's fossil fuel-based industries. The scope and cost of any set of just transition policies will depend heavily on whether the contraction is steady or episodic. Under a pattern of steady contraction, there will be uniform annual employment losses in Korea over both the 2022 – 2030 and 2031 – 2050 periods, with the steady rates determined by the overall level of industry contraction within the given time period. But it is not realistic to assume that the pattern of industry contraction will necessarily proceed at a steady rate. An alternative pattern would entail relatively large episodes of employment contraction, followed by periods in which a much smaller amount of employment losses occur. This type of pattern would result, for example, if one or more relatively large fossil fuel-based firms were to undergo large-scale cutbacks, or even shut-downs, at a given point in time.

The costs of a just transition will be much lower if the transition is able to proceed smoothly rather than through a series of episodes. As will be clear from the figures below, one important reason for this is that, under a smooth transition, the proportion of workers who will leave the labor force through retirement in any given year will be predictable. This will enable the transition process to avoid having to provide support for a much larger share of workers who will experience displacement, i.e. job loss and the need to become reemployed. The share of displaced workers requiring support would rise if several large businesses were to shut down abruptly and lay off their full work force at once, including both younger as well as older workers. Similarly, it will be easier to find new jobs for displaced workers if the pool of displaced workers at any given time is smaller.

In our calculations below, we proceed by assuming that Korea will successfully implement a relatively smooth contraction of its fossil fuel industries. This indeed would be one important feature of a well-designed and effectively implemented just transition program. As a practical matter, a relatively smooth transition should be workable as long as policymakers remain focused on that goal.

Labor Force Attrition in Fossil Fuel-Based Industries through Retirements

As noted above, the impact of the fossil fuel-based industry's contraction on workers in the industry will be strongly influenced by the pattern at which workers will be leaving the workforce through retirement. As such, we need to estimate how the retirement rates in the relevant sectors are likely to proceed.

To estimate the labor force attrition rate in the fossil fuel-based industries due to retirement, we take into account the following:

- The South Korean labor market operates with what is termed a "mandatory" retirement age of 60.
- In practice, employers frequently force workers to retire through formal and informal mechanisms, lowering the typical retirement age to younger than 60. Workers retiring before turning 60 will frequently retire at around 55.[62]

- A high proportion of workers do not actually leave the labor force once they "retire" from their existing jobs at somewhere between the ages of 55 and 60. Rather, approximately 58 percent remain in the labor force, but change their status to a short-term fixed contract arrangement or to self-employment.[63] These workers frequently accept post-retirement jobs that provide lower pay and fewer benefits.

Following from these considerations, we estimate labor market attrition rates as follows:

- We estimate the percentage of fossil fuel-based workers who will turn 55 or older over the period 2022 – 2030.
- We then estimate the percentage of that cohort of workers that are likely to leave the labor force, based on data from the "Economically Active Population Survey" from Statistics Korea.[64]

The figures we report in Table 4.4 incorporate these assumptions into our calculations.

Employment Contraction Rates

Table 4.4 shows our estimates on annual employment reductions in South Korea's fossil fuel-based industries over 2022 – 2030 that would result from a steady contraction of these industries. We also incorporate into Table 4.4 the employment contraction pattern for Korea's nuclear power industry. This employment contraction in Korea's nuclear energy industry will reflect the 15 percent reduction of nuclear power generation between 2022 – 2030, as we discussed in Section 2.

We also then show estimates as to the proportion of workers who will move into retirement by 2030 both in the fossil fuel and nuclear energy industries. Once we know the share of workers in both the fossil fuel and nuclear energy industries who will move into retirement over this time period, we can then estimate the number of workers who will be displaced as South Korea reduces its fossil fuel-based industries by 45 percent through 2030 and cuts nuclear power generation by 15 percent.

We can see, step-by-step, how these various considerations come into play through the figures we report in Table 4.4. We begin with column 1, showing figures for gas station workers. There were, again, as of the most recent 2018 figures, about 63,000 gas station workers employed throughout South Korea. We assume that economic activity in this sector, as with all fossil fuel-based industries, will contract by 45 percent as of 2030. As we see in row 2 of the table, this means that total employment in these sectors will fall by 28,350 as of 2030. This in turn means that there will be 34,650 jobs retained in gas station employment as of 2030 (i.e. 63,000 - 28,350 = 34,650). If we then assume that the contraction in these industries proceeds at a steady rate between 2022 – 2030, this means that 3,150 jobs in these industries will be lost each year, as we see in row 3 (i.e. 28,350 job losses in total/9 years of industry contraction = 3,150 job losses per year).

We see in row 4 that, of the workers presently employed in gas stations, 63 percent of them—i.e. 39,690 in total—will reach the age of 55 or over during 2022 – 2030. Working from the Korean labor market statistics, we estimate that 42 percent of these 55 and over workers will actually leave the labor force after they reach age 55. That means that a total

TABLE 4.4
Attrition by Retirement and Job Displacement for Fossil Fuel and Nuclear Power Industry Workers in South Korea, 2022 – 2030

	1) Gas station workers	2) Other fossil fuel workers	3) All fossil fuel workers *(columns 1 + 2)*	4) Nuclear power workers	5) All workers *(columns 3 + 4)*
1) Total workforce as of 2018	63,000	78,462	141,462	11,696	153,158
2) Job losses over 9-year transition, 2022-2030 *(=row 1 x % of total jobs lost)*	28,350 *(45% of all jobs)*	35,308 *(45% of all jobs)*	63,658	1,754 *(15% of all jobs)*	65,412
3) Average annual job loss over 9-year production decline *(= row 2/9)*	3,150	3,923	7,073	195	7,268
4) Number of workers reaching "old age" (55 yrs. and over) during 2022-2030 *(=row 1 x % of workers at least 46 yrs. old in 2021*)*	39,690 *(63% of all workers)*	40,016 *(51% of all workers)*	79,706	5,263 *(45% of all workers)*	84,969
5) Number of workers who reach 55 yrs. and over during 2022-2030 and leave the labor force *(=row 4 x % of 55+ yrs. old not in the labor force**)*	16,670 *(42% of 55 and over workers)*	16,807 *(42% of 55 and over workers)*	33,477	2,211 *(42% of 55 and over workers)*	35,688
6) Number of workers per year retiring and leaving the labor force during 9-year transition period *(=row 5/9)*	1,852	1,867	3,720	246	3,965
7) Number of workers displaced/ requiring re-employment *(= row 3 – row 6)*	1,298	2,056	3,354	0	3,354***

Note:
*We assume that this share is well approximated by the worker characteristics in 2019.
**According to Statistics Korea, 57.6 percent of those aged 55 and older were in the labor force and 42.4 percent were not in the labor force in 2019.
***Note that this figure does not equal row 3 minus row 6 because for nuclear power electricity workers there are more workers voluntarily retiring than there are job losses (col. 4), i.e., row 3 minus row 6 in column 4 is a negative number. However, we simply treat this as zero displaced workers.
Source: Tables 4.1-4.3.

of 16,670 gas station workers will leave the labor force between 2022 – 2030. As we show in row 6, the average rate of labor force exits per year among these gas station workers is therefore 1,852.

Given that total job losses in gas station employment will average 3,150 per year over the 2022 – 2030 period, that in turn means that the total number of workers currently employed in Korea's gas station sector that will experience displacement and will require re-employment will be 1,298 workers per year. We show this figure in row 7 of Table 4.4.

In column 2, we work through the same set of calculations for the 78,462 workers employed in all other fossil fuel-based sectors in Korea. As we see in row 7 of column 2, our estimate is that 2,056 workers per year in Korea's fossil fuel-based sectors will experience displacement and require reemployment between 2022 – 2030. In column 3, we add the figures in columns 1 and 2, combining our estimates for both gas station and other fossil fuel-industry based workers. We see in row 7 of column 3 that we estimate that a total of 3,354 fossil fuel-based workers in all sectors that will be displaced and require reemployment resulting from the 45 percent contraction of fossil fuel consumption in South Korea as of 2030.

Column 4 then proceeds through the same set of calculations, as applied now to the 11,696 workers in South Korea's nuclear power industry. For this case, we calculate that, after accounting for voluntary retirements, no job displacements will result through the 15 percent contraction of nuclear power generation by 2030.

This is a critical result. Of course, these figures are not meant to be precise estimates. They rather aim to provide broadly accurate approximations. Among other factors beyond what these figures themselves show, we again have to recognize that the pattern of contraction is not likely to be as smooth as is being assumed in our calculations. Nevertheless, precise details aside, it is the overall finding from this steady contraction pattern that is most central: that the number of workers in South Korea who are likely to experience job displacement through the country transitioning away from CO_2-generating energy sources will be negligible, especially in comparison with the more than 800,000 new jobs that will be created through the clean energy investment program through 2030. The same broad conclusion holds true with respect to the 15 percent contraction in nuclear power generation. Given that there are over 150,000 people employed presently in Korea's fossil fuel-based and nuclear power industries, we acknowledge that it may appear implausible that there should be only about 3,000 – 4,000 workers per year who would be displaced through a program to cut consumption from CO_2-generating energy sources by 45 percent as of 2030. Nevertheless, this result emerges straightforwardly through the calculations we present in Table 4.4.

Transition in Auto Manufacturing from ICEVs to ZEVs

Korea has not established a firm target date for phasing out either the sale or manufacture of ICEVs. In 2019, President Moon set a goal that 30 percent of all vehicles manufactured in Korea would be ZEVs.[65] The government has also discussed a provisional date of 2035 for ending sales of combustion engine vehicles, but nothing has been mandated.

In part, the delay in setting a firm timeframe reflects concern among Korea's manufacturers that a 2035 phase-out is too soon for enabling producers to make a relatively smooth transition to an all zero-emissions fleet.[66] At the same time, as of the November 2021 COP26 conference, 26 national governments and nearly 48 regional, state and municipal governments pledged to end the sale of fossil fuel-powered vehicles by 2040 or sooner within their areas of jurisdiction. Eleven auto manufacturers, including Ford, General Motors and Mercedes-Benz, also pledged at COP26 to exclusively produce ZEVs by 2040.[67]

It is likely that Korean manufacturers will need to commit to a similarly robust transition program in order to remain competitive in the global auto manufacturing market. Hyundai has already moved in this direction, announcing in September 2021 that it will stop selling traditional combustion engine vehicles in Europe in 2035 and in other major markets as of 2040. It also committed to completely migrate to battery and fuel cell vehicles by 2045.[68]

Given these developments, we work here with the assumption that South Korea will proceed to phase out ICEV manufacturing and expand ZEV manufacturing at the rate proposed by the International Energy Agency in its 2021 study *Net Zero by 2050*. In this IEA study, ZEVs account for 60 percent of all auto manufacturing by 2030 and 100 percent by

TABLE 4.5
Direct and Indirect Job Creation in South Korea through Manufacturing Internal Combustion Engine Powered (ICEVs) versus Electric and Hydrogen-Powered Vehicles (ZEVs)
Job creation per KRW 1 billion in efficiency investments

	Direct jobs	Indirect jobs	Direct+ indirect jobs
Internal Combustion Engine Powered Vehicles (ICEVs)	1.8	6.0	7.8
Electric and Hydrogen-Powered Vehicles (ZEVs)	2.1	4.8	6.9

Source: See Appendix 1.

2035. We therefore assume here that ICEV manufacturing will contract by 60 percent as of 2030 and end altogether by 2035. The question we consider here is what impact this transition will have on overall employment in the Korean auto manufacturing sector.[69]

Table 4.5 shows estimates of the direct and indirect employment/output ratios for both ICEVs and ZEVs in South Korea. As the table shows, we estimate that manufacturing ICEVs in Korea generates 1.8 direct jobs and 6.0 indirect jobs per KRW 1 billion in expenditures, for a direct plus indirect job total of 7.8 jobs per KRW 1 billion. By contrast, producing ZEVs in South Korea will produce 2.1 direct plus 4.8 indirect jobs, for a total of 6.9 direct plus indirect jobs per KRW 1 billion. Thus, in considering comparative overall job creation, a shift from manufacturing ICEVs to ZEVs in Korea would reduce employment by about 11 percent in the auto manufacturing sector.

However, it is also the case that the transition from ICEV to ZEV manufacturing will entail a shift in the composition of employment in Korea's auto industry. Specifically, the 7.8 jobs per KRW 1 billion to manufacture ICEVs are concentrated almost entirely in building the engine and parts and in assembling the vehicle.[70] By contrast, with ZEVs, we estimate from Korea's industrial structure that about 40 percent of employment will be in the areas of battery manufacturing, semiconductor manufacturing and various types of R&D work. As such, only about 4.5 jobs per KRW 1 billion in ZEV manufacturing will be in activities that are equivalent to ICEV manufacturing.

Overall then, we estimate that about half of the workers employed in ICEV manufacturing will be able to readily transfer into comparable positions in ZEV manufacturing. The other half of the ICEV workforce will need to be trained in other areas of ZEV auto manufacturing, such as battery production, or move into new positions in other economic sectors.

Estimating Job Losses through ICEV to ZEV Auto Manufacturing

Based on our assumption of an approximately 50 percent rate of job loss in the traditional areas of employment in ICEV manufacturing, we can estimate the extent of job loss in this sector through 2030. As noted above, our estimate will assume that ICEV manufacturing in Korea contracts by 60 percent as of 2030. We also work with the same set of assumptions as in the discussion above on fossil fuel, gas station, and nuclear power workers as to the rate at which workers will retire through 2030, given the current age composition of the workforce.

Table 4.6 shows the set of calculations through which we generate our job loss estimate. To begin with, row 1 shows that employment in Korea's auto manufacturing sector as of 2018 is 367,778. This figure is about 2.5 times larger than the 153,158 workers employed in Korea's fossil fuel-based sectors, including gas stations, as well as its nuclear power generating sector. This auto manufacturing employment level amounts to about 1.5 percent of overall employment in Korea.

Working with our assumptions that 1) ICEV manufacturing will fall by 60 percent as of 2030 and 2) 50 percent of auto manufacturing employment will be lost through the transition from ICEV to ZEV manufacturing, we show in row 2 of Table 4.6 that this will result in a 30 percent loss of overall auto manufacturing jobs as of 2030—i.e. a loss of 110,333 jobs. Averaged over the 9-year transition from 2022 – 2030, and assuming a steady transition process, this means that an average of 12,259 jobs will be lost in Korea's auto manufacturing sector through the transition from ICEV to ZEV manufacturing.

TABLE 4.6
Attrition by Retirement and Job Displacement for Auto Manufacturing Workers in South Korea
Steady Transition, 2022 – 2030

	Auto manufacturing workers
1) Total workforce as of 2018	367,778
2) Job losses over 9-year transition, 2022-2030 *(= row 1 x 0.30)* *Assume: 60% ICEV contraction by 2030; 50% of ICEV job losses transfer automatically into ZEV manuf. jobs*	110,333
3) Average annual job loss over 9-year production decline *(= row 2/9)*	12,259
4) Number of workers reaching 55 yrs. and over during 2022-2030 *(=row 1 x % of workers at least 46 yrs. old in 2021*)*	150,789 *(41% of all workers)*
5) Number of workers who reach 55 yrs. and over during 2022-2030 *and* leave the labor force *(=row 4 x % of 55+ yrs. old not in the labor force**)*	63,331 *(= 42% of 55 and over workers)*
6) Number of workers per year retiring and leaving the labor force during 9-year transition period *(=row 5/9)*	7,037
7) Number of workers requiring re-employment *(= row 3 – row 6)*	5,222

Note:

*We assume that this share is well-approximated by the worker characteristics in 2019.

**According to Statistics Korea, 57.6 percent of those aged 55 and older were in the labor force and 42.4 percent were not in the labor force in 2019.

Source: Local Area Labor Force Survey (LLFS) 2019; and Bank of Korea Economic Statistics System. See Appendix 1 for details.

In rows 4 – 6, we proceed through the equivalent set of calculations as we performed above for the fossil fuel-based and nuclear power sector workers to estimate the retirement and labor force exit rates for auto manufacturing workers between 2022 – 2030. Thus, we estimate that 150,789 workers within the existing auto manufacturing labor force will reach age 55 or older. Of these 150,789 workers, we estimate that 63,331 will exit the labor force as of 2030. This averages to 7,037 auto manufacturing workers leaving the labor force every year between 2022 – 2030.

Finally, in row 7, we compare our estimate of 7,037 workers per year exiting the auto manufacturing labor force between 2022 – 2030 with the 12,259 jobs that will be lost per year, on average, through Korea's transition from ICEV to ZEV manufacturing over these 9 years. As we see in row 7, the figure for workers displaced and requiring reemployment will be 5,222.

Of course, as noted above in the discussion on job losses among fossil fuel-based industry workers, these figures with respect to auto manufacturing workers are also not meant to be understood as precise estimates, but rather to provide broadly accurate magnitudes. As one complicating factor relative to our calculations, we cannot be certain that ZEV manufacturing will expand to 60 percent of overall auto manufacturing by 2030, and that, correspondingly, ICEV manufacturing will contract by 60 percent. The extent of job displacement will depend on what the actual pace is at which Korea transitions from ICEV to ZEV manufacturing.

Just Transition Policies for Displaced Workers

We have estimated that, between 2022 – 2030, there will be a relatively small number of workers who will face job displacement as a result of the 45 percent contraction in the consumption of oil, coal and natural gas in South Korea. Our estimate, again, is that about 3,400 workers will be displaced. This job displacement figure includes our estimate that about 7,100 jobs per year will be eliminated in Korea's fossil fuel-based industries between 2022 – 2030 but that, concurrently, about 3,700 workers in these areas of employment will be retiring and leaving the labor force. These figures include both workers employed in gas stations as well as in all other areas of fossil fuel-based employment. We also estimated that no nuclear power industry workers will face displacement over 2022 – 2030.

We calculated that the transition of South Korea's auto manufacturing industry from internal combustion engine vehicle to zero-emissions vehicle production is likely to produce a larger pool of displaced workers, averaging about 5,200 per year, between 2022 – 2030, as ICEV manufacturing contracts by 60 percent as of 2030. This is because, by our estimates, about 12,300 jobs will be lost per year in auto manufacturing through the transition from ICEV to ZEV production, but that about 7,000 workers per year will be retiring and leaving the labor force in Korea's auto manufacturing industry.

These estimates do assume that the transition out of both fossil fuel consumption, nuclear power, and ICEV manufacturing in South Korea will proceed in a relatively steady pattern. If the transition is more irregular and episodic, the figures on job displacements will be higher. This is because the number of workers who would lose their jobs when very large layoffs occur in an irregular pattern will likely be larger than the steady number of workers who will be leaving the labor force at any given time. But even if we assume that job displacements in a few years of heavy layoffs would be twice as high as the average of 8,600 workers per year under a steady transition—i.e. if we assume, for example, that the job displacement figure is closer to 18,000 workers during years of heavy layoffs—the overall number of displaced workers even in those heavy lay-off years will remain relatively modest in comparison with our estimate that job creation from building a clean energy infrastructure in South Korea will generate over 800,000 new jobs.

Even though the number of workers that will be displaced through South Korea's clean energy transition will likely be relatively small under either a steady or episodic transition pattern through 2022 – 2030, it is nevertheless critical that policies be established to provide displaced workers with transitional support. We do not attempt in this study to develop a specific just transition program.[71] But as a basic framework, we propose that a just transition program should include the following forms of support for all displaced workers:

- **Employment guarantees.** These would be new employment opportunities made available within the pool of more than 800,000 jobs generated by the clean energy transition program. As needed, additional employment opportunities could be provided through public-sector employment more generally. These guarantees should be made available to all workers facing displacement, including those employed in subcontracting firms.
- **Wage insurance.** At least for an initial period of 2 – 3 years, displaced workers should be guaranteed to receive compensation at their new jobs that would at least equal their pay levels in their fossil fuel-based industry jobs.
- **Retraining support.** This would include sufficient levels of retraining, as needed, for all displaced workers.
- **Relocation support.** Displaced workers should receive a one-time payment, as needed, to cover the costs that they will incur in the event they need to relocate when accepting a new job.
- **Pension guarantees.** This form of support should be provided for all workers, those moving into retirement as well as those with ongoing retirement accounts with their existing employers. This provision should also be extended to workers holding severance pay arrangements.

Because the number of displaced workers will be relatively small, it follows that the costs of providing generous just transition support for all displaced workers in the areas that we have highlighted will be correspondingly modest. Especially in light of its relatively small costs, establishing a set of generous just transition programs for all displaced fossil fuel-based industry workers should be incorporated as a central feature of South Korea's overall clean energy transition project.

5. ACHIEVING A ZERO EMISSIONS ECONOMY BY 2050

If South Korea is able to bring overall CO_2 emissions in the country down to approximately 350 million tons by 2030—a 45 percent decline relative to the 2018 level of 631 million tons—it should also be able to establish a zero emissions economy by 2050.

In fact, enabling Korea to meet its 2050 emissions reduction target will not require fossil fuel energy consumption in the country, and thereby CO_2 emissions, to fall precisely to zero. This is because, as we have discussed in Section 3, as much as 21 million tons of CO_2 emissions can be absorbed by 2050 through the country's reforestation program. Nevertheless, as a means of simplifying the analysis here, we assume that the goal will be for South Korea to reach zero emissions by 2050. The global climate stabilization project would then be further strengthened as the country's reforestation program contributes to absorbing the accumulated stock of CO_2 in the atmosphere.

South Korea should be able to establish a zero-emissions energy infrastructure as of 2050 basically through continuing the clean energy investment project that will have advanced over 2022 – 2030. Moreover, on an annual basis, the scale of the investments in energy efficiency and clean renewable energy between 2031 – 2050 that will be needed to reach zero emissions by 2050 will be significantly smaller than what would be needed between 2022 – 2030.

As we saw in Table 2.7, our estimate of the clean energy investment costs for bringing emissions down from 631 to 350 million tons by 2030 was about 3.6 percent of Korea's GDP per year between 2022 – 2030. Over 2031 – 2050, as we will see, we estimate that the average annual clean energy investment costs necessary to bring emissions down to zero to be about 1.4 percent of Korea's average GDP. The impact of the smaller investment project on job opportunities throughout the country will also be more modest than during 2022 – 2030, though still strongly in the positive direction.

We do not attempt to develop here an assessment as to the range of technical requirements for achieving a zero emissions economy in South Korea by 2050. But as we have briefly reviewed in Section 1, a substantial literature does examine these technical requirements in depth, both for South Korea specifically and on a global basis.[72]

Within a framework that recognizes the technical feasibility of bringing CO_2 emissions to zero by 2050, our focus here is to assess the economic trajectory of how this goal can be accomplished while the country's overall GDP and job opportunities continue to grow. Of course, considering how such a trajectory is likely to proceed entails making a series of assumptions about the economy's long-term growth path. This exercise necessarily becomes increasingly speculative the further out one moves in time. To keep our discussion grounded within a realistic framework, we rely on a small number of assumptions that are credible within the body of knowledge that is available to us at present.

The assumptions on which we rely are as follows:

1. *Economic growth.* We assume that average economic growth in South Korea proceeds at the same rate as we have assumed for 2022 – 2030, i.e. at 2.5 percent per year.
2. *Energy efficiency.* We have already assumed that Korea will have achieved major gains in energy efficiency between 2022 – 2030. Specifically, we assume that the economy's energy intensity ratio will have fallen from 4.6 to 3.1 Q-BTUs per KRW 1,000 trillion of GDP—a 31 percent improvement, equal to a 4.1 percent improvement per year over 2022 – 2030. We assume that further efficiency gains are possible through continued investments, and that the costs of achieving these efficiency gains will remain at KRW 35 trillion per Q-BTU, the same cost figure for our 2022 – 2030 scenario. We base this assumption of stable overall costs on two considerations: 1) technological improvements will occur in raising efficiency standards; but 2) the "low-hanging fruit" possibilities for efficiency gains will have dissipated. We assume that these two factors will roughly counterbalance each other.
3. *Clean renewable energy.* Technological advances in generating, storing and transmitting renewable energy will certainly occur between 2031 – 2050, especially given that these industries will have already scaled up dramatically over 2022 – 2030. But to proceed cautiously, we assume only a modest rate of average technological improvement for renewables overall—that the average costs of creating 1 Q-BTU of renewable capacity falls at an average rate of 1.0 percent per year between 2031 – 2050. This is a modestly slower rate of technical improvement than the 1.5 percent rate we assumed for 2022 – 2030. We make this conservative assumption in our calculations to reflect the difficulties that may be encountered in sustaining technical advances over a period of decades after an initial set of innovations have been achieved. Working with this assumption implies that the average cost of expanding renewable energy supply will fall from our average figure for 2022 – 2030 of KRW 213 trillion per Q-BTU to an average of KRW 177 trillion over 2031 – 2050.
4. *Job creation.* We again examine employment creation generated through three channels: 1) energy efficiency and clean renewable energy investments; 2) reforestation investments; and 3) the transition from purchasing imported fossil fuel energy to producing clean energy within Korea's domestic economy. We then estimate job creation figures under two alternative assumptions: that overall labor productivity (i.e. the weighted average of employment/output ratios for the individual investment activities) remains fixed at its 2022 level, or, alternatively, that overall labor productivity improves at an average annual rate of 1.5 percent per year.

Working from these assumptions on 1) economic growth; 2) the costs of achieving energy efficiency gains and an expanded clean renewable energy supply; and 3) labor productivity, we then develop projections as to how South Korea could become a zero emissions economy by 2050. We present these results in Tables 5.1 – 5.3.

In Table 5.1, we show South Korea's GDP projection for 2050 based on a 2.5 percent average annual growth rate for 2031 – 2050. This growth path begins at the 2030 GDP baseline of KRW 2,419 trillion. This figure is itself a projection, of course, which we derived through assuming that Korea's GDP would grow at an average annual rate of 2.5 percent between 2021 – 2030, starting from the 2020 actual GDP level of KRW 1,890 trillion. Based on these assumptions, as we see in Table 5.1, South Korea's GDP will be KRW 3,964 trillion in 2050. We then calculate the midpoint GDP level between 2031 – 2050—i.e. at 2040—under this scenario. As we see, the estimated GDP at the 2040 midpoint will be KRW 3,097 trillion.

TABLE 5.1
GDP Level for 2020 and Projections for 2031, 2040, and 2050
Figures are in constant 2020 KRW

2030 GDP	KRW 2,419 trillion
Projected average growth rate through 2050	2.5%
Projected 2031 GDP	KRW 2,479 trillion
Projected 2040 GDP	KRW 3,097 trillion
Projected 2050 GDP	KRW 3,964 trillion

Source: KEEI and authors' calculations.

TABLE 5.2
Assumptions for South Korea Clean Renewable Investment Proportions, 2031 – 2050

Solar investments	**46%**
Solar, onshore, community, commercial, residential	25%
Solar, onshore utility scale	18%
Solar, offshore utility scale	3%
Wind investments	**49%**
Wind, offshore	23%
Wind, onshore	26%
Additional renewable investments	**5%**
Low-emissions bioenergy	1.25%
Tidal	1.25%
Small-scale hydro	1.25%
Geothermal	1.25%

In Table 5.2, we show our assumptions as to the relative shares at which Korea's renewable energy infrastructure will develop over 2031 – 2050. We again developed these assumptions on the basis of consultations with Dr. Pil Seok Kwon of the Green Energy Strategy Institute. As Table 5.2 shows, for 2031 – 2050, we assume that solar investments will equal 46 percent of the total. Solar onshore, community, commercial and residential projects are at 25 percent of the 46 percent total; solar onshore utility scale projects are at 18 percent; and solar offshore utility scale are at 3 percent. We assume that wind investments will total to 49 percent of the total over 2031 – 2050, with offshore projects at 23 percent and onshore at 26 percent. The remaining 5 percent of overall renewable investments are again divided equally between low-emissions bioenergy, tidal, small-scale hydro and geothermal.

In Table 5.3, we then present a simple scenario for Korea to reach zero fossil fuel consumption and, correspondingly, zero CO_2 emissions, by 2050. The key features of this scenario include the following:

1. Korea's energy intensity ratio falls from the 2030 figure of 3.1 to 1.7 Q-BTUs of energy/KRW 1,000 trillion in GDP. This would represent a 45 percent improvement in average energy efficiency throughout the Korean economy. This is a roughly 3.0 percent improvement per year between 2031 – 2050.
2. We continue to assume that this gain in energy efficiency will generate a rebound effect of 10 percent. That is, given a GDP in South Korea of about KRW 4,000 trillion as of 2050 and an energy intensity ratio of 1.7, it follows that, absent any rebound effects, Korea's overall energy consumption in 2050 would be 6.7 Q-BTUs. But with the 10 percent rebound effect, total energy consumption in 2050 will be at 7.3 Q-BTUs.

TABLE 5.3
South Korea Energy Consumption and Emissions:
2030 and 2050 Projections

	1) 2030 through Clean Energy Investment Program	2) 2050 through Clean Energy Investment Program
1) Real GDP 2020	KRW 2,419 trillion	KRW 3,964 trillion
2) Energy intensity ratio *(Q-BTUs consumption/ KRW 1,000 trillion of GDP)*	3.1	1.7
3) Energy consumption *(Q-BTUs)*	7.9	7.3 *(= 6.7 with efficiency gain + 0.6 rebound effect)*
Energy mix for supply		
4) Non-renewables and bioenergy *(Q-BTUs—rows 5 – 9)*	*5.1*	*0.6*
5) Petroleum	1.4	0
6) Coal	1.4	0
7) Natural gas	1.2	0
8) Nuclear	1.1	0.6
9) High-emissions bioenergy	0.02	0
10) Clean renewables *(Q-BTUs = row 3 - row 4)*	*2.8*	*6.7*
11) Solar	1.8	3.1
12) Wind	0.8	3.2
13) Hydro	0.05	0.1
14) Tidal	0.05	0.1
15) Low-emissions bioenergy	0.05	0.1
16) Geothermal	0.05	0.1
Emissions		
17) Total CO_2 emissions *(million metric tons)*	350	0
18) Emissions intensity ratio *(CO_2 emissions per consumed Q-BTUs = row 17 / row 3)*	44.3	0

Source: For non-renewables and nuclear: KEEI (2021), see "Total Primary Energy Supply" table. For renewables: U.S. EIA (n.d.), "International -- South Korea."

3. All fossil fuel consumption will have been phased out by 2050. This is how South Korea can reach zero CO_2 emissions by 2050.
4. In line with the government's plan, we assume that nuclear energy in South Korea will be reduced to 0.6 Q-BTUs between 2031 – 2050.
5. With all fossil fuel energy having been phased out by 2050, and nuclear energy supply reduced to 0.6 Q-BTUs, it follows that 6.7 Q-BTUs of the economy's total energy demand of 7.3 Q-BTUs as of 2050 will be supplied by clean renewable energy sources. The figures in rows 11 – 16 of Table 5.3 reflect the relative shares of total renewable supply that we reported in Table 5.2, i.e. solar at 46 percent, wind at 49 percent and all other renewable sources providing the remaining 5 percent.

In Table 5.4, we then estimate the investment costs necessary between 2031 – 2050 for Korea to arrive at a 1.7 energy intensity ratio by 2050 and then for renewable energy supply to increase from its 2030 level of 2.8 Q-BTUs to 6.7 Q-BTUs. As we see in panel A of Table 5.4, we estimate the total cost of bringing energy intensity down from 3.1 to 1.7 Q-BTUs per KRW 1,000 trillion in GDP will be KRW 196 trillion. This amounts to an average of KRW 10 trillion per year over 2031 – 2050, or about 0.3 percent of average GDP over this 20-year span.

In panel B, we perform a comparable set of calculations for clean renewable energy investments between 2031 – 2050. As of 2030, clean renewable energy supply will be at 2.8 Q-BTUs. This means that the net expansion of clean renewables by 2050 will need to be 3.9 Q-BTUs. As we see in rows 3 – 6 of panel B, achieving this greater productive capacity in clean renewables will require a level of investment averaging KRW 35 trillion per year. This amounts to about 1.1 percent of South Korea's average GDP between 2031 – 2050.

In panel C, we then summarize these results for achieving zero emissions in South Korea as of 2050. As we see, we estimate these overall costs to be KRW 886 trillion, which averages to KRW 44 trillion per year over 2031 – 2050. As a share of South Korea's projected midpoint GDP over 2031 - 2050, these annual cost figures would amount to 1.4 percent of GDP. As mentioned above, these figures are significantly below the cost level we have estimated for the initial 2022 – 2030 investment period that would be necessary to bring Korea's CO_2 emissions down to 350 million tons by 2030. We estimated those costs to amount to about 3.6 percent of Korea's average GDP between 2022 – 2030.

TABLE 5.4
South Korea Clean Energy Investment Program for 2031–2050

A) Energy Efficiency Investments

1. 2050 Energy intensity ratio	1.7 Q-BTUs per KRW 1,000 trillion GDP (*45% improvement over 3.1 Q-BTU per KRW 1,000 trillion GDP 2030 ratio)*
2. Total energy consumption	7.3 Q-BTUs *(6.7 Q-BTUs = KRW 3,964 trillion GDP x 1.7 intensity ratio +0.6 Q-BTUs rebound effect)*
3. Total energy consumption at 2030 intensity ratio	12.3 Q-BTUs *(=KRW 3,964 GDP x 3.1 intensity ratio)*
4. Efficiency gains relative to 2030 intensity ratio before rebound effect	5.6 Q-BTUs *(= 12.3 Q-BTUs – 6.7 Q-BTUs in consumption prior to 0.6 Q-BTUs rebound effect)*
5. Energy saving relative to 2030 after rebound effect	5.0 Q-BTUs *(=12.3 Q-BTUs – (6.7 Q-BTUs in consumption prior to rebound effect + 0.6 Q-BTUs))*
6. Average investment costs per Q-BTU in efficiency gains	KRW 35 trillion per Q-BTU
7. Costs of efficiency gains	KRW 196 trillion *(=KRW 35 trillion x 5.6 Q-BTUs in savings)*
8. Average annual costs over 2031 – 2050	KRW 10 trillion *(= KRW 196 trillion/20 years)*
9. Average annual costs of efficiency gains as % of 2040 midpoint GDP	0.3% *(= KRW 10 trillion/KRW 3,097 trillion)*

B) Clean Renewable Energy Investments

1. Total renewable supply necessary	6.7 Q-BTUs *(=7.3 total consumption – 0.6 in nuclear supply in 2050)*
2. Expansion of renewable supply relative to 2030 level	3.9 Q-BTUs *(=6.7 Q-BTUs – 2.8 Q-BTUs of 2030 clean renewable energy supply)*
3. Average investment costs per Q-BTU for expanding renewable supply	KRW 177 trillion per Q-BTU *(= KRW 213 trillion per Q-BTU in 2020 with 1.0% average annual cost reduction through 2040 midpoint)*
4. Costs of expanding renewable supply	KRW 690 trillion *(=3.9 Q-BTUs x KRW 177 trillion)*
5. Average annual costs over 2031 – 2050	KRW 35 trillion *(= KRW 690 trillion/20 years)*
6. Average annual costs of renewable supply expansion as % of 2040 midpoint GDP	1.1% *(= KRW 35 trillion/3,097 trillion)*

C) Overall Clean Energy Investments: Efficiency + Clean Renewables

1. Total clean energy investments	KRW 886 trillion *(= KRW 196 trillion for energy efficiency + KRW 690 trillion for renewables)*
2. Average annual investments	KRW 44 trillion *(= KRW 886 trillion/20 years)*
3. Average annual investments as share of 2040 midpoint GDP	1.4% *(= KRW 44 trillion/KRW 3,097 trillion)*
4. Total energy savings or clean renewable capacity expansion	8.9 Q-BTUs *(= 5.0 Q-BTUs in energy saving after rebound effect + 3.9 Q-BTUs in clean renewable supply expansion)*

Sources: Tables 5.1, 5.2, and 5.3.

2031 – 2050 Employment Creation through Investment Projects

In Tables 5.5 and 5.6, we show our estimates of job creation through this program, in terms of both energy efficiency and clean renewable energy investments Our job estimation methods are the same as those that we presented in Section 3.

As Table 5.5 shows, we estimate that the energy efficiency investments will generate about 131,000 jobs per year on average between 2031 – 2050, assuming that the jobs per KRW ratios remain at the levels we reported in Section 3 (we relax that assumption below). In Table 5.6, we estimate that the jobs created by renewable energy investments between 2031 – 2050 will total to 346,980.

TABLE 5.5

Annual Job Creation in South Korea through Energy Efficiency Investments, 2031 – 2050

Job creation through average annual spending of KRW 10 trillion in efficiency investments

ASSUMPTIONS FOR ENERGY EFFICIENCY INVESTMENTS

- 20% on building retrofits
- 20% on industrial efficiency
- 20% on electrical grid upgrades
- 20% on public transportation expansion/upgrades
- 20% on expanding zero-emissions auto fleet

	Spending amounts	Direct jobs	Indirect jobs	Direct + indirect jobs	Induced jobs *(=40% of direct + indirect)*	Direct, indirect + induced jobs
Building retrofits	KRW 2.0 trillion	12,000	11,200	23,200	9,200	32,400
Industrial efficiency, including combined heat and power	KRW 2.0 trillion	9,400	8,200	17,600	7,000	24,600
Electrical grid upgrades	KRW 2.0 trillion	7,000	8,200	15,200	6,000	21,200
Public transportation expansion/upgrades, including rail	KRW 2.0 trillion	16,200	7,600	23,800	9,600	33,400
Expanding high efficiency automobile fleet	KRW 2.0 trillion	4,200	9,600	13,800	5,600	19,400
TOTALS	**KRW 10 trillion**	**48,800**	**44,800**	**93,600**	**37,400**	**131,000**

Sources: See Tables 5.4 and 3.1.

TABLE 5.6
Annual Job Creation in South Korea through Clean Renewable Energy Investments, 2031 – 2050
Job creation through average annual spending of KRW 35 trillion in clean renewable investments

ASSUMPTIONS FOR CLEAN RENEWABLE INVESTMENTS

- 25% on solar, onshore, community, commercial, residential
- 18% on solar, onshore utility scale
- 3% on solar, offshore utility scale
- 23% on wind, offshore
- 26% on wind, onshore
- 1.25% on low-emissions bioenergy
- 1.25% on tidal
- 1.25% on small-scale hydro
- 1.25% on geothermal energy

	Spending amounts	Direct jobs	Indirect jobs	Direct + indirect jobs	Induced jobs (=40% of direct + indirect)	Direct, indirect + induced jobs
Solar: onshore community, commercial, and residential scales	KRW 8.8 trillion	25,520	29,040	54,560	22,000	76,560
Solar: onshore utility scale	KRW 6.3 trillion	17,640	19,530	37,170	15,120	52,290
Solar: offshore utility scale	KRW 1.1 trillion	2,750	3,080	5,830	2,310	8,140
Wind: offshore	KRW 8.1 trillion	29,160	33,210	62,370	25,110	87,480
Wind: onshore	KRW 9.1 trillion	32,760	38,220	70,980	28,210	99,190
Low-emissions bioenergy	KRW 0.4 trillion	5,040	1,440	6,480	2,600	9,080
Tidal	KRW 0.4 trillion	1,320	1,440	2,760	1,120	3,880
Small-scale hydro	KRW 0.4 trillion	1,960	1,640	3,600	1,440	5,040
Geothermal	KRW 0.4 trillion	2,040	1,760	3,800	1,520	5,320
TOTALS	**KRW 35 trillion**	**118,190**	**129,360**	**247,550**	**99,430**	**346,980**

Sources: See Tables 5.4 and 3.3.

2031 – 2050 Employment Creation through Phasing Out Fossil Fuel Imports

As we discussed in Section 2, the South Korea economy's phase out of imported fossil fuel energy, and its corresponding increasing reliance on domestically-produced renewable energy, will generate significant positive gains in domestic employment. These employment gains will increase cumulatively over time. We saw through the illustrative model we presented in Table 3.11 that the average employment gain was about 60,000 jobs per year as fossil fuel imports fell from the starting figure of 3.8 percent of GDP in 2022 to 2.1 percent in 2030. We follow the same framework here to illustrate the impact of fossil fuel imports falling steadily from 2.1 percent in 2031 down to zero as of 2050. We summarize this impact in Table 5.7, with the full set of calculations presented in Appendix 2.

As Table 5.7 shows, the employment impacts of Korea phasing out its fossil fuel imports will be very large over 2031 – 2050. This is a result of Korea's fossil fuel energy

TABLE 5.7
Job Creation through Phasing-out Fossil Fuel Imports, 2031 – 2050

2031 fossil fuel energy import costs under BAU	3.8% of GDP
2031 fossil fuel energy import costs under Clean Energy Program	2.1% of GDP
2031 – 2050 average annual fossil fuel energy import cost reduction to reach zero imports by 2050	0.11 percentage points per year of import/GDP ratio

Job Creation Impacts

	With fixed labor productivity	With 1.5% annual labor productivity growth
2031 – 2050 average annual job creation through clean energy program relative to BAU fixed at 3.8% of GDP annual import ratio	674,123	513,560
2050 job creation with zero fossil fuel imports rather than imports at 3.8% of GDP	1.21 million	921,800

Sources: See Appendix 2 for detailed calculations.

imports continuing to fall steadily over 2031 – 2050 relative to the fixed 3.8 percent of GDP figure under the BAU assumptions. Under the assumptions of the clean energy program, Korea's fossil fuel energy import share falls between 2031 – 2050 from 2.1 percent of GDP to zero. This decline in Korea's fossil fuel import share will also be occurring while Korea's GDP continues to grow by 2.5 percent per year.

As we see in Table 5.7, the average employment gain over 2031 – 2050 will range between about 514,000 – 674,000 jobs, depending on whether or not we assume that labor productivity grows at 1.5 percent per year over this period. For 2050, the final year of the project, in which fossil fuel imports will have fallen to zero, job creation through having phased out imports will range between about 920,000 and 1.2 million jobs, depending on whether we assume a 1.5 percent productivity growth rate. Whether or not we incorporate productivity growth into these calculations, it remains the case that the employment gains over 2031 – 2050 through phasing out fossil fuel energy imports will be about 10 times larger than the roughly 60,000 average job creation figure produced by the first phase of energy import substitution between 2022 – 2030. This much larger increase in employment results, again, from the combined effects over time of an expanding GDP and a declining share of GDP being spent on imports. The overall impact is that, as an average over 2031 – 2050, the phasing out of South Korea's fossil fuel energy imports will become the largest source of job creation generated by the economy's clean energy transition, measured in comparison with the BAU scenario of a fixed share of fossil fuel energy imports at 3.8 percent of GDP.

In Table 5.8, we bring together the full set of employment impacts of this 2031 – 2050 phase of South Korea's transition project, through which the economy drives CO_2 emissions down from 350 million tons in 2030 to zero emissions by 2050. The figures in Table 5.8 also include the modest though steady employment effects of the reforestation program we de-

TABLE 5.8
Average Annual Job Creation through Combined Channels, 2031 – 2050

- *Energy efficiency and renewable energy investments*
- *Reforestation*
- *Phasing out fossil fuel energy imports*

	Job creation with fixed employment/output ratios	Job creation with 1.5% annual labor productivity growth
Energy efficiency and renewable energy investments: *KRW 48 trillion/year*	477,980	364,130
Reforestation investments: *KRW 631 billion/year*	11,930	9,090
Phase-out of fossil fuel energy imports: *KRW 65 trillion/year in average reduced imports*	674,123	513,560
Total job creation	1.2 million	900,000
Total job creation as share of 2020 South Korea labor force *(labor force at 28.4 million)*	4.2%	3.2%

Sources: : Tables 3.9, 5.5, 5.6, and 5.7.

scribed in Section 3, with average annual job creation from this program remaining between about 9,000 and 12,000 jobs.

Overall, as we see, our estimate is that average employment gains will be between about 900,000 and 1.2 million, with the range between these two estimates again resulting from whether we assume labor productivity will remain fixed or grow at a 1.5 percent per year average.

This level of employment expansion is modestly larger than the roughly 800,000 – 850,000 jobs per year that we estimate will be generated over the 2022 – 2030 phase of the project, through which the country's CO_2 emissions will fall by 45 percent, from 631 to 350 million tons. The average employment gains through 2031 – 2050 are larger than those for 2022 – 2030 despite the fact that, according to our modeling framework, clean energy investment spending will need to be at around 3.6 percent of GDP between 2021 – 2030 to bring emissions down to 350 million tons, while this investment figure needs to average only 1.4 percent of GDP between 2031 – 2050 to reach zero emissions by 2050. What happens in the scenarios we have developed is that the employment impact of substituting domestically produced clean energy for imported fossil fuel energy becomes increasingly impactful over time, even while clean energy investment spending diminishes as a share of South Korea's overall economic activity.

Overall then, the impact of these sustained employment gains over 2031 – 2050 will be comparable, if not somewhat larger, to those over 2022 – 2030. This will occur within a context in which, according to several recent projections, Korea's labor force is not likely to grow, and even to contract, at least through 2035.[73] Table 5.8 reflects these labor force projections by incorporating the assumption, shown in row 5, that Korea's labor force remains fixed at its 2020 figure of 28.4 million people. Under this assumption, we then see that the impact on job opportunities generated by the economy's zero emissions project will be substantial, adding in the range of 3.2 – 4.2 percent to the economy's overall labor force. In fact, as Korea's zero emissions project generates expanded employment opportunities through 2031 – 2050, more people are likely to enter the labor force as a result and be successful in securing jobs for themselves.

Employment Loss, Worker Displacement and Transition Support over 2031 – 2050

In Tables 5.9 – 5.10, we work through the same set of calculations as we did in Section 4 to estimate job losses and numbers of workers who will face displacement over 2031 – 2050 through Korea's clean energy transition. As in Section 4, we estimate job losses and displacements resulting from both the continued contraction of the economy's fossil fuel-based sectors (Table 5.9) and through the transition in Korea's auto manufacturing industry (Table 5.10) from producing internal combustion engine-powered vehicles (ICEVs) to zero emissions vehicles (ZEVs),

We also incorporate into these estimates the contraction of Korea's nuclear energy industry between 2031 – 2050. As we discussed in Section 2, we assume that nuclear energy production will fall to about 45 percent of its 2022 level by 2050. We show the impact of this nuclear phase-out in column 4 of Table 5.9.

In Table 5.9, we show that 2,951 workers will face displacement through the 2031 – 2050 phase out of both the fossil fuel and nuclear energy sectors in South Korea. This job displacement figure results through our estimate that an average of 4,387 jobs will be lost every year through the fossil fuel and nuclear phase out between 2031 – 2050, while an average of 1,436 workers will retire voluntarily every year over this period.

In Table 5.10, we estimate that the number of ICEV manufacturing workers who will be displaced and require reemployment between 2031 – 2035, on the assumption that Korea transitions fully into manufacturing ZEVs by 2035. ICEV job displacements will be heavy during these five years, averaging 11,498, after we take account of about 3,200 workers per year leaving the labor force voluntarily. But then of course, there will be no further job displacements through ICEV manufacturing contraction after 2035. The full extent of job displacements from 2036 – 2050 will therefore include only the roughly 3,000 workers per year resulting from the fossil fuel and nuclear energy phase outs.

As we discussed in Section 4 with respect to the workers over 2022 – 2030 facing displacement, all of the workers that are displaced over 2031 – 2050 deserve generous support through public policy. This includes the roughly 14,500 workers facing displacement between 2031 – 2035 with ICEV manufacturing shutting down, and the roughly 3,000 workers between 2036 – 2050, as Korea's fossil fuel industry becomes fully phased out, and the nuclear power industry continues to contract. This support should include employment guarantees, wage insurance, retraining support, relocation support and pension guarantees. The fact that, according to our estimate, the Korean economy will gain an average of about 1 million jobs over 2031 – 2050 due to its clean energy transition program will greatly facilitate generous support programs program for these displaced workers.

TABLE 5.9

Attrition by Retirement and Job Displacement for Fossil Fuel and Nuclear Power Industry Workers in South Korea, 2031 – 2050

	1) Gas station workers	2) Other fossil fuel workers	3) All fossil fuel workers *(columns 1 + 2)*	4) Nuclear power workers	5) All workers *(columns 3 + 4)*
1) Total projected workforce as of 2030/total job losses by 2050	34,650	43,154	77,804	9,942	87,746
2) Average annual job loss over 20-year production decline *(= row 1/20)*	1,733	2,158	3,890	497	4,387
3) Number of workers reaching 55 yrs. and over during 2031-2050 *(=row 1 x % of workers at least 36 yrs. old in 2031*)*	28,760 *(83% of all workers)*	32,366 *(75% of all workers)*	61,126	7,258 *(73% of all workers)*	68,384
4) Number of workers who reach 55 yrs. and over during 2031-2050 *and* leave the labor force *(=row 3 x % of 55+ yrs. old not in the labor force**)*	12,079 *(42% of 55 and over workers)*	13,594 *(42% of 55 and over workers*	25,673	3,048 *(42% of 55 and over workers)*	28,721
5) Number of workers per year retiring and leaving the labor force during 20-year transition period *(=row 4/20)*	604	680	1,284	152	1,436
6) Number of workers displaced/requiring re-employment *(= row 2 – row 5)*	1,129	1,478	2,606	345	2,951

Note:
*We assume that this share is well approximated by the worker characteristics in 2019.
**According to Statistics Korea, 57.6 percent of those aged 55 and older were in the labor force and 42.4 percent were not in the labor force in 2019.
Source: Tables 4.1 and 4.4.

TABLE 5.10

Attrition by Retirement and Job Displacement for ICEV Auto Manufacturing Workers in South Korea, 2031 – 2035

5-Year Transition from 2030 ICEV production level to zero ICEV/100% ZEV production by 2035

1) Total ICEV workforce as of 2030	147,111
2) ICEV job losses net of ZEV job gains over 5-year transition, 2031-2035 *(= row 1 x 0.5)* *Assume: ICEV contraction to zero by 2035 with 50% of ICEV job losses transfer automatically into ZEV manuf. jobs*	73,556
3) Average annual job loss over 5-year production decline *(= row 2/5)*	14,711
4) Number of workers reaching 55 yrs. and over during 2031-2035 *(=row 1 x % of workers at least 51 yrs. old in 2031*)*	38,249 *(=26% of all workers)*
5) Number of workers who reach 55 yrs. and over during 2031-2035 *and* leave the labor force *(=row 4 x % of 55+ yrs. old not in the labor force**)*	16,065 *(=42% of 55 and over workers)*
6) Number of workers per year retiring and leaving the labor force during 5-year transition period *(=row 5/5)*	3,213
7) Number of workers displaced/requiring re-employment *(= row 3 – row 6)*	11,498

Note:
*We assume that this share is well-approximated by the worker characteristics in 2019.
**According to Statistics Korea, 57.6 percent of those aged 55 and older were in the labor force and 42.4 percent were not in the labor force in 2019.

Source: Tables 4.5 and 4.6.

6. FINANCING REQUIREMENTS FOR KOREA'S CARBON-NEUTRALITY PROJECT

We have argued that the primary way through which South Korea can achieve its stated emissions reduction targets—an emissions cut of more than 40 percent by 2030 and to reach carbon neutrality by 2050—will be to phase out the consumption of oil, coal, and natural gas as energy sources. The Korean economy will then have to undertake large-scale investments to raise energy efficiency standards throughout its economy and to dramatically expand its production of clean renewable energy sources.

In terms of specifics, we have estimated, as a high-end figure, that for the Korean economy to concurrently phase-out fossil fuel consumption while continuing to grow at a healthy rate will entail an average level of investments in energy efficiency and renewable energy at about KRW 78 trillion per year between 2022 – 2030. This would be equal to about 3.6 percent of Korea's GDP over this eight-year period. We estimate that, of the KRW 78 trillion spending total, about KRW 64 trillion, 82 percent, will need to be devoted to expanding the renewable energy supply, with 65 percent of these funds going to solar and 30 percent to wind energy projects. The remaining KRW 14 trillion, 18 percent, would be divided equally into energy efficiency investments in the broad areas of building retrofits, industrial efficiency, electrical grid upgrades, public transportation, and zero-emissions vehicles. This level of renewables and efficiency will enable Korea to grow at an average GDP growth rate of 2.5 percent per year while also reducing CO_2 emissions by 45 percent by 2030. For financing the second phase of Korea's clean energy transition, over the 20-year period 2031 – 2050, we have estimated that investments in efficiency and renewables will need to average about KRW 44 trillion per year, equal to about 1.4 percent of GDP. This second phase of Korea's clean energy transition will enable the economy to reach zero emissions by 2050 while GDP continues to grow at an average 2.5 percent per year rate.

In addition to these energy efficiency and renewable investment levels, we have also estimated that South Korea will need to invest about KRW 631 billion per year if it chooses to proceed with a reforestation program similar in scale to the one that the government has been considering to date. Finally, we have incorporated into our estimates on overall energy supply an assumption that nuclear energy consumption in Korea will decline to 85 percent of its current level by 2030 and be at 45 percent of the current level by 2050. Maintaining Korea's nuclear energy capacity at these reduced levels will not require additional large-scale investments.

The question we examine in this section is how South Korea can succeed in mobilizing financial resources to the extent necessary to meet these energy efficiency and renewable energy investment goals—i.e. to finance efficiency and renewable investments equal to 3.6 percent of GDP between 2022 – 2030 and 1.4 percent of GDP between 2031 – 2050. We will focus on the initial 2022 – 2030 period. The financial requirements between 2022 – 2030, at 3.6 percent of GDP per year, will be much larger than those over the 2031 – 2050 period. Moreover, we will not consider the financing requirements for a reforestation program. The features of any such program are still under consideration. In any case, the financing needs for a program undertaken at a scale roughly in line with what the government has described to date will be much smaller than those required to build a viable clean energy infrastructure in South Korea.

Government Financing Initiatives

The South Korean government has been actively advancing a range of initiatives to promote a large-scale clean energy investment program for the country. The government's December 2020 study, *2050 Carbon Neutral Strategy of the Republic of Korea* describes in general terms its aims and approaches to the project. Thus, the section of the study titled "Mobilizing Green Finance," states as follows:

> Fostering green industry is a key to the success in green transition. For the continued growth of green industry, securing reliable funding sources is essential, and there are several means of mobilizing funding sources that can be arranged by the Government. For instance, providing loan interest deduction for solar energy businesses, LED lamp projects and other green projects could be one option while selling investment funds for green industry growth could also be effective. The scale and types of such green investment funds should be expanded and diversified.
>
> Korea will continue to expand its investment in certified green technologies and facilities for air pollution prevention and GHG emissions reduction. Continuous efforts are needed to create policy funds investing in environmental businesses and overseas environmental projects. Such policy funds could be mobilized through the combination of government funding and private investments raised for the purpose of fostering green industry growth. The investments made from such policy funds could play a role as pump-primer and contribute to further growth of environmental businesses, especially the ones that are small but have strong potential. It is also important to support those businesses to ensure they will grow into flagship companies and expand their entry into the overseas market (2020, p. 119).

In terms of specific measures, the government has already developed a program that issues green bonds. These are special purpose bonds issued to finance eco-friendly projects at subsidized interest rates. In 2013, the Korean Export-Import bank was the first institution in the country to issue green bonds.[74]

Korea has also been active in developing a carbon pricing system throughout the economy. As the government's 2050 *Carbon Neutral Strategy* study states, "Carbon pricing is the most cost-effective market mechanism that incentivizes economic actors to reduce greenhouse gas emissions," (2020, p. 109). The specific approach to carbon pricing that the government has adopted thus far has been its Emissions Trading Scheme (ETS). According to the *Carbon Neutral Strategy* study, the ETS "sets emissions caps in consideration of its reduction target and allows companies to freely trade their surplus allowances. The scheme has an effect of incentivizing corporate investments in low-carbon technologies," (2020, p. 109). Korea was the first Asian country to adopt a nationwide ETS.

Along with its existing ETS, the Korean government is also considering implementing, as a complementary measure, a direct tax on the use of fossil fuels, i.e. a "carbon tax." Correspondingly, it would eliminate its existing fossil fuel subsidy programs. Regarding such initiatives, the *Carbon Neutral Strategy* study states that "the taxation on the use of fossil fuels works as a positive tool to accelerate the low-carbon fuel transition while fossil fuel subsidies have negative impacts," (2020, p. 110).

All three of these measures—the ETS, a carbon tax, and the elimination of existing fossil fuel subsidies—will generate revenue that the government can channel into financing clean energy investments. The funds that become available through these measures could be used both to finance direct public investments in clean energy projects and to subsidize private investments. Towards those ends, the government announced in May 2021 its intention to establish a Climate Response Fund in 2022. The fund will draw resources from other accounts and funds in the government's existing budget, including its current fossil fuel subsidies, as well as from the income of the ETS and any possible future carbon tax program. [75]

In fact, Korea has recently demonstrated its willingness and capacity to mobilize large-scale funding to finance the country's clean energy transition. Thus, according to the *Emissions Gap Report 2021* of the United Nations Environment Programme (UNEP), Korea devoted a greater share of COVID relief-related funding to green investments than any other member country within the Group of Twenty (G20) high-income countries. According to the UNEP report, Korea channeled about 9 percent of GDP into what UNEP defined as either "positive" or "highly positive" green investments as part of its overall COVID relief interventions. These green investments included electric vehicle incentives and public transport modernization, clean energy infrastructure investments, energy efficiency upgrades, natural capital investments and clean energy research and development programs (UNEP 2021, p. 40 – 42). According to UNEP, no other G20 member country devoted more than 5 percent of GDP to these clean energy investments as part of their COVID relief program.[76]

Overall, according to the International Monetary Fund, Korea channeled about 6.4 percent of its GDP into direct spending on COVID relief and another 10.0 percent of GDP into loan guarantees and other forms of financial support to private businesses.[77] Korea's overall COVID relief interventions therefore totaled to more than 16 percent of GDP, with the government's support for green investments being the largest single category of funding within the overall portfolio of initiatives. This recent experience during the COVID crisis demonstrates that Korea certainly possesses the financial capacity to advance a sustained clean energy investment program at 3.6 percent of GDP or higher between 2022 – 2030.

Despite this, a 2021 analysis by Ha-Hyeon Cho of the government's green financing initiatives, commissioned by the National Assembly Budget Office, concludes that the level of financial support provided to date is insufficient for achieving the government's emission reduction targets. Cho writes as follows:

> 2050 Carbon neutrality is an area that requires mid- to long-term investment, and measures to encourage private sector investment in addition to fiscal spending should be prepared. However, fiscal expenditure accounts for a large proportion of financial resources for related fiscal policies such as the Green New Deal and the Climate Response Fund. The total government's carbon-neutral budget in 2022 is worth KRW 12 trillion, and in order to achieve carbon neutrality in 2050 and the mid-term goal in 2030, the size of the carbon-neutral budget may increase every year. Rather than relying solely on the government's fiscal expenditure, measures that can stimulate private investment should be considered. Various fiscal expenditures are planned for the realization of 2050 carbon neutrality, but on the other hand, financing is insufficient or unclear (2021, p. 115).

Following from Cho's analysis, it is critical to consider ways through which the Korean government can expand its financing support for clean energy investments. Such increased levels of support can be provided both through increases in direct public funding as well as measures to incentivize private investment funding.

An Illustrative Clean Energy Financing Program

For purposes of illustration, we consider here a combination of measures through which the South Korean government can realistically mobilize an average of KRW 78 trillion per year between 2022 – 2030, i.e. 3.6 percent of average GDP over these years. Of course, other proposals, built around other combinations of policies, could also be viable.

Our proposal includes three new sources of public revenues, all of which could operate under the rubric of the government's newly established Climate Response Fund. These new revenue sources would then be allocated both to support direct public investments as well as subsidies for private investments within the government's ongoing green bond program.

The three new sources of public revenue would be: 1) converting the government's existing fossil fuel subsidies into clean energy investment subsidies; 2) transferring a share of Korea's military budget into clean energy investments; and 3) enacting a carbon tax. Most of the revenue generated by the tax would be rebated directly to Korean citizens. But a significant share of the revenues would still be available to support clean energy investments. We briefly discuss each of these proposals, moving from the smallest potential source of additional revenues (rechanneling fossil fuel subsidies into clean energy funding) to the largest (a carbon tax with rebates). We then discuss how these new public revenue sources can be channeled into supporting a green bond program that will incentivize private clean energy investments.

Converting Fossil Fuel Subsidies into Clean Energy Investments

According to research generated by the OECD, International Monetary Fund and International Energy Agency, South Korea provided a total of about KRW 1.6 trillion ($1.4 billon) in fossil fuel subsidies as of 2020. Of this total, by far the largest share, at about 83 percent, was channeled into supporting petroleum consumption in Korea. Most of remaining funds supported coal consumption. Natural gas subsidies were negligible.[78]

Converting this KRW 1.6 trillion into supporting energy efficiency and renewable energy investments would provide about 2 percent of the total funding needed to meet the KRW 78 trillion per year average investment level that will be required between 2022 – 2030. But through the green bond program, this relatively small funding level can be leveraged into supporting a much larger amount of private investments. Of course, eliminating Korea's fossil fuel subsidies will also end the government's mutually incompatible policies of, at once, encouraging fossil fuel consumption through subsidies while attempting to achieve carbon neutrality by 2050.

Transferring 10 percent of Korea's Military Budget into Clean Energy Investments

Korea's proposed military budget for 2022 is KRW 54.7 trillion ($46.3 billion). This figure represents an increase of nearly 22 percent in inflation-adjusted won relative to the country's 2018 military budget.[79] That is equal to an average annual military spending increase of about 5 percent per year since 2018.

For Korea, and equally for all other countries, the case for transferring a significant share of the country's military budget into financing clean energy investments is straightforward. That is, we assume that, at least in principle, the fundamental purpose of military spending is to provide greater security for the citizens of each country. The worsening of the climate crisis over time means increasing insecurity for the vast majority of people in all regions of the globe and, indeed, for putting at risk the very prospect of continuing human life on earth as we know it.

For the specific case of Korea, the fact that its proposed 2022 military budget is roughly 22 percent higher than the figure of only four years ago suggests that it is realistic to transfer in the range of 10 percent of the proposed 2022 budget into clean energy investments. That would mean that KRW 5.5 trillion in funds could be added to the government's Climate Response Fund. This would equal about 7.1 percent of the KRW 78 trillion that we have estimated is required per year, on average, between 2022 – 2030, for clean energy investments. This KRW 5.5 trillion per year would represent a major infusion of support for clean energy investments. This is especially true because, as with the fossil fuel subsidy fund transfer, a large share of these funds could then be leveraged into financing green bonds provided for private investors.

Carbon Tax with Rebates

A carbon tax, as one specific variant of a carbon pricing policy, has the merit of shaping a clean energy transition through two channels. It will raise fossil fuel prices and thereby discourage consumption while also generating a new source of government revenue. At least part of the carbon tax revenue can then be channeled into supporting an economy's clean energy project. But carbon taxes also produce the major negative effect of imposing a disproportionate tax burden on low- and middle-income people, since low- and middle-income people spend a larger fraction of their income on electricity, transportation, and home-heating fuel. An equal-shares rebate is the simplest way to ensure that the full impact of the tax will be equalizing across all population cohorts.

We therefore consider the following tax-and-rebate program for Korea. Focusing on 2022 as the first year of the clean energy investment program, we begin with a tax at a low rate of KRW 40,000 per ton of carbon. Assuming that Korea's emissions level for 2022 is 631 million tons, this level of carbon taxation would generate KRW 25.2 trillion in revenue. Focusing on gasoline prices, a rough rule of thumb for estimating the impact of a carbon tax on retail prices is that retail gasoline prices will rise by about 0.26 percent per liter (= 1 percent per gallon) relative to the carbon tax increase.[80] Thus, starting the tax at KRW 40,000 per ton will add about KRW 100 to the retail price of a liter of gasoline. As of January 2022, the average price per liter of gasoline in Korea was KRW 1,632.[81] The carbon tax of KRW 40,000 per ton would therefore increase the average retail price of gasoline in Korea by about 6 percent.

Again for purposes of illustration, if we assume that 25 percent of this revenue will be used to finance clean energy investments, that amounts to KRW 6.3 trillion for investment projects. This level of government revenue would amount to about 8.1 percent of the KRW 78 trillion average annual figure that will be required per year for the clean energy investment program between 2022 – 2030. Here again, these revenues, channeled into the Climate Response Fund, can be used, at least in part, for incentivizing private investments through subsidized green bonds.

At the same time, the 75 percent of the total revenue that is rebated to the public in equal shares would then amount to KRW 18.9 trillion. This amounts to about KRW 370,000 for every citizen in Korea, an increase in average per capita income in Korea of about 1.1 percent.

In Table 6.1, we present what is, again, an illustrative scenario in which the carbon tax rate increases steadily from the initial rate of KRW 40,000 in 2022 to KRW 75,000 by 2030 while the country's CO_2 emissions fall by 45 percent over this 9-year period. The increases in the carbon tax rate therefore corresponds with the decline in CO_2 emissions, from 631 tons in 2022 to 350 tons by 2030. The result is that annual revenues from the tax remain roughly stable through the full period. As we see in Table 6.1, the average revenues per year would be KRW 27.2 trillion per year. KRW 6.8 trillion, 25 percent of this average figure per year, would be channeled into the Climate Response Fund. The remaining KRW 20.4 trillion will be distributed as equal-shares rebates of KRW 392,000 for all Korean citizens. The tax burden faced by Korean consumers will also remain approximately stable, because the level of fossil fuel consumption will be falling while the tax rate increases.

TABLE 6.1

Revenue from Carbon Tax

Proposed tax rate rises from KRW 40,000 to KRW 75,000 per ton between 2022 – 2030

Year	1) Annual emissions *(million metric tons—assume emissions fall by 45% by 2030)*	2) Carbon tax rate *(won per ton of CO_2 emissions)*	3) Annual revenue *(= columns 1 x 2)*
2022	631	KRW 40,000	KRW 25.2 trillion
2023	596	KRW 44,375	KRW 26.4 trillion
2024	561	KRW 48,750	KRW 27.3 trillion
2025	526	KRW 53,125	KRW 27.9 trillion
2026	491	KRW 57,500	KRW 28.2 trillion
2027	455	KRW 61,875	KRW 28.2 trillion
2028	420	KRW 66,250	KRW 27.8 trillion
2029	385	KRW 70,625	KRW 27.2 trillion
2030	350	KRW 75,000	KRW 26.3 trillion
Total	----	----	**KRW 244.6 trillion**
Annual average	490.6	KRW 57,500	KRW 27.2 trillion

Sources: Projections based on program to reduce emissions incrementally by 45 percent as of 2030.

Summary of Clean Energy Investment Financing Framework

Table 6.2 summarizes the totals for average clean energy investment funding over 2022 – 2030 as well as the sources of increased public revenues for clean energy investments that we have described. As we have discussed above, the total KRW 78 trillion per year spending level includes KRW 64 trillion in renewable energy investments and the remaining KRW 14 trillion for energy efficiency investments. The three new revenue sources include: 1) converting KRW 1.6 trillion in fossil fuel subsidies; 2) transferring KRW 5.5 trillion out of military spending; and 3) generating KRW 27.2 trillion in carbon tax revenues, with 6.8 trillion channeled into the Climate Response Fund. The total revenues received through these three sources amounts to KRW 13.9 trillion per year. This is equal to about 18 percent of the KRW 78 trillion needed per year, on average, to finance Korea's clean energy investment program over 2022 – 2030.

The remaining roughly KRW 64 trillion in required investment funds, at about 2.9 percent of average GDP over 2022 – 2030, will need be provided by private investors. As we have discussed, these private investors can be incentivized through a combination of measures. The first such set of incentives will be through the large-scale green bond subsidy program. As noted above, the scale for the green bond program can be substantially smaller than the financial relief programs enacted during the COVID pandemic, while still providing major support for private clean energy investments.

Private clean energy investments in Korea can be further incentivized through regulations that promote high efficiency and renewable energy and discourage fossil fuel consumption. Both the elimination of fossil fuel subsidies and enactment of the carbon tax will clearly serve this purpose. But the carbon tax rate must be set high enough to impact energy consumers' behavior.

TABLE 6.2

An Illustrative Financing Framework for Clean Energy Investments in South Korea

Average investment level for 2022 – 2030:
KRW 78 trillion in public and private investments; 3.6 percent of average GDP

Clean Energy Investment Areas

- Clean Renewable Energy: KRW 64 trillion/year
  - 65% funding for solar/30% for wind projects
- Energy Efficiency: KRW 14 trillion/year

Public Sources of Investment Funds: KRW 13.9 trillion

- Converting existing fossil fuel subsidies: KRW 1.6 trillion
- Transferring 10% of military budget: KRW 5.5 trillion
- Carbon tax revenues: KRW 6.8 trillion

Private Sources of Investment Funds: KRW 64.1 trillion

Policies for incentivizing private investors

- Subsidized green bond lending
- Regulations
  - Eliminating fossil fuel subsidies
  - Carbon tax
  - Renewable portfolio standards

Another form of regulation that can incentivize private clean energy investment and discourage fossil fuel consumption is a renewable portfolio standard. South Korea's current clean energy policy mix does already include this policy tool. Under this policy, companies in Korea with power generating facilities of 500 megawatts or more are required to produce a given percentage of their total power generation through renewable energy sources. In December 2021, the MOTIE announced a series of increases in the renewable energy mandatory supply ratio. The mandatory ratio is now 12.5 percent for 2022. It is scheduled to increase steadily to 25 percent by 2026.[82] This ratio will need to be raised beyond this 25 percent figure for 2026. Indeed, the ratio should reach 45 percent or thereabouts by 2030 in order for Korea to achieve its 2030 emissions reduction target of at least 40 percent.

Overall, the combination of policies that we have described here by way of illustration are capable of producing an average of KRW 78 trillion per year in combined public and private investments over 2022 – 2030 to build the country's clean energy infrastructure. Building this clean energy infrastructure, in turn, will be the single most important project for enabling Korea to achieve carbon neutrality by 2050.

Appendix 1
Methodology for Generating Employment Estimates and Data on Job Quality and Worker Characteristics

Methodology and Data Sources for Estimating Direct and Indirect Employment

The employment outcomes of investments in the renewable energy, energy efficiency sector, or the sustainable agriculture sections are estimated using the Input-Output (I-O) table of South Korea. Input-Output (I-O) tables are national accounting systems that show linkages between industries and are usually used to analyze how changes in final demand affect industrial output and employment. Input-Output tables are constructed from country-specific data incorporating information at the firm level. These tables have been widely used to estimate employment since Wassily Leontief first developed them in the 1930s.[83]

Miller and Blair (2009) note that the two main assumptions in input-output tables are fixed coefficients and fixed input proportions. Fixed technical coefficients signify that the production technology exhibits constant returns to scale. Fixed proportions imply that industry *j* will use the same mix of inputs from all industries even as demand increases for industry *j*'s output – the basic I-O modeling does not allow for input substitution. Given these limitations, I-O tables are best suited to study the current state of the economy and make short-term projections. We, therefore, need to exercise some caution while using the I-O tables for long-term predictions. For instance, the assumption of constant returns to scale is relevant only for relatively small changes in output.

Moreover, I-O data is being captured at a point in time (such as an annual census), making them static. Thus, we must be aware of not only homogeneity and proportionality but also of fixed prices. If over time, input prices change, then we would expect industries to substitute cheaper inputs for the more expensive ones.

Therefore, the limitations of an I-O model lie in three assumptions (homogeneity, proportionality, and fixed prices), which are made to simplify the study. However, the strengths of this model lie in the transparency of the model and the relatively limited number of assumptions compared to more complex general equilibrium models that typically rely on a far greater number of assumptions.[84]

The input-output tables are used in one of the following three ways: a) to determine the current state of economic interactions (static); b) to modify assumptions regarding production functions or prices, or to change the final demand (comparative static), or c) to incorporate technological change or permit expansion of the economy by introducing capital accumulation into the framework (dynamic). This paper uses it to study comparative static analysis: the employment effects of increased final demand for renewable energy and energy efficiency.

The industrial categories in the I-O tables of South Korea currently do not explicitly identify 'Renewable Energy' or 'Energy Efficiency.' Nonetheless, the component activities of these sectors are captured within the explicitly defined industrial sectors that comprise the input-output model. For example, the electronic components used to manufacture solar panels are categorized in the electronic signal equipment and other electronic components industry. Therefore, if we can identify the various components and their weights that make up the Renewable Energy and Energy Efficiency (REEE) industry, we can study the impact of increased demand for REEE products and services. The methodology for this strategy is presented in Miller and Blair (2009). PERI economists have employed this methodology in various studies[85] and in consulting work for the US Department of Energy. The estimates produced by PERI have been corroborated through survey work as well as through data collected by the US Department of Energy as part of the energy provisions of the American Recovery and Reinvestment Act 2009.

This paper constructs the employment requirements table using South Korea's input-output table and commodity-specific employment/output ratio. Multiplying the Leontief Inverse Coefficient

Matrix by the industry-specific E/O ratios yields the employment requirements table. The number of jobs (both direct and indirect) associated with a given amount of expenditure on the final demand for the products or services of a given industry or a set of industries.

As discussed above, the input-output table of South Korea does not explicitly identify clean energy industries as such. Therefore, we had to create "synthetic" sectors that are proxies for various sectors of renewable energy (RE) and energy efficiency (EE). Based on past modeling experiences by PERI and various publications on the components and costs of renewable energy and energy efficiency installations[86], we construct RE and EE categories. The weighting scheme used for estimations is presented in Table A.1.

Data Sources

We obtain the 165-sector level Input-Output matrix for the year 2018 from the Bank of Korea Database (https://www.bok.or.kr/eng/main/main.do). We also used the Bank of Korea database to get the employment figures. Unless otherwise noted, all jobs numbers are in full-time equivalent units (FTE).

Employment Multipliers

The employment impacts of investments in the energy sector are largely determined by the labor intensity of the production process. The labor intensity of an industry can be measured by the employment/output ratio, which denotes the number of workers per KRW 1 billion of output. The sectors such as agriculture and education tend to have high employment-output ratios, while those such as manufacturing have lower values. The employment multipliers derived through the I-O model are not just the E-O ratio of a given industry but are the result of all the industries in the supply chain. Thus, suppose the employment multiplier for wind power, for example, is a function of the labor intensities of steel, hardware, construction, and all the industries, directly and indirectly, involved in the production of wind power.

Estimating Induced Employment

Induced effects refer to the additional employment, output and value added that is produced when the additional employment income generated by an initial demand stimulus—as captured by the direct and indirect effects—is spent elsewhere in the economy. The magnitude of the induced effects depends on how the additional employment income translates into household expenditures and the size of the multiplier effects associated with the increase in household spending.

Induced effects are often estimated by endogenizing the household sector in the I-O model. The assumption is that increases in employee compensation (or value added) finance greater household spending, as reflected in the vector of household consumption in overall final demand. The endogenous household model often yields very large induced effects, in part because the propensity to consume out of employee compensation implicit in the endogenous household I-O model is large.

Instead of relying on the implicit consumption function in the I-O accounts, we estimate the relationship between real gross employee compensation and real personal consumption expenditures econometrically using a dynamic empirical model. This gives us a more accurate sense of how household consumption responds to changes in employee compensation. We then integrate this estimated relationship into our basic input-output model to calculate induced effects.

TABLE A1.1

Specification of Relative Weights for the Set of Activities in Energy Efficiency and Renewable Energy Investment Projects

Sector	Industry	Weights
Weatherization	Repair of buildings	100%
Industrial energy efficiency	Electric wires and cables	10%
	General purpose machinery parts	20%
	Other general-purpose machinery and equipment	10%
	Other special-purpose machinery and equipment	10%
	Constructions of industrial plants and facilities for manufacturing	20%
	Research and development services	30%
Smart grids	Semiconductors and related devices	5.0%
	Electronic signal equipment	7.5%
	Other electronic components	12.5%
	Other electrical components	12.5%
	Electric wires and cables	12.5%
	General purpose machinery parts	12.5%
	Other general-purpose machinery and equipment	12.5%
	Constructions of general facilities	25.0%
Public transport	Construction of facilities for traffic	25.0%
	Railway transport services	20.0%
	Road transport services	30.0%
	Water transport services	5.0%
	Air transport services	5.0%
	Supporting services for transportation	10.0%
	Other services incidental to transportation	5.0%
Electric vehicles	Batteries	25.0%
	Semiconductor and display board manufacturing machinery	5.0%
	Motor vehicles	50.0%
	Motor vehicle engine and parts	10%
	Research and development services	5.0%
	Other scientific, technical, and professional services	5.0%
Bioenergy	Grains and other edible crops	12.5%
	Other crops	12.5%
	Forest goods	17.5%
	Agriculture, forestry, and fishing related services	12.5%
	Crude petroleum and natural gas	12.5%
	Constructions of industrial plants and facilities for manufacturing	20.0%
	Research and development services	12.5%

TABLE A1.1 ***(cont.)***
Specification of Relative Weights for the Set of Activities in Energy Efficiency and Renewable Energy Investment Projects

Sectors	Industry	Weights
Solar: onshore community, commercial and residential	Glass products	2.5%
	Non-ferrous metal ingots	2.5%
	Other fabricated metal products	5.0%
	Semiconductors and related devices	10.0%
	Electronic signal equipment	5.0%
	Other electronic components	5.0%
	Capacitors, rectifiers, and electric transmission and distribution equipment	15.0%
	Batteries	15.0%
	Electric wires and cables	10.0%
	Electricity supply	5.0%
	Other construction	20.0%
	Research and development services	2.5%
	Other scientific, technical, and professional services	2.5%
Solar: onshore utility-scale	Glass products	2.5%
	Non-ferrous metal ingots	2.5%
	Other fabricated metal products	5.0%
	Semiconductors and related devices	12.0%
	Electronic signal equipment	5.0%
	Other electronic components	5.0%
	Capacitors, rectifiers, and electric transmission and distribution equipment	10.0%
	Batteries	15.0%
	Electric wires and cables	8.0%
	Electricity supply	10.0%
	Other construction	20.0%
	Research and development services	2.5%
	Other scientific, technical, and professional services	2.5%
Solar: offshore utility-scale	Glass products	2.5%
	Plastic products	3.0%
	Non-ferrous metal ingots	2.5%
	Other fabricated metal products	5.0%
	Semiconductors and related devices	12.0%
	Electronic signal equipment	5.0%
	Other electronic components	5.0%
	Capacitors, rectifiers, and electric transmission and distribution equipment	10.0%
	Batteries	15.0%
	Electric wires and cables	5.0%
	Electricity supply	10.0%
	Other construction	5.0%
	Water transport services	10.0%
	Research and development services	5.0%
	Other scientific, technical, and professional services	5.0%

TABLE A1.1 ***(cont.)***
Specification of Relative Weights for the Set of Activities in Energy Efficiency and Renewable Energy Investment Projects

Sectors	Industry	Weights
Tidal power	Other plastic products	5.0%
	Metal foundries	5.0%
	Structural metal products and metal tanks	10.0%
	Treatment and coating of metals	2.5%
	Other fabricated metal products	2.5%
	Batteries	5.0%
	Electric wires and cables	5.0%
	Engines and turbines	15.0%
	Electricity supply	10.0%
	Water supply	5.0%
	Other constructions	15.0%
	Water transport services	10.0%
	Research and development services	5.0%
	Other scientific, technical, and professional services	5.0%
Sustainable agriculture	Grains and other edible crops	10.0%
	Vegetables and fruits	15.0%
	Other crops	5.0%
	Cattle	10.0%
	Other animals	15.0%
	Fishery goods	10.0%
	Agriculture, forestry, and fishing related services	10.0%
	Fertilizer and pesticides	5.0%
	Agricultural machinery and machinery for construction	10.0%
	Other constructions	5.0%
	Research and development services	2.5%
	Other scientific, technical, and professional services	2.5%
Afforestation	Forest goods	25.0%
	Agriculture, forestry, and fishing related services	25.0%
	Agricultural machinery and machinery for construction	20.0%
	Other constructions	20.0%
	Research and development services	2.5%
	Other scientific, technical, and professional services	7.5%

Source: Appendix 1 text.

The first step of the process is to estimate the relationship between personal consumption expenditures and employee compensation. To do this, we begin with the following dynamic empirical model:

$$C_t = \alpha + \beta C_{t-1} + \gamma E_t + \epsilon_t$$

In the above equation, C_t represents real household consumption expenditures in time period 't', E_t represents real employee compensation, and ϵ_t is a stochastic error term. We are interested in how changes in employee compensation affect changes in personal consumption expenditures. Therefore, we estimate the model in first differences. First differencing also ensures that the variables are stationary (based on augmented Dickey-Fuller unit root tests). The GDP-deflator for household consumption expenditure is used to transform nominal values into real variables. The time series is annual and extends from 1970 to 2019. All data come from the Korea Statistical Information Service.

The estimated model is (rounding off the coefficients):

$$\begin{aligned} C_t = {} & \underset{(1.30)}{3670.75} - \underset{(-0.59)}{0.07C_{t-1}} + \underset{(6.55)}{0.77E_t} \end{aligned}$$

t-values are reported in parentheses. From this model, we can calculate the impact of a change in employee compensation on personal consumption expenditures, taking into account the dynamic feedback effects captured by the lagged endogenous variable:

$$\frac{\gamma}{1-\beta} = \frac{0.77}{1+0.07} = 0.7237$$

This implies that a KRW 1 billion increase in gross employee compensation will be associated with a KRW 723.7 million increase in household consumption.

The value of the estimated propensity to consume out of additional employee compensation, i.e. x is approximately 0.72. The second step is to find "y," which shows the increase in employee compensation for a KRW 1,000 increase in household final demand. We assume that this ratio (y) is given by the wage share ratio defined as the ratio of total employee compensation to total value added for the Korean economy. The value of y for 2018 is 0.463.

Then, we calculate the total impact on household consumption of a KRW 1,000 increase in employee compensation. This would be given by the following expression:

Total impact on HH consumption = $x + x^2 y + x^3y^2 + x^4y^3 + \ldots\ldots$

in which x is the estimated propensity to consume out of additional employee compensation (0.7237, according to our estimates described above) and y is the additional employee compensation generated by a KRW 1,000 increase in final household demand (0.463, from the basic input-output model). We can factor out a single x, giving us:

Total impact on HH consumption = $x[1 + xy + (xy)^2 + (xy)^3 + \ldots\ldots]$

The expression in the brackets is an infinite series. Since $xy<1$, we know that the series converges to:

Total impact on HH consumption = $x/(1-xy)$.

Using our estimates, the total impact on household consumption expenditures of a KRW 1,000 increase in employee compensation is KRW 1,080.4.

Next, we need to estimate what a KRW 1 billion change in final household consumption would create in additional jobs from the basic input-output model. Using the basic input-output model, we estimate that an additional KRW 1 billion of spending in the Korean economy would generate around 9.5 additional jobs (direct+indirect).

However, we are interested in the number of jobs that would be generated by an additional KRW 1 billion in employee compensation. We know that KRW 1,000 in employee compensation will generate KRW 1,080.4 in induced household consumption. Therefore, KRW 1 billion in additional employee compensation generates KRW 1.0804 billion in new household expenditures and approximately 10.3 additional jobs (9.5*1.0804)—when all dynamic multiplier effects are considered.

We can apply this general analysis of induced effects to any specific stimulus—all we need to know is the direct and indirect effects of the stimulus in terms of employee compensation. For each KRW 1 billion in additional employee compensation generated, we know that 10.3 additional jobs would be generated through induced effects. For example, an additional KRW 10 billion spent on building weatherization generates KRW 6.69 billion in additional employee compensation through the direct and indirect effects. These direct and indirect effects would generate about 116 new jobs. These numbers come directly from the basic input-output model. The induced job creation—taking into account all multiplier effects—would amount to approximately 69 additional jobs (6.69 * 10.3) for a total employment impact of 185 (116+69) jobs. In this case, we see that the induced jobs represent 59.1 percent of the combined direct and indirect employment.

This estimate for induced effects is high relative to that for other high-income economies. By comparison, using the same modeling approach, Pollin et al. (2014) found that induced effects generated an employment increase for the U.S. economy of about 40 percent of a combined direct and indirect employment expansion.[87]

Our approach in this study is to err with our estimates, if at all, through overstating the costs of the clean energy investment program and, correspondingly, to understate its benefits. This is why, in Section 2, we incorporated high-end estimates of the costs of achieving energy efficiency gains and expanding renewable energy supply. Using this same approach, we assume that induced employment effects for South Korea are 40 percent, i.e. the same as the U.S. economy, according to our model framework. That is, we assume that induced effects for the Korean economy are approximately one-third smaller than the 59 percent estimate that we have derived through our model.

Methodology on Estimating Characteristics of Clean Energy Jobs

Our strategy for identifying the types of jobs that would be added to the economy due to an investment involves two steps.

The first step is to calculate, for each specific investment program, the level of employment generated in each of the over 165 industries through the input-output (I-O) model as explained above in this appendix.

Next, we apply this information on the industry composition of the new employment created by an investment with data on workers currently employed in the same industrial mix of jobs. We use the characteristics of these workers to create a profile of the types of jobs and the types of workers that will likely hold the jobs created with each investment. These characteristics include compensation, gender, regular status, and educational credentials. We also analyze workers' contract terms—duration if fixed, or open-ended—to approximate the share of regular jobs with long contract terms that will generated by each investment.

Our information about the workers currently employed in the industrial mix of jobs created by an investment is based on microdata from the semi-annual household survey, Local Area Labor Force Survey (LLFS), published by Statistics Korea. The LLFS includes information from about 234,000 households. The survey is conducted semi-annually (April and October) covering such topics as basic demographic characteristics, educational attainment, and employment status of all household members ages 15 years and older. To get worker characteristics at a detailed industry level we use 2019 data from LLFS Type 1B.

To create a profile of the types of jobs and the types of workers that will likely hold the jobs created with each investment, we estimate, for each of 232 industries in the 10th version of the Korea Standard Industry Classification (KSIC), the worker attributes of interest (e.g, percent with a high school degree or less). We include in our pool of workers: wage and salary workers, as well as self-employed workers and unpaid workers and we use the LLFS provided sampling weight to make these estimates nationally representative. We then weight our industry estimates based on the LLFS worker data with the industry shares generated by our I-O modeling described above in this appendix. This creates a profile of workers with an industry composition that matches that of the jobs that we estimate will be added by investing in a clean energy sector.

The 10th version of KSIC and the industry classification used in the national accounting system used in the I-O tables for our employment estimates described above differ. As noted above, the industrial classification used in the I-O matrix for our employment estimates includes 165 sectors and the LLFS industrial classification includes 232 sectors. To merge information from these two sets of data, we created a crosswalk between the two datasets. This process results in a common industrial classification scheme of 120 sectors.

Methodology on Estimating Employment Levels and Characteristics of Jobs in Fossil Fuel Related Industries, Nuclear Power, and Auto Manufacturing

Employment Levels of Fossil Fuel-Related Industries

For four fossil-fuel related commodities, we are able to use employment figures directly from the Bank of Korea's database on employment mentioned above in this appendix. These include: (1) Gas manufacturing; distribution of gaseous fuel through mains; (2) Refinery products of crude oil, (3) Coal, and (4) Crude petroleum and natural gas.

For the remaining fossil-fuel related commodities and nuclear power employment, we turned to a combination of data to approximate 2018 employment levels.

Fossil fuel electric supply employment. According to a 2020 country analysis of South Korea by the U.S. Energy Information Administration (EIA):

> Fossil fuel sources accounted for about 69% of South Korea's electricity generation in 2019, and the share of nuclear power accounted for 25%...Coal-fired power, which is a baseload source, is the dominant fossil fuel used to generate electricity (40%), and natural gas-fired capacity is the second-largest source (26%). Nuclear power, also a baseload source, will increase capacity and production in the near term from plants that are already under construction (p. 8).[88]

Based on this EIA report, we approximate 32,280 FTE jobs engaged in producing the fossil fuel electricity supply since 69 percent of jobs in "Electricity supply" equals 32,280.

Gas station employment. Gas and oil station employment is not directly reported in the Bank of Korea's database for 2018. To approximate gas and oil station employment, we work first with employment figures from the 2015 Economic Census, published by Statistics Korea, which reports that there were 12,052 automotive oil stations (with 47,303 workers) and 1,755 automotive gas stations (10,587 workers), for a total of 13,807 (57,890 workers). Oil stations combine other retail/services along with supplying gas while gas stations are narrowly focused on providing fuel. According to several news and industry publications, approximately 11,400 gas and oil stations operated in 2020.[89] Based on these publications' figures, we estimate that approximately 12,600 gas and oil stations operated in 2018 (12,600 = average of 11,400 and 13,800). Based on the 2015 Economic Census data, gas stations employed 4-6 workers per establishment. Therefore, we estimate that in 2018, approximately 57,000 workers operated gas and oil stations (57,000 = 12,600 establishments x 5 workers/establishment).

Oil and gas pipeline construction. We could not find estimates of oil and gas pipeline construction from government data sources like the Economic Census or the Bank of Korea's database for 2018. This is likely because there exist few, if any, jobs in oil and gas pipeline construction. According to the EIA, there is only one company owns and operates the gas pipeline network: Korea Gas Corporation. Any pipeline construction activity done by KOGAS may be categorized within that company's industry—i.e., the "Manufacture of Gas; distribution of gas through mains" which is reported in Table 4.1. Likewise, only one company owns and manage oil pipelines: Daehan Oil Pipeline Corporation (DOPCO).[90] Also, again according to the EIA, "tankers and trucks distribute most of the country's oil." Finally, a review of current news sources did not identify any major oil or gas pipeline construction projects.

For the following four sectors, we estimate employment figures by using information from the 2015 Economic Census-and apply it to the Bank of Korea's 2018 employment data. Specifically, from the economic census we estimate employment for:

1. **Wholesale—**petroleum and petroleum products. According to the 2015 Economic Census, "Wholesale of solid fuel and related products" and "Wholesale of liquid fuel and related products" made up 0.4% of wholesale and retail trade employment. According to the 2018 employment data, 0.4 percent of all wholesale and retail employment in 2018 is equal to 14,740 FTE jobs.
2. **Mining machinery and equipment manufacturing**. According to the 2015 Economic Census, "manufacture of mining treatment and handling equipment" made up 0.05% of manufacturing employment. According to the 2018 employment data, 0.05% of all manufacturing employment in 2018 is: 1,745 FTE jobs.
3. **Oil and gas field machinery and equipment manufacturing.** The 2015 economic census does not have this specific sector enumerated. We therefore approximate this sector by the closely related sector, "mining machinery and equipment manufacturing," or 1,745 FTE jobs.
4. **Oil and gas pipeline transportation.** According to the 2015 Economic Census, "Transportation by pipeline" employment made up 0.03% of all transportation employment. We use this figure to approximate "Oil and gas pipeline transportation." According to the 2018 employment data, 0.03% of all transportation employment in 2018 is: 420 FTE jobs.

Employment Levels of Nuclear Power Electricity Production

According to the 2020 country analysis of South Korea by the EIA discussed above, nuclear power supplied 25 percent of S Korea's electric power. Based on this report, we estimate that of the 46,783 workers involved in producing the commodity "electricity supply" in 2018, 25 percent are associated with nuclear power electric generation, or about 12,000 FTE jobs.

Employment Levels of Auto Manufacturing

To estimate employment in auto manufacturing, we use employment data from the Bank of Korea 2018 employment data for: "Motor vehicles" and "Motor vehicle engine and parts" combined.

Estimating Characteristics of Jobs in Fossil Fuel-Related Industries, Nuclear Power, and Auto Manufacturing

To create a profile of the types of jobs and the types of workers in fossil fuel-related industries, nuclear power, and auto manufacturing, we use the same basic methodology as for the profiles generated for clean energy investments. The only difference for these sectors is that we can estimate these characteristics directly from the LLFS, i.e., we do not need to create "synthetic" industries. To create average characteristics for the fossil-fuel related industries, we create a weighted average using the employment shares listed in Table 4.1.

Appendix 2
Estimating the Employment Impact of Phasing Out Fossil Fuel Imports, 2031 – 2050

We present here the full set of calculations through which we derived the summary figures presented in Table 5.5. The assumptions in Table A2.1 are the same as those described in the main text for Table 3.11.

TABLE A2.1
Employment Impact of Phasing Out Fossil Fuel Imports, 2031 – 2050

1) Year	2) GDP *(KRW trillions)*	3) Energy imports under BAU *(in KRW trillions; = 3.8% of GDP)*	4) Energy import share under Clean Energy Program *(reduce to zero by 2050)*	5) Energy imports under Clean Energy Program *(in KRW trillions)*	6) Annual reduction in energy imports under Clean Energy Program *(in KRW trillions; = column 3-5)*	7) Clean energy imports *(in KRW trillions; = 0.6% of GDP)*	8) Net import substitution *(in KRW trillions; = column 6-7)*	9) Annual job creation through net import substitution *(= column 8 x 9.5 jobs per KRW 1 billion)*
2031	2,480	94.2	2.1%	52.1	42.2	14.9	27.3	259,144
2032	2,542	96.6	2.0%	50.6	46.0	15.3	30.8	292,312
2033	2,605	99.0	1.9%	49.0	50.1	15.6	34.4	326,976
2034	2,671	101.5	1.8%	47.2	54.3	16.0	38.2	363,191
2035	2,737	104.0	1.7%	45.4	58.6	16.4	42.2	401,012
2036	2,806	106.6	1.5%	43.4	63.2	16.8	46.4	440,497
2037	2,876	109.3	1.4%	41.3	68.0	17.3	50.7	481,706
2038	2,948	112.0	1.3%	39.1	72.9	17.7	55.2	524,700
2039	3,021	114.8	1.2%	36.7	78.1	18.1	60.0	569,543
2040	3,097	117.7	1.1%	34.2	83.5	18.6	64.9	616,300
2041	3,174	120.6	1.0%	31.6	89.1	19.0	70.0	665,039
2042	3,254	123.6	0.9%	28.8	94.9	19.5	75.4	715,829
2043	3,335	126.7	0.8%	25.8	100.9	20.0	80.9	768,744
2044	3,418	129.9	0.7%	22.7	107.2	20.5	86.7	823,857
2045	3,504	133.2	0.6%	19.4	113.8	21.0	92.8	881,245
2046	3,592	136.5	0.4%	15.9	120.6	21.5	99.1	940,987
2047	3,681	139.9	0.3%	12.2	127.7	22.1	105.6	1,003,166
2048	3,773	143.4	0.2%	8.3	135.0	22.6	112.4	1,067,865
2049	3,868	147.0	0.1%	4.3	142.7	23.2	119.5	1,135,173
2050	3,964	150.6	0.0%	0.0	150.6	23.8	126.9	1,205,178
Total	----	----	----	----	----	----	----	**13,482,464**
Average	----	----	----	----	90.0	19.0	71.0	674,123

Source: Figures derived in Section 3

Appendix 3
South Korea's Nuclear Power Industry:
Current Phase-Out and Power Generation Projections through 2085

TABLE A3.1
Nuclear Energy Power Plants in South Korea: *Locations, Operational Status, and Projected Lifetimes*

Reactor	Status	Capacity *(megawatts)*	License starts	License ends	Scheduled lifetime
Kori 1	Permanent shutdown	587	6/19/77	6/18/17	40 years
Wolsong 1	Permanent shutdown	679	11/21/82	12/24/19	40 years
Kori 2	Operational	650	4/9/83	4/8/23	40 years
Kori 3	Operational	950	9/29/84	9/28/24	40 years
Kori 4	Operational	950	8/7/85	8/6/25	40 years
Hanbit 1	Operational	950	12/23/85	12/22/25	40 years
Hanbit 2	Operational	950	9/12/86	9/11/26	40 years
Wolsong 2	Operational	700	11/2/96	11/1/26	30 years
Hanul 1	Operational	950	12/23/87	12/22/27	40 years
Wolsong 3	Operational	700	12/30/97	12/29/27	30 years
Hanul 2	Operational	950	12/29/88	12/28/28	40 years
Wolsong 4	Operational	700	2/8/99	2/7/29	30 years
Hanbit 3	Operational	1000	9/9/94	9/8/34	40 years
Hanbit 4	Operational	1000	6/2/95	6/1/35	40 years
Hanul 3	Operational	1000	11/8/97	11/7/37	40 years
Hanul 4	Operational	1000	10/29/98	10/28/38	40 years
Hanbit 5	Operational	1000	10/24/01	10/23/41	40 years
Hanbit 6	Operational	1000	7/31/02	7/30/42	40 years
Hanul 5	Operational	1000	10/20/03	10/19/43	40 years
Hanul 6	Operational	1000	11/12/04	11/11/44	40 years
Shin-Kori 1	Operational	1000	5/19/10	5/18/50	40 years
Shin-Kori 2	Operational	1000	12/2/11	12/1/51	40 years
Shin-Wolsong 1	Operational	1000	12/2/11	12/1/51	40 years
Shin-Wolsong 2	Operational	1000	11/14/14	11/13/54	40 years
Shin-Kori 3	Operational	1400	10/30/15	10/29/75	60 years
Shin-Kori 4	Operational	1400	2/1/19	1/31/79	60 years
Shin-Hanul 1	Under Construction	1400	7/9/21	7/8/81	60 years
Shin-Hanul 2	Under Construction	1400	8/1/21	8/1/81	60 years
Shin-Kori 5	Under Construction	1400	3/31/24	3/30/84	60 years
Shin-Kori 6	Under Construction	1400	3/31/25	3/30/85	60 years

Sources: Data on the capacity, license, and lifetime information of each reactor in operation are from the Nuclear Safety and Security Commission: "https://www.nssc.go.kr/en/index.do" The potential dates for the lifetime start and end dates for reactions that are not yet in operation are taken from the Korea Power Exchange: https://new.kpx.or.kr/eng/.

TABLE A3.2
Total Projected Nuclear Power Plant Generating Capacity, 2022 –2085

Year	Projected capacity *(megawatts)*	Year	Projected capacity *(megawatts)*
2022	26,050	2055	8,400
2023	26,800	2056	8,400
2024	27,250	2057	8,400
2025	25,350	2058	8,400
2026	23,700	2059	8,400
2027	22,050	2060	8,400
2028	21,100	2061	8,400
2029	20,400	2062	8,400
2030	20,400	2063	8,400
2031	20,400	2064	8,400
2032	20,400	2065	8,400
2033	20,400	2066	8,400
2034	19,400	2067	8,400
2035	18,400	2068	8,400
2036	18,400	2069	8,400
2037	17,400	2070	8,400
2038	16,400	2071	8,400
2039	16,400	2072	8,400
2040	16,400	2073	8,400
2041	15,400	2074	8,400
2042	14,400	2075	7,000
2043	13,400	2076	7,000
2044	12,400	2077	7,000
2045	12,400	2078	7,000
2046	12,400	2079	5,600
2047	12,400	2080	5,600
2048	12,400	2081	2,800
2049	12,400	2082	2,800
2050	11,400	2083	2,800
2051	9,400	2084	1,400
2052	9,400	2085	0
2053	9,400		
2054	8,400		

Sources: Data on the capacity, license, and lifetime information of each reactor in operation are from the Nuclear Safety and Security Commission: "https://www.nssc.go.kr/en/index.do" The potential dates for the lifetime start and end dates for reactions that are not yet in operation are taken from the Korea Power Exchange: https://new.kpx.or.kr/eng/.

Endnotes

1 https://data.worldbank.org/indicator.

2 According to the World Bank's World Development Indicators, the total of 45.9 billion tons of greenhouse gas emissions (all figures in CO_2 or CO_2 equivalent) as of 2018 consist of: 34.0 billion tons of CO_2 emissions from combusting fossil fuels (74.1 percent of total); 8.1 billion tons of methane produced from both energy generation and agriculture (17.6 percent of total); 3.0 billion tons of nitrous oxide generated through a combination of energy, industry and agricultural production (6.5 percent of total); and byproduct emissions of hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride. See: https://data.worldbank.org/indicator).

3 Korea Energy Economics Institute, *Monthly Korea Energy Trends*, 2021-11, Appendix table on p. 26. Note that this figure excludes fossil fuel consumption for non-energy use, including oil as a petrochemical feedstock and coal for coking: http://www.keei.re.kr/keei/download/MET2111e.pdf.

4 The major source of overall greenhouse gas emissions, in South Korea and elsewhere, is carbon dioxide (CO_2). In South Korea, CO_2 emissions produce about 93 percent of overall greenhouse gases as of the most recent 2018 figures. Methane and nitrous oxide are the other significant sources of greenhouse gases in Korea, contributing 4 and 2 percent respectively to the country's overall greenhouse gas emissions as of 2018. The government has explicitly committed to cutting methane emissions by 30 percent as of 2030 as part of its overall program.

5 https://unfccc.int/sites/default/files/resource/LTS1_RKorea.pdf.

6 https://www.korea.net/Government/Briefing-Room/Presidential-Speeches/view?articleId=205893.

7 https://iea.blob.core.windows.net/assets/ab5343c6-5220-4154-a88e-750de58b9c8c/ReformingKoreasElectricityMarketforNetZero.pdf.

8 See Hong (2017), Hong et al. (2019) Deloitte Economics Institute (2021) and Kwan et al (2021).

9 The 631 million metric tons of CO_2 emissions as of 2018 comes from https://data.worldbank.org/indicator. Other sources report slightly different emissions figures.

10 https://data.worldbank.org/indicator. The government has explicitly committed to cutting methane emissions by 30 percent as of 2030 in conjunction with its carbon neutrality program.

11 https://unfccc.int/sites/default/files/resource/LTS1_RKorea.pdf.

12 https://www.iea.org/reports/korea-2020; MOTIE has also commissioned more detailed studies on specific aspects of Korea's green transition program, including the December 2021 study, Reforming Korea's Electricity Market for Net Zero: https://iea.blob.core.windows.net/assets/ab5343c6-5220-4154-a88e-750de58b9c8c/ReformingKoreasElectricityMarketforNetZero.pdf.

13 https://www.reuters.com/business/environment/skorea-commits-challenging-goal-cutting-emissions-40-2018-levels-by-2030-2021-10-18/.

14 https://www.korea.net/Government/Briefing-Room/Presidential-Speeches/view?articleId=205893. Also, the range of perspectives on South Korea's green transition by the candidates for the March 2022 presidential election are summarized in Kim (2022).

15 https://wwfkr.awsassets.panda.org/downloads/KEV-2050-SUM-EN.pdf.

16 https://gesi.kr/forum/view/86547.

17 An August 2021 study by Deloitte, *South Korea's Turning Point: How Climate Action Can Drive Our Economic Future*, argues that the Korean economy is particularly well-positioned to both play a leadership role and benefit itself through developing a robust decarbonization project. This report is not as specifically focused as the three other studies cited in this section in terms of presenting a path for reaching zero emissions by 2050. But it gives greater attention to the economic costs of climate inaction.

18 The 631 million metric tons of CO_2 emissions as of 2018 comes from https://data.worldbank.org/indicator. Other sources report slightly different emissions figures

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19 Korea Energy Economics Institute, *Monthly Korea Energy Trends*, 2021-11, Appendix table on p. 26. Note that this figure excludes fossil fuel consumption for non-energy use, including as oil as a petrochemical feedstock and coal for coking: http://www.keei.re.kr/keei/download/MET2111e.pdf.

20 However, plastics manufactured from petrochemicals do release CO_2 emissions when they are incinerated. This source of CO_2 emissions will become increasingly significant in the absence of measures to dramatically reduce plastic consumption through various means, including reducing packaging, increasing plastic recycling and transitioning to renewable feedstocks in plastic production—i.e. bioplastics. See Serpell et al. (2021); https://kleinmanenergy.upenn.edu/research/publications/balancing-act-can-petrochemicals-be-both-emissions-free-and-zero-waste/.

21 This average GDP growth assumption is nearly equal to the 2.4 percent growth rate assumed in Hong et al., who derived their assumption from KEEI data (see Hong et al. p. 427).

22 Thus, Bloomberg reports on 3/18/21 that "The Koreans are more focused on the downstream elements of the value chain than the Europeans and they'll probably import hydrogen for the time being." https://www.bloomberg.com/news/articles/2021-03-18/hydrogen-rivalry-intensifies-with-south-korea-challenging-europe. For discussions on various aspects of hydrogen energy and hydrogen fuel cell vehicles in South Korea, see also: https://link.springer.com/article/10.1007/s10098-020-01936-6; https://www.petrolplaza.com/news/28464; https://www.economist.com/science-and-technology/2020/07/04/after-many-false-starts-hydrogen-power-might-now-bear-fruit; https://asia.nikkei.com/Business/Companies/South-Korea-s-SK-bets-16bn-on-hydrogen-Five-things-to-know; https://www.greencarcongress.com/2020/12/20201218-irena.html.

23 https://www.koreatimes.co.kr/www/nation/2021/07/371_312722.html; https://www.tandfonline.com/doi/full/10.1080/25751654.2019.1585585.

24 In Appendix 3, we present details on the government's nuclear power-plant phase-out program, covering the years 2022 – 2085.

25 See Chomsky and Pollin (2020), pp. 86 – 90 for a brief review of these issues and relevant literature.

26 These detailed plans are summarized in IEA, Korea 2020 Energy Policy Review, p. 59: https://www.iea.org/countries/korea.

27 See Han, P. and S. Kimura (eds.), Energy Outlook and Energy Saving Potential in East Asia 2020, Jakarta: ERIA (https://www.eria.org/uploads/media/Books/2021-Energy-Outlook-and-Saving-Potential-East-Asia-2020/08); especially Chapter 1, "Main Report," by Han Phoumin, Shigeru Kimura, and Cecilya Laksmiwati Malik (https://www.eria.org/uploads/media/Books/2021-Energy-Outlook-and-Saving-Potential-East-Asia-2020/08; Ch.1-Main-report-new.pdf); and Chapter 9, "Republic of Korea Country Report," by Boo, K-J. (https://www.eria.org/uploads/media/Books/2021-Energy-Outlook-and-Saving-Potential-East-Asia-2020/16_Ch.9-Korea.pdf).

28 Some figures that we report in this study were originally reported in U.S. dollars, including those estimating the costs per Q-BTU of energy efficiency gains. We convert these dollar figures into won at the average 2020 exchange rate of 1 dollar = 1,181 won.

29 These more recent studies include Molina (2014), Ackerman et al. (2016) and Rosenow and Bayer (2016).

30 We develop these conclusions on the basis of reviewing a range of recent literature, including: Brockway, P.E., Sorrell, S., Semieniuk, G., Heun, M.K., Court, V., 2021. Energy efficiency and economy-wide rebound effects: a review of the evidence and its implications. Renew. Sustain. Energy Rev. 141; Chen, Y., Ardila-Gomez, A., Frame, G., 2017. Achieving energy savings by intelligent transportation systems investments in the context of smart cities. Transp. Res. Part D Transp. Environ. 54, 381–396.; Jin, S.-H., 2019. Home appliances' rebound effects estimated by a modified nonlinear model: an empirical study in South Korea. Energy Effic. 12, 2187–2199.; Sorrell, S., Dimitropoulos, J., 2008. The rebound effect: Microeconomic definitions, limitations and extensions. Ecol. Econ. 65, 636–649.

31 Korea Energy Economics Institute, Monthly Korea Energy Trends, 2021-11, Appendix table on p. 28. http://www.keei.re.kr/keei/download/MET2111e.pdf.

32 Specifically, we will estimate this 10 percent rebound effect based on the difference between the level of energy consumption prior to any efficiency gains and the level that would result strictly through an efficiency gain. For example, if, through efficiency investments, energy consumption were to fall by 2 Q-BTUs from 10 to 8 Q-BTUs, with a 10 percent rebound effect, overall consumption would "rebound" back by 0.2 Q-BTUs, to 8.2 Q-BTUs rather than stabilize at 8.0 Q-BTUs.

33 The difference between primary and final energy consumption is that primary consumption measures total domestic energy demand, while final consumption refers to what end users actually consume. The difference relates mainly to what the energy sector needs itself and to transformation and distribution losses. The main source of energy distribution losses is through burning fossil fuels to generate electricity. Distri-

bution losses through this energy transformation process is generally in the range of 60 – 65 percent.

34 Such detailed figures are also available at https://www.irena.org/publications/2021/Jun/Renewable-Power-Costs-in-2020.

35 Measured on a full life-cycle basis, bioenergy generates emissions levels comparable to those for coal through burning wood or through generating ethanol from corn. We therefore refer to these as "high-emissions" bioenergy sources. Using food crops to produce bioenergy also exerts upward pressure on food prices. But bioenergy can be generated at low- or zero emissions levels, as a "low emissions" energy source. This can result through using non-food crops as feedstocks, such as switchgrass, corn stover, and waste grease, and through utilizing renewable energy sources for refining these raw materials as needed. See Pollin (2015) for further details and references.

36 These figures are from the EIA, "Levelized Costs," https://www.eia.gov/outlooks/aeo/electricity_generation.php.

37 https://www.iea.org/reports/world-energy-outlook-2021, Table B4, p. 333.

38 The full methodology for generating these costs is presented in Pollin et al. (2014) pp. 136-37.

39 Unwin (2019) and Boretti (2020) analyze the current prospects for tidal power, including technological developments and costs. Among the areas of both Unwin and Boretti's focus is South Korea's Sihwa Lake tidal power station, which is the largest tidal power facility in the world.

40 https://www.nrel.gov/news/program/2021/documenting-a-decade-of-cost-declines-for-pv-systems.html.

41 By working with a high-end figure for renewable capital costs, we effectively take account of significant additional storage costs to build Korea's renewable energy infrastructure. On this issue of storage costs, Park (2021) reported in The JoonsAng on 9/28/21 that the government's Carbon Neutrality Committee reported a high-end estimate of KRW 1248 trillion in total costs to build sufficient renewable energy storage capacity for Korea to achieve carbon neutrality. The same article also reported a lower-end estimate of KRW 787. Measured as an annual average range over the full 29-year transition period 2022 – 2050, these storage cost estimates would amount to between KRW 27 – 43 trillion per year. This range of cost estimates can be accounted for within the high-end assumption we are working with for overall renewable capital expenditures. This average annual cost figure over 2022 – 2030, at KRW 213 trillion, is fully 76 percent higher than the KRW 121 trillion figure that we derive in working with the most recent renewable capital cost estimates developed by the U.S. Department of Energy.

42 We report this 2018 figure for South Korea's CO2 emissions because it was the most recent figure published at the time of writing.

43 As reported in Hong (2019), p. 427.

44 It is notable that this 9 percent decline in consumption, equal roughly to a 1 percent decline in consumption per year while the economy grows at 2.5 percent per year, generally aligns with the assumption within the International Energy Agency's 2021 global zero emissions model for 2050, which assumes that absolute consumption will fall by 0.6 percent per year as global GDP rises by 3 percent per year.

45 Nevertheless, polling evidence suggests that South Korean public opinion strongly supports a clean energy transition program for the country, even if the transition requires increasing energy costs. A 2020 study by Kim, Kim and Yoo, "Public Acceptance of the 'Renewable Energy 3020 Plan': Evidence from a Contingent Valuation Study in South Korea," surveyed consumers on their willingness to pay for implementing this plan, assuming the plan would be financed by raising electricity rates. Kim et al. found that the public was willing to pay as much as a 56.5 percent premium for electricity as a means of financing this plan.

46 A July 2021 study by Climate Analytics, Employment Opportunities from a Coal-to-Renewables Transition in South Korea, estimates employment impacts of a clean energy transition for South Korea, focusing, as the title states, on the coal-to-renewables component of this transition. Climate Analytics estimates that the coal-to-renewables transition could create 92,000 jobs per year by 2030 in comparison with a current policies plan. Of course, this figure is less than 15 percent the size of our estimate that, between 2022 – 2030, about 790,000 jobs will be generated through building a renewable energy infrastructure adequate to meet Korea's energy demand as fossil fuel consumption and CO2 emissions fall by 45 percent. Two sources of this disparity in the respective estimates are that: 1) Climate Analytics measures direct job creation only, while our 790,000 figure includes direct, indirect and induced job creation. Our figure for direct job creation only is 276,000; and 2) Climate Analytics measures renewable job creation net of the jobs that would continue through maintaining the economy's existing coal-based infrastructure. By contrast, our figure measures gross job creation through the full range of renewable investments, at KRW 78 trillion per year

in investment expenditures. This is the level of investment that we have estimated is necessary between 2022 – 2030 to provide adequate energy supplies while fossil fuel consumption is reduced by 45 percent. We then examine separately, in Section 4, job losses in coal and other fossil fuel-based sectors through Korea's 45 percent fossil fuel phase out as of 2030. In contrast with Climate Analytics, we do not examine scenarios in which the consumption of coal and other fossil fuels are maintained at levels that are too high to meet Korea's emission target of reducing emissions by at least 40 percent as of 2030.

47 We use the available measures in the 2019 Local Area Labor Force Survey to best approximate the share of regular jobs in each industry, although the definition of regular jobs varies somewhat across the literature. For a discussion of the definition of regular and non-regular jobs, see Byung-jin Ha and Sangheon Lee (2013) "Dual dimensions of non-regular work and SMEs in the Republic of Korea: Country case study on labour market segmentation," Employment Sector Employment Working Paper No. 148, 2013. For a broader discussion of job quality issues related to regular and non-regular employment, see: "2015 KLI Labor Statistics," by The Korea Labor Institute, December 2015, (https://www.kli.re.kr/kli_eng/downloadEngPblFile.do?atchmnflNo=19740); and "Strengths, gaps and weaknesses in Korea's income and employment support measures", in Towards Better Social and Employment Security in Korea, OECD Publishing, Paris, 2018 (https://doi.org/10.1787/9789264288256-6-en).

48 https://koreajoongangdaily.joins.com/2021/05/17/national/socialAffairs/Korea-Forest-ServICEV-forestation-tree-planting/20210517190500477.html.

49 https://www.nongmin.com/news/NEWS/POL/GOV/339360/view.

50 https://www.sciencedirect.com/science/article/abs/pii/S0264837711000615.

51 See, for example, Smith (2006); Brienen et al. (2015); Luyssaert et al. (2008); Pan et al. (2013); Pugh et al. (2019); and MacDowell (2020).

52 https://onlinelibrary.wiley.com/doi/full/10.1111/j.1757-1707.2011.01102.x ; https://www.sciencedirect.com/science/article/pii/S030626191630945X ; https://www.manomet.org/wp-content/uploads/old-files/Manomet_Biomass_Report_Full_June2010.pdf.

53 See Korean Forest Service (2021).

54 Our estimates are based on the government's own projections for the program. We do not address here the views expressed by critics that the CO_2 absorptive capacity estimated by the government is excessive relative to the scope of the program. See again: https://koreajoongangdaily.joins.com/2021/05/17/national/socialAffairs/Korea-Forest-Service-forestation-tree-planting/20210517190500477.html. Critics also contend that, in fact, the primary aim of the program is to expand logging activity in South Korea rather than to contribute to reaching the country's net zero emissions target.

55 https://koreajoongangdaily.joins.com/2021/05/17/national/socialAffairs/Korea-Forest-Service-forestation-tree-planting/20210517190500477.html.

56 That is, we multiply the 310 million tons of cumulative CO_2 absorption by the costs at between $40 and $50 per ton to derive a $12.4 - $15.5 billion total cost figure, converted to KRW.

57 That is, KRW 14.6 trillion/30 = 488 billion and KRW 18.3 trillion/30 = 610 billion.

58 These figures exclude Korea's fossil fuel imports that are consumed as inputs in petrochemical and steel production, rather than to produce energy.

59 In fact, from the Korea input-output tables, we estimate that the import share of energy efficiency investments will amount to 10.6 percent while that for renewable energy investments will be 14.4 percent.

60 Between 2012 and 2020, average labor productivity in South Korea increased at an average annual rate of 1.1 percent. These productivity estimates are from the Korea Productivity Center database at: https://www.kpc.or.kr/Productivity/StatisticDB.asp.

61 To be more precise, the 141,462 employment figure combines data from two sources: the Korean input-output tables for all sectors other than those for gas and oil stations and the 2015 Economic Census for the oil and gas station figures. The two sets of data are not exactly equivalent. The input-output tables reports numbers of full-time equivalent employment levels, while the Census combines data on part-time as well as full-time workers. As such, the figures on gas station employment are biased upwards relative to the full-time equivalent figures for all the other fossil fuel-based sectors. This is because, as we can see from Table 4.2, most of the gas and oil station jobs are not regular jobs, i.e., jobs that are mostly full-time, with longer-term or unlimited-term contract arrangements. However, most of the gas and oil station jobs are full-time, with their 'non-regular' status being determined more often by their shorter-term contract arrangement. Because

of this, it is likely that any bias in our figure for gas station employment is likely to be relatively small.

62 https://www.kli.re.kr/downloadBbsFile.do?atchmnflNo=9935.

63 https://www.kli.re.kr/downloadBbsFile.do?atchmnflNo=9935.

64 http://kostat.go.kr/portal/eng/pressReleases/5/5/index.board?bmode=download&bSeq=&aSeq=377710&ord=1.

65 https://english1.president.go.kr/briefingspeeches/speeches/677.

66 An October 2020 article in The Korea Times reported that "Opinions are emerging that Korea's move to start the ban in 2035 could be too progressive, given the ban's impact on the domestic automobile industry, which accounts for a significant portion of the country's overall economic growth," http://www.koreatimes.co.kr/www/tech/2021/03/419_297838.html.

67 https://www.theguardian.com/environment/2021/nov/10/cop26-car-firms-agree-to-end-sale-of-fossil-fuel-vehicles-by-2040#:~:text=The%20agreement%20to%20sell%20only,diesel%20car%20sales%20by%202030.

68 https://pulsenews.co.kr/view.php?year=2021&no=861332.

69 An October 2021 study by Cambridge Econometrics, The Macroeconomic Impact of Decarbonizing Korea's Passenger Car Fleet, examines a broader set of issues in the transition from ICEVs to ZEVs in the Korean economy. These include the infrastructure transitions necessary to support a ZEV-dominant auto fleet, the impact on vehicle sales and consumer spending, as well as impacts on employment, balance-of-payments and other macroeconomic considerations.

70 Working from the relevant engineering literature and specified within South Korea's input-output tables, we estimate that the relative weights for ICEV manufacturing to be 70 percent vehicle assembly and 30 percent engine and parts manufacturing. With ZEVs, we estimate relative weights at 50 percent vehicle assembly, 25 percent battery manufacturing, 10 percent for engine and parts manufacturing and 5 percent each for R&D and "other" scientific, technical, and professional services.

71 We have developed specific programs of this type for the U.S. economy overall, and for several U.S. states. See, e.g. https://irp-cdn.multiscreensite.com/6f2c9f57/files/uploaded/zero-carbon-action-plan-ch-03.pdf and https://peri.umass.edu/publication/item/1032-green-new-deal-for-u-s-states.

72 See, again, for example: The Government of the Republic of Korea (2020) 2050 Carbon Neutral Strategy for the Republic of Korea: Towards a Sustainable and Green Society; International Energy Agency (2020) Korea 2020 Energy Policy Review; International Energy Agency and Korea Energy Economics Institute (2021) Reforming Korea's Electricity Market for Net Zero; International Energy Agency (2021) Net Zero by 2050: A Roadmap for the Global Energy Sector; and International Renewable Energy Agency (2021) Reaching Zero with Renewables.

73 https://www.kedglobal.com/newsView/ked202109140002.

74 "Eco-friendly financing' Green bond issuance", May 16, 2019, Newspim. https://www.newspim.com/news/view/20190515002550.

75 http://www.koreaherald.com/view.php?ud=20210517000885.

76 https://wedocs.unep.org/bitstream/handle/20.500.11822/36996/EGR21_CH5.pdf.

77 https://www.imf.org/en/Topics/imf-and-covid19/Fiscal-Policies-Database-in-Response-to-COVID-19.

78 https://fossilfuelsubsidytracker.org/country/.

79 https://www.janes.com/defence-news/news-detail/south-korea-finalises-usd4632-billion-defence-budget-for-2022#:~:text=South%20Korea's%20defence%20budget%20for,(MND)%20in%20Seoul%20announced.

80 James Boyce, The Case for Carbon Dividends (Cambridge, UK: Polity Press, 2019).

81 https://www.globalpetrolprices.com/South-Korea/gasoline_prices/.

82 https://biz.chosun.com/policy/policy_sub/2021/12/28/QEGPDUS7AJDCLDD7YZAIKPM6WA/.

83 For a detailed discussion of the I-O method, including data collection and the mathematical underpinnings, see the U.S. Bureau of Economic Analysis "Concepts and Methods of the U.S. Input-Output Accounts" at

http://www.bea.gov/papers/pdf/IOmanual_092906.pdf.

84 For example, some of the typical underlying assumptions in a CGE include perfect competition, profit-maximization, market-clearing conditions, productions at full capacity and full employment. See Pollin et al. (2014a and 2014b) for detailed discussions on these methodological issues.

85 See, for example, Pollin et. al. (2014a).

86 See for example, various "Renewable Energy Cost Analysis" studies published in 2012 by the IEA.

87 See also Ernst and Sarabia (2015) for a review of relative induced effects for forty high- and upper-middle income economies between 1995 - 2009. Using a different modeling approach, this study also finds that induced effects are significantly larger than the average for this group of economies.

88 https://www.eia.gov/international/content/analysis/countries_long/South_Korea/south_korea.pdf.

89 See "Number of gas stations in South Korea as of December 2020, by operator," published by Statista (https://www.statista.com/statistics/1026088/south-korea-number-of-gas-stations-by-operator/); "Gas stations plan for a future without gas," Korea JoongAng Daily, 7/25/21 (https://koreajoongangdaily.joins.com/2021/07/25/business/industry/hyundai-oilbank-gs-caltex-sk-innovation/20210725070112348.html); and "South Korean Gas Stations' Choice: Evolve or Go Extinct," CSP Daily, 7/31/19 (https://www.csp-dailynews.com/fuels/south-korean-gas-stations-choice-evolve-or-go-extinct).

90 https://www.eia.gov/international/analysis/country/KOR/background.

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