Executive summary

2050 Climate neutrality roadmap for Korea

K-map scenario 2.0

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Repowering Korea's technological leadership in favour of a clean economy

GESI Green Energy Strategy Institute

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Key insights

Powering net zero: renewable expansion and grid transformation for Korea

Korea will have no choice but to substantially expand wind and solar power if it wants to achieve its climate neutrality target at lower costs. By 2050, the total installed capacity of wind and solar power will need to reach about 423 gigawatts (GW), compared to 22.9 GW in 2022. This is an average annual capacity addition of 8.4 GW until 2030 and 16.7 GW from 2030 to 2050. Integrating these renewables into the power grid will necessitate significant reinforcement of the transmission grid (approximately 40 percent more transmission capacity than today). Hydrogen turbines (85 GW in 2050) will play a crucial role in maintaining the balance of supply and demand during periods of low renewable output. Over half of this hydrogen will be domestically produced using renewable resources, while the remainder will be imported.

To address grid bottlenecks, Korea must adopt a comprehensive, state-of-the-art grid planning process that involves all relevant stakeholders. Additionally, it should introduce a flexible grid access framework for renewable energy projects, similar to the United Kingdom's Connect-and-Manage system.

This accelerated deployment of renewables will facilitate the phase-out of coal power by 2035, according to this analysis. However, further measures – such as implementing a forward market to limit future coal generation – will be essential to ensure climate mitigation targets are met.

Decarbonising Korean industry: strategies for maintaining global competitiveness

Industrial decarbonisation is gaining momentum worldwide, driven by the adoption of supportive policy frameworks (such as the Inflation Reduction Act in the United States and Carbon Border Adjustment Mechanism in the European Union) and the launch of global initiatives to procure low-carbon industry products. This global context places additional pressure on Korean industry. It is crucial to move away from the mindset that considers heavy industry as *hard to abate* and embrace the clean technologies that turn it into a *fast-to-abate* sector to maintain its global competitiveness. By embracing this proactive strategy, Korean industry emissions can be reduced to 190 megatonnes of carbon dioxide equivalent ($MtCO_2e$) by 2030 – 40 $MtCO_2e$ below the government target.

In the steel sector, low carbon technological options are mature. These include retrofitting conventional blast furnaces for integration with electric arc furnace processes (BF-EAF) by 2030, introducing hydrogen reduction steelmaking from 2033, and installing carbon capture and storage (CCS) facilities in existing blast furnace-basic oxygen furnace processes (BF-BOF) from 2036. Similarly, in the cement sector, replacing fossil fuels with circular resources and designing alternative products to bring down the clinker-to-cement ratio will be essential.

The main drivers of this transition will be voluntary initiatives to purchase low-carbon products, green public procurement requirements, and strengthening low-carbon product standards. To facilitate this transition and support the global competitiveness of Korean industry, new support schemes such as the carbon contracts for difference (CCfD) must be carefully designed.

Solar rooftop: an additional pillar to support the transformation of the Korean buildings sector

The transformation of the buildings sector will be driven primarily by energy efficiency improvements and a shift to low-carbon heating methods. Additionally, installing photovoltaic (PV) panels on half of the roof area of residential buildings constructed or retrofitted after 2025 could lead to the deployment of more than 12 GW of solar PV by 2050. Expanding this target to cover existing residential buildings as well would result in the 28 GW of solar PV capacity, equivalent to nearly 10 percent of all installed solar PV capacities in the country. If rooftop PV systems were also extended to tertiary and industrial buildings, their potential would be even greater. This development not only reduces households' electricity consumption but also generates additional revenues for Korean citizens, fostering community acceptance of renewable energy projects in the country. To achieve this, making solar PV mandatory for newly constructed or retrofitted residential buildings is essential. To alleviate the burden on consumers, this obligation should be accompanied by a coherent support scheme that particularly targets low-income households. Additionally, incentivising regulations or peer-to-peer markets at the distribution grid level would enable PV electricity surplus trading between households, further encouraging solar PV installation in the buildings sector.

Driving towards decarbonisation: Korea needs an electric vehicle revolution

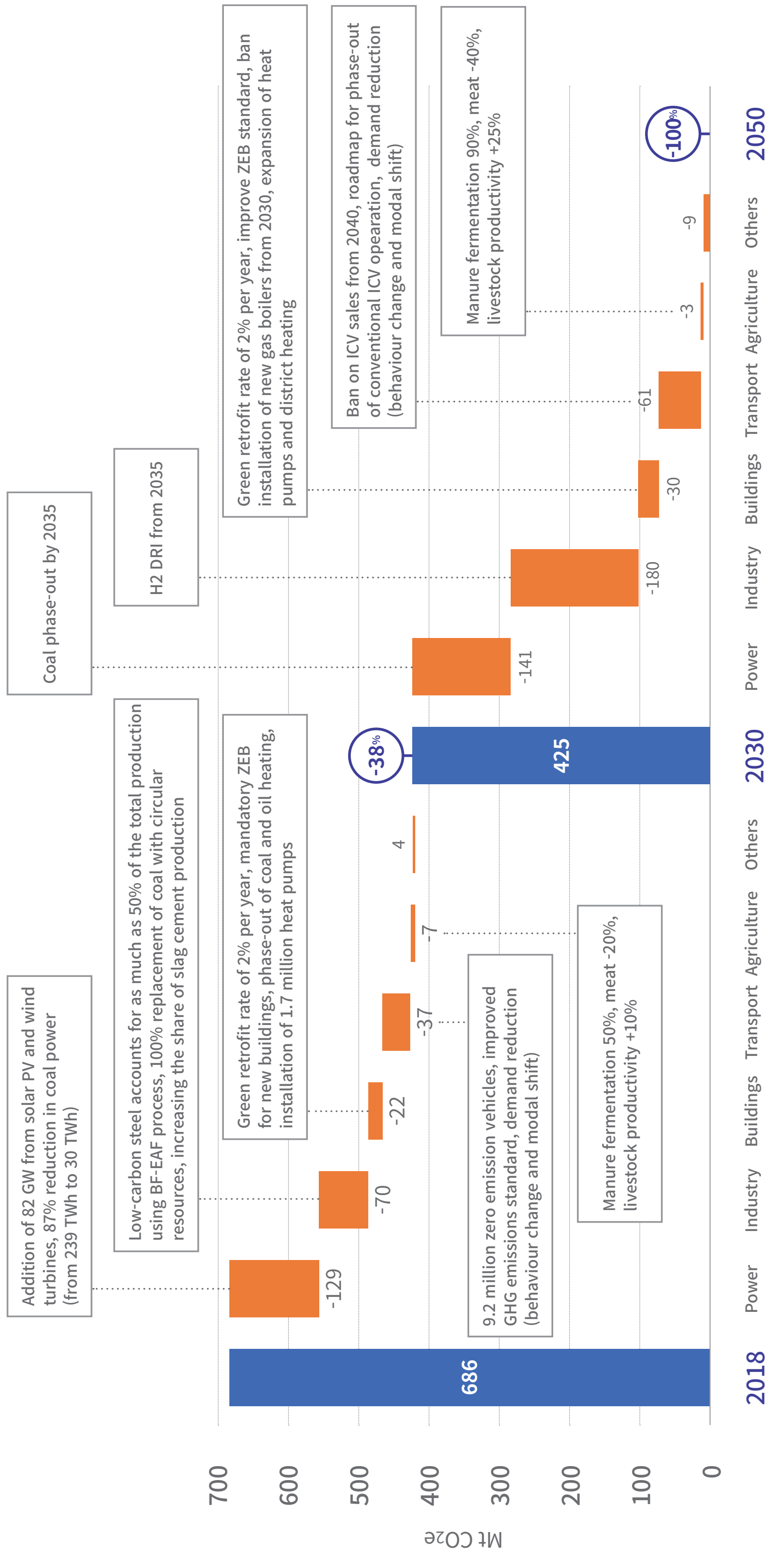
The decarbonisation of the transport sector is lagging in Korea, particularly in road transport where greenhouse gas emission (GHG) reductions have stagnated. However, Korean car manufacturers are leading the way in zero-emission vehicle development, especially electric vehicles. By expanding domestic sales, at least yearly 1.5 million electric vehicles could be supplied to Korean consumers by 2030. Including imports, this figure could reach 1.8 million. This would represent a diffusion of a total of 9.2 million electric vehicles in Korea by 2030. This acceleration could reduce the emissions of the road transport sector by 10.1 $MtCO_2e$ more than the government's target by 2030. To promote this development, the government should introduce stricter GHG emission standards, in line with the practices of other industrial jurisdictions such as the EU or the US. In addition, the government should develop and implement a concrete roadmap for the phase-out of conventional internal combustion engines, with concrete end-dates for their use.

Harvesting sun and crops: agrivoltaics is one pathway to sustainable energy and rural development in Korea

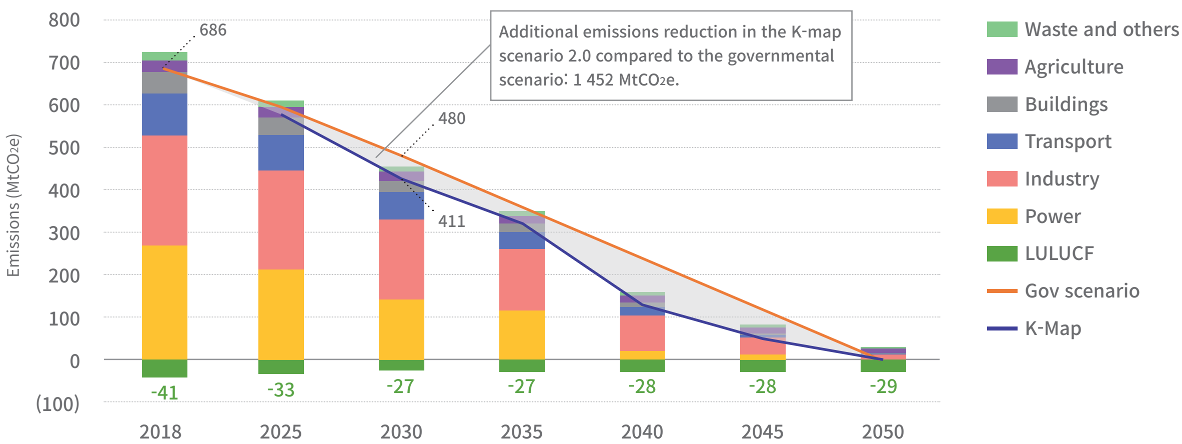
Agrivoltaics is a technology that allows land to be used simultaneously for farming and generating photovoltaic electricity. Installing agrivoltaic systems on approximately 6.2 percent of Korea's 1.9 million hectares of agricultural land could yield around 60 GW of solar power capacity by 2050, generating a substantial 106 terawatt hours (TWh) of electricity in that year alone. Though conservative, this estimate takes into account the pressing climate crisis, food scarcity and sustainable development needs of rural communities in Korea. With improved rural adoption of agrivoltaics, the potential benefits could be even greater.

To support the development of agrivoltaics, a comprehensive approach is necessary – one that considers the energy transition, food security and rural sustainability. In the short term, it is essential to promote agrivoltaics centred around self-sustainable farming and to dispel negative perceptions of solar power within rural communities. In the medium term, measures such as profit sharing could facilitate large-scale agrivoltaic projects or locally-led solar initiatives. Looking ahead, long-term efforts should focus on promoting the energy transition across rural spaces, including transport, housing and agricultural machinery with a view to achieving balanced regional development in rural areas.

[Figure 1] K-map scenario 2.0 for Korean climate neutrality by 2050



[Figure 2] Comparison of emission trends and cumulative emissions



1. Introduction

Despite its commitment to achieving climate neutrality by 2050, Korea has faced challenges in making significant progress on climate protection over the past two years. Greenhouse gas (GHG) emissions have, in fact, been on the rise again. In addition, according to the 1st National Carbon-Neutral Green Growth Basic Plan (2023-2042) it released in March 2023, the Korean government only plans to reduce GHG in earnest after 2029.
Against this backdrop, a consortium of four think tanks – the Green Energy Strategy Institute, the Green Transition Institute, the NEXT Group and Agora Energiewende – has conducted the present analysis with the goal of identifying measures and market segments that can be transformed rapidly, in line with Korea's climate-neutrality commitment, while enhancing the country's competitiveness. This analysis builds upon the *2050 Climate Neutrality Roadmap for Korea* (commonly known as the K-map scenario), which was released two years ago. The consortium has examined specific measures and sub-segments across five emission sectors: power, industry, transport, buildings and agriculture. Each chapter of this analysis presents updates, fresh insights and policy proposals tailored to these sectors.

2. Power sector

2-1. Updated K-map scenario in the power sector

The 2022 K-map scenario 1.0 showcased the importance of renewables-based electricity (as well as flexibility options such as storage capacities) when it comes to achieving carbon neutrality in Korea. However, this K-map scenario 2.0 did not consider power grid infrastructures or potential congestions that could limit the development of renewables. Effectively, delays in the planned expansion of transmission and distribution grids[1] have led to delays in renewable energy projects. Indeed, complaints about construction, difficulties in securing sites and delays in licensing have meant that many grid plans have not met their target dates, with delays ranging from 14 to 114 months. As a result, only 30.2 GW of the total 48.2 GW of renewable energy projects were connected to the transmission grid and started commercial operation from 2018 to 2023, according to KEPCO. The remaining 18 GW (37.2 percent of all projects) are either still at the approval stage or have been cancelled due to inadequate transmission and distribution network capacity.[2] This negatively affects the investment decisions of renewable energy operators, which in turn leads to the expansion of conventional fossil power plant operations.

This new analysis examines the scale of the transmission network required to achieve climate neutrality in Korea[3] and how its reinforcement is a prerequisite to renewables uptake.[4]

According to our findings, 157 GW of transmission capacities are needed by 2050, 39 percent more than today. If grid deployments are delayed by about five years, which is the historical average, solar deployment will also be delayed, resulting in 10 percent lower electricity generation of PV in 2050. In this case, 30 percent more hydrogen-based electricity would be required to fill the gap.

Considering grid constraints and realistic, albeit ambitious grid development plans, the expansion of renewables capacity in Korea by 2050 has been revised down to 301 GW of solar PV, 98 GW of offshore wind (including 42 GW of floating offshore wind) and 24 GW of onshore wind. To ensure that supply and demand can be balanced at lower costs, 85 GW of zero-carbon hydrogen power plants and 116 GW of battery storage will be required by 2050. Note that 43 percent of the zero-carbon hydrogen in the power sector will be imported. By 2050, wind and solar power would account for about 61 percent of total electricity generation, while about 22.5 percent would come from hydrogen turbines and 15.6 percent from nuclear. If Korea were to locally produce more hydrogen for seasonal storage, it

1 Every two years, KEPCO (Korea Electric Power Corporation) prepares a long-term power system plan that encompasses transmission network construction plans. It divides the country into six regions and 42 sub-regions, forecasts electricity demand and presents construction plans for the planning period (15 years).

2 The cost of the 18 GW of renewable energy projects waiting to be connected is 10.6 trillion Korean won (8 billion US dollars), according to an assessment conducted by MP Kim Seongwhan.

3 A multi-node cost optimisation model is used that works out the optimal power system configuration of generators, storage and interconnectors between nodes to meet future power demand under the given constraints. The model considers the costs associated with installing and operating new generators, storage systems and transmission lines, the fuel costs for generators and greenhouse gas prices, while also taking into account constraints such as the need to match hourly electricity demand and supply or technical characteristics of generators, storage systems and reserves.

4 The previous K-map scenario 1.0 did not consider the power grid – specifically the location of generation resources and the electricity demand. In reality, the regional distribution of power generation and demand can lead to grid congestions, thereby reducing utilisation of power generation facilities and, in some cases, leading to unmet demand.

would need to dimension its renewables capacity at even higher levels. Since renewable energy resources are mainly concentrated in the southern part of the country, while electricity demand is concentrated in the metropolitan area, additional transmission lines and battery storage will need to be installed to supply electricity to the metropolitan area when renewable energy generation increases. It will also become more economical to increase the capacity of hydrogen turbines in the metropolitan area.

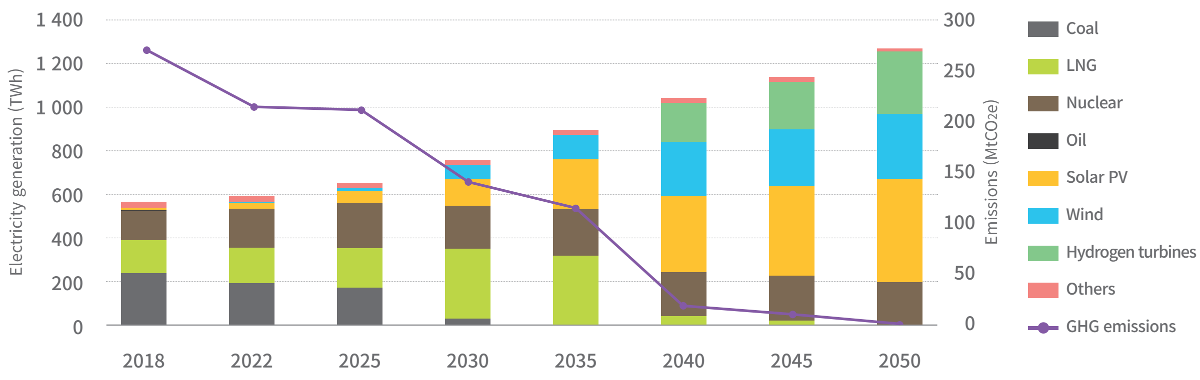
In addition, when the interregional transmission network is considered, we observe greater interaction between the interregional grid – which provides flexibility at system level – and the battery storage facilities used to balance demand and supply at regional level. As a consequence, batteries are mostly used for short-term operations, while the role of long-term storage is assumed by hydrogen turbines.

As a result of grid bottlenecks, a lower volume of renewables will be connected to the grid by 2035 than initially envisaged in the K-map scenario 1.0. Nonetheless, coal power generation can still be reduced down to a share of only 4 percent by 2030, though this will come at the cost of a higher share of gas-fired turbine power plants (operating initially with natural gas – 42 percent in 2030 – and in the future with zero-carbon hydrogen). After 2035, once grid deployment has picked up speed, renewables will be able to rapidly increase on the path to net zero by 2050. This trajectory will result in the power sector's cumulative GHG emissions increasing by

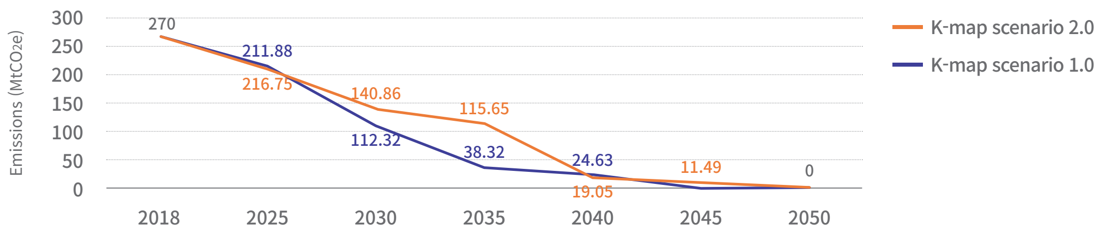
[Table 1] Power mix for carbon neutrality in Korea

Year		2018	2022	2030	2040	2050
Installed capacity (GW)	Coal	36.9	38.1	4.5	0	0
	Natural gas	37.8	41.2	54.9	6.9	0
	Nuclear	21.8	24.7	28.9	31.7	31.7
	Oil	4.3	0.9	0	0	0
	Solar PV	7.1	21.0	67.5	197.5	301.0
	Wind	1.4	1.9	22.5	94.3	122.7
	Hydrogen tubines	0	0	0	60.8	85.2
	Battery (storage capacity)	1.6	4.1	5.3	73.8	116.4
	Others	4.9	5.5	4.7	4.4	3.0
Power generation (TWh)	Coal	234 (42.2)	193 (32.7)	30 (3.9)	0 (0)	0 (0)
	Natural gas	153 (27)	164 (27.7)	323 (42.4)	43 (4.1)	0 (0)
	Nuclear	133 (23.6)	176 (29.8)	198 (26.1)	201 (19.3)	197 (15.6)
	Oil	6 (1)	2 (0.3)	0 (0)	0 (0)	0 (0)
	Solar PV	8 (1.5)	27 (4.6)	120 (15.8)	346 (33.2)	475 (37.5)
	Wind	2 (0.4)	3 (0.6)	69 (9)	250 (24)	297 (23.5)
	Hydrogen tubines	0 (0)	0 (0)	0 (0)	181 (17.3)	286 (22.5)
	Battery (storage capacity)	4.8	10.2	21.3	295.2	465.5
	Others	24 (4.3)	25 (4.3)	21 (2.7)	21 (2.1)	12 (1)
GHG emissions in power sector ($MtCO_2e$)		270	214	141	19	0

[Figure 3] Power generation and GHG emissions by year



[Figure 4] Annual GHG emissions in the K-map scenario 1.0 and 2.0



about 27 percent (until 2050) compared to the previous K-map scenario 1.0. This in turn will put more pressure on other sectors to step up their decarbonisation efforts (see suggestions relating in particular to the industry sector in the next chapter), while also necessitating ambitious measures to accelerate grid reinforcement.

2-2. Policy suggestions for power sector decarbonisation

2-2-1. Accelerate transmission and distribution development through more integrated and inclusive planning practices

In the past, when the power system was dominated by large generators with only a small share of renewable energy, grid expansion was not a major challenge in Korea because there was less uncertainty about power plant construction plans. With growing shares of renewables and an increased number of involved stakeholders, however, more integrated grid planning aligned with renewables development is becoming critical to facilitate the integration of renewables. In addition, while grid planning tended in the past to primarily consider the supply of large-scale generators and inflexible power demand, it will be necessary in the future to consider not only various renewable energy facilities but also the electrification of other sectors such as transport, buildings and industry. Advanced planning methods based on a longer planning period and greater integration between various sectors in different scenarios will therefore be needed.

The UK has advanced its transmission and distribution system planning by (1) developing multiple future scenarios for other sectors, including electricity, transport and heating, (2) conducting economic analyses that better take uncertainty into account and (3) engaging stakeholders in transmission and distribution system planning. In particular, multiple energy scenarios are developed to respond to uncertainties related to electricity demand and supply up to 2050; these are used as the basis for transmission and distribution system development and investment decisions, as well as for national and local government policy development.

This process is also more inclusive by inviting a wide range of stakeholders to propose solutions with a view to ensuring that the required infrastructure benefits from greater social acceptance. This process allows generators or large electricity consumers to include their own grid demands in the planning. The economics and efficiency of the options proposed by the stakeholders are evaluated by the Network Options Assessment process; this identifies the most cost-effective options, which are then scrutinised before construction plans are finalised.

2-2-2. Introduce a more flexible grid access scheme for renewable energy projects, similar to the UK's Connect-and-Manage system

To be able to commence commercial operation, renewable energy generators need to have access to spare grid capacity. Within the current framework in Korea, known as the fixed connection method, grid connection is possible only after grid expansion, so renewable energy facilities with relatively short construction periods risk facing connection delays.

Since the UK launched its Connect-and-Manage (C&M) scheme in 2010,[5] 163 large-scale generators – representing approximately 37 GW – have applied for access via this scheme (as of December 2013). These projects were guaranteed connection on average five years earlier than in the previous Invest and Connect scheme. The increase in renewable energy access has led to a reduction of almost 1 $MtCO_2e$ compared to before the C&M scheme was implemented (Ofgem, 2013).

2-2-3. Lift restrictive distancing rules that penalise solar PV deployment

Solar PV is one of the most cost-effective technologies for achieving climate neutrality. However, solar power projects often face conflict and opposition from local communities, prompting most jurisdictions to introduce distancing rules for solar projects in municipal ordinances. The range of the restrictive distances varies from municipality to municipality, from less than 100 metres to more than 500 metres.

5 Connect-and-Manage was introduced to allow generators to access the transmission system before completing some of the transmission reinforcements that would otherwise have needed to be completed ahead of their connection date.

Eliminating the distancing restrictions in relation to roads – while keeping those in relation to residential areas – could provide Korea with 524 TWh of additional solar PV generation potential. By contrast, only 104 TWh of additional deployment potential would be obtained by eliminating the distancing restrictions in relation to residential areas and keeping those in relation to roads. According to this updated K-map scenario 2.0, solar PV installations will need to increase by an average of 9.6 percent per year to achieve carbon neutrality in the power sector. It is therefore necessary to eliminate the distancing restrictions in relation to roads while limiting the distance from residential areas to a maximum of 100 metres in order to increase acceptance by local residents.

2-2-4. Introduce a forward market to limit coal power generation

Coal-fired power generation is still a dominant source of power generation in Korea (32 percent of the power mix in 2022) despite restrictions on generators to reduce air pollutants such as fine dust. In an effort to make thermal power less economical, an environmental dispatch order system was implemented in January 2012 to ensure that the cost of purchasing CO_2 emission credits would be reflected in the power generation costs. Due to shortcomings in the Korean Emission Trading System (power plants receive 90 percent of their CO_2 allocation for free) and the low price of CO_2 emissions, however, thermal power is still the cheapest source of electricity generation in Korea.

An electricity forward market with a tight cap on coal power generation should therefore be introduced. This would involve the government setting an annual cap on coal power generation based on mid- to long-term emission targets, and coal power operators bidding for annual power generation in the forward market based on their GHG emission factors for the last three years. The market operator would select market participants based on the bids submitted by power producers and their GHG emissions, and only the winning coal power producers would be eligible to participate in the all-day wholesale power market. This system would allow coal power generation to be managed in accordance with government emission targets, regardless of economic factors such as the cost of greenhouse gas credits or coal-fired power generation prices.

3. Industry sector

3-1. Updated K-map scenario in the industry sector

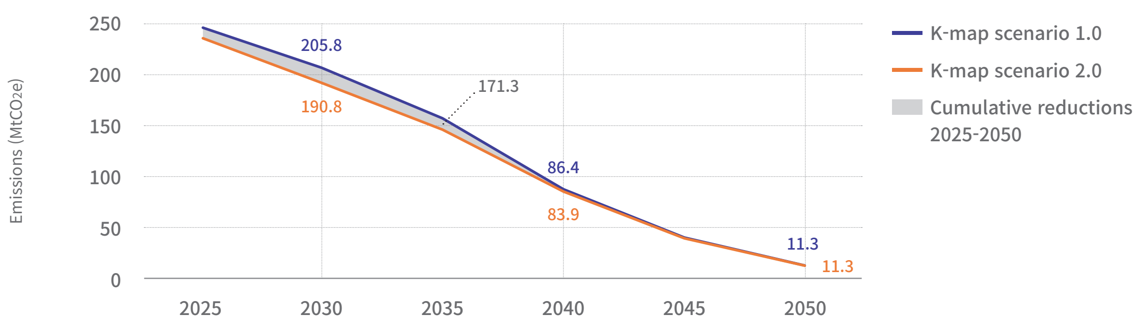
Over the last few years, several global initiatives have been launched to promote the purchase of low-carbon industry products, such as *SteelZero*, *ConcreteZero* and the *First Movers' Coalition*. This global context is driving demand for low-carbon products, ultimately incentivising a shift in production. In this updated K-map scenario 2.0, we analyse how this global demand could support a shift towards low-carbon industry production in Korea, looking specifically at the steel and cement sectors.

While the fundamental assumptions and structure of the previous K-map scenario 1.0 remain unchanged, the decarbonisation strategies of Korean steel and cement companies, as well as the long-term prospects of these industries, have been updated[6].

Overall, we found that the transformation of the steel and cement sectors could contribute to an additional cumulative reduction in emissions of 171 $MtCO_2e$ from 2025 to 2050, compared to the previous K-map scenario 1.0. In particular, industry sector emissions could be reduced to 190 $MtCO_2e$ by 2030, which is nearly 40 $MtCO_2e$ less than in the government's industrial emission target of 230 $MtCO_2e$ in the *Carbon Neutral Green Growth Plan*.

This sends out two important messages. First, it means that near-term reductions in the industry sector will be possible even before breakthrough low-carbon production technologies are commercialised. Private companies tend to be reluctant to invest in GHG abatement technologies in the short and medium term due to profit instability and stranded asset concerns. If there is demand for low-carbon products, however, manufacturers have no choice but to increase investment in new low-carbon technologies to maximise their profits. Second, the steel and cement sectors support key industries that drive the Korean economy, including construction, car manufacturing and shipbuilding, so decarbonising steel and cement will reduce the carbon footprint of the entire Korean industry, thereby enhancing its international competitiveness.

[Figure 5] Outlook for GHG emissions of the industrial sector



6 To examine the potential for increased demand for low-carbon products (from both the public and private sectors), recent trends and low-carbon standards were analysed, stakeholder interviews were performed and policies in Korea, the US and the EU were assessed.

3-2. Emission reduction potential derived from low-carbon product demand signals in industry sector

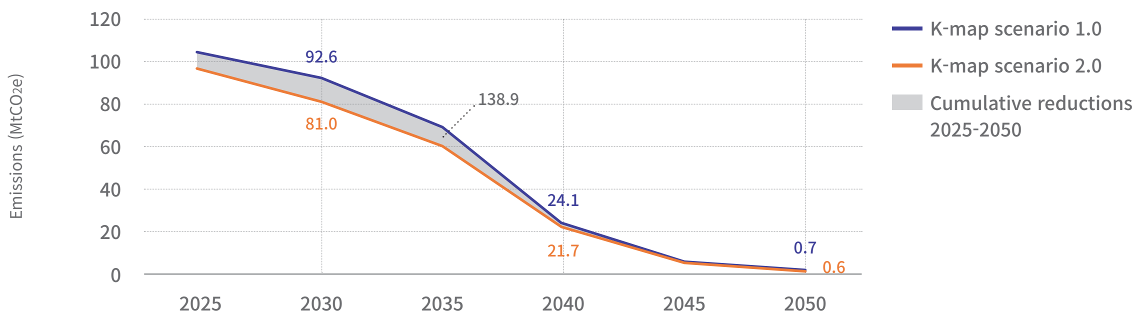
Being the main actors in the industry sector, companies are inherently engaged in the production of goods and services and determine the mode and scale of their production activities with the aim of maximising profits. Therefore, in order to encourage them to decarbonise their production activities, there must be demand for low-carbon or carbon-neutral products in the marketplace, leading to their purchase at a price that does not compromise the profitability of producers. This report identifies private business trends and public policies[7] that create demand signals for low-carbon products as key variables that can accelerate the decarbonisation of the industrial sector and analyses the resulting GHG reduction potential.

3-2-1. Additional reduction potential in the steel industry

In order to fulfil SteelZero's low-carbon steel standard[8] (participating companies commit to procuring low-carbon steel to meet half of their steel consumption by 2030), domestic steel manufacturers in Korea will need to retrofit conventional blast furnaces for integration with electric arc furnace processes (BF-EAF) by 2030, introduce hydrogen reduction steelmaking from 2033 and install CCS facilities[9] to remaining conventional blast furnaces from 2036.

This strategy will allow GHG emissions to be further reduced by an additional 140 MtCO2e from 2025 to 2050 compared to the previous K-map scenario 1.0. As can be seen in Figure 5, the largest additional reductions will be achieved before 2030, as manufacturers need a rapid transition to fulfil

[Figure 6] Outlook for GHG emissions in the steel industry



7 Governments can promote the creation and maturation of low-carbon markets through regulation. In particular, policies to disclose the results of lifecycle assessments and provide incentives to manufacture goods – such as cars and buildings – using low-carbon products and raw materials are rapidly being introduced.

8 Launched in 2020, the initiative requires participating companies to purchase low-carbon steel to cover 50% of their steel needs by 2030 and carbon-neutral steel to cover 100% of their steel needs by 2050. As of December 2023, 36 companies were participating, including Ørsted, Volvo Cars and Maersk. SteelZero's low-carbon standard is 1.4 tCO_2/t-steel or less in the case of 0% scrap, which is about 30% lower GHG emissions than the carbon intensity of the steel manufactured by POSCO in 2022 (about 2.05 tCO_2/t-steel).

9 1.25 million tonnes of steel production in 2036 to 0.37 million tonnes of steel production in 2044, and complete phase-out of conventional blast furnaces by 2045.

[Table 2] Outlook for GHG emissions in the steel industry

(Unit: $MtCO_2e$)	2025	2030	2035	2040	2045	2050
K-map scenario 2.0	96.4	81.0	60.3	21.7	4.7	0.6
K-map scenario 1.0	104.7	92.6	68.7	24.1	5.0	0.7

interim procurement targets (those adopted by the SteelZero coalition).

The Korean steel sector has so far failed to significantly reduce its GHG because there has still been demand for steel products manufactured via the BF-BOF route. However, if demand for low-carbon steel increases, the cost effectiveness of blast furnaces will quickly decline, so the transition away from blast furnace operations will occur even before the hydrogen reduction process has been commercialised. The steel sector will therefore be able to complete the transition more quickly than in the K-map scenario 1.0, and the transition to low-carbon BF-EAF processes will be more effective than the blast furnace-based hyper BF-BOF process adopted in the K-map scenario 1.0. By 2030, the low-carbon BF-EAF process output will reach 68 percent of primary steel product output, thereby reducing the role of conventional blast furnaces. Hydrogen reduction steelmaking is expected to be commercialised from 2033, with conventional blast furnaces being finally retired by 2045. Coal demand in the steel sector will also decline rapidly with the transition away from blast furnaces and will be completely eliminated by 2045.

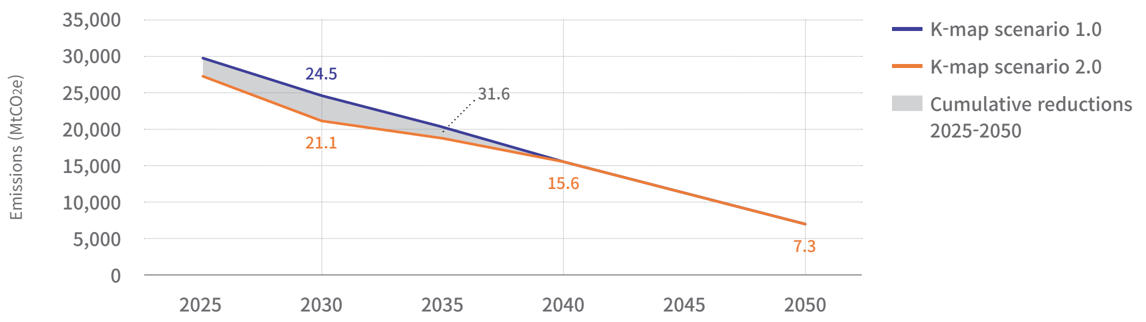
3-2-2. Additional reduction potential in the cement industry

The cement industry is driven mainly by domestic demand. Demand for low-carbon cement will therefore be incentivised mostly by governmental policies such as green building certification standards or public procurement standards rather than by the impact of global low-carbon cement initiatives. In the demand-led K-map scenario 2.0 for the cement sector, a stricter building Life Cycle Assessment (LCA) will be introduced into the Korean building certification system G-SEED[10], taking into account low-carbon building materials, and the maximum allowable emission standard for low-carbon product certification will be raised to the level of the best globally available technology. Furthermore, industry's use of coal will be completely replaced by circular resources, which is also the goal of Korea's leading cement producers, and the industry-wide clinker-to-cement ratio will fall to 73.7 percent by 2030.

This would lead to an additional reduction of 32 $MtCO_2e$ from 2025 to 2050 compared to the previous K-map scenario 1.0. The largest reductions occur in 2030, due to the 100 percent replacement of metallurgical coal by circular resources. Additional reductions after 2030 are achieved by an increase in the share of slag cement production, thereby contributing to a lower clinker ratio, though the effect is fairly modest. Therefore, new products other than slag cement need to be developed to

10 G-SEED certifies buildings as eco-friendly if they contribute to energy conservation and environmental pollution reduction throughout the entire process, i.e. from the production, design, construction, maintenance and management of building materials to their disposal.

[Figure 7] Outlook for GHG emissions in the cement industry



[Table 3] Outlook for GHG emissions in the cement industry

(Unit: $MtCO_2e$)	2025	2030	2035	2040	2045	2050
K-map scenario 2.0	27.3	21.1	18.8	15.5	11.4	7.3
K-map scenario 1.0	29.6	24.5	20.2	15.6	11.5	7.3

significantly reduce the clinker-to-cement ratio and increase the share of climate-friendly Supplementary Cementitious Materials (SCMs).

3-3. Policy suggestions for industry sector decarbonisation

3-3-1. Enhance low-carbon certification criteria

According to the Low Carbon Product Standard in Korea, low-carbon products must emit fewer GHGs on average than their peers and achieve a 3.3 percent GHG reduction compared to their own emissions three years earlier. Given the oligopolistic structure of Korea's steel sector, this definition of low-carbon products has a limited ability to encourage competition in terms of GHG reduction efforts by steel companies.

In addition, the Korean green building certification system G-SEED needs to be updated. However, G-SEED grants bonus points according to the number of low-carbon building materials used, not according to the embedded emissions of the building materials. It also grants bonus points if a building LCA is conducted, irrespective of its result. Because of these design defects, G-SEED has not contributed to creating demand for low-carbon building materials.

3-3-2. Increase incentives for low-carbon products

Since low-carbon products cost more to produce than conventional products, incentives are needed to offset this difference. Subsidies are normally the most effective way to do this. Subsidies for low-carbon steel and cement should be introduced in much the same way as the electric vehicle subsidy programme[11] was introduced in Korea in 2011.

In addition to direct subsidies, mandatory disclosure schemes can support demand for green products while minimising budgetary expenditure. The EU's proposed automotive LCA disclosure scheme encourages carmakers to voluntarily disclose LCA information. This is expected to lead to behavioural changes among consumers and investors, which in turn is putting pressure on the global automotive industry to procure green materials. It is a policy that will allow low-carbon products to compete in the market without direct financial support from the government.

3-3-3. Expand the scope of green public procurement and the intensity of obligations

To increase demand for low-carbon products, the government needs to expand and strengthen green public procurement. Korea has a green public procurement system in place but fails to generate demand for low-carbon steel and cement effectively. This is not only because the low-carbon certification standards for steel and cement are very lenient, but also because public organisations can fulfil their green public procurement obligations without purchasing low-carbon steel or cement. Even if a product has high GHG emissions, for example, it can still be recognised as green if it meets other environmental criteria such as non-use of hazardous substances or low water consumption. Moreover, steel is not even covered by the Minimum Green Standard Product Purchase Program, one of Korea's green public procurement programmes.

The scope and content of the existing green public procurement system should therefore be expanded. GHG emissions should be added as an essential criterion to the definition of green products, and steel products should be added to the list of products subject to the Minimum Green Standard Product Purchase Program.

11 After the introduction of EV subsidies, the share of EV sales increased from 0.02 percent in 2011 to 5.7 percent in 2022.

4. Buildings sector

4-1. Recent trends and update of the K-map scenario in the buildings sector

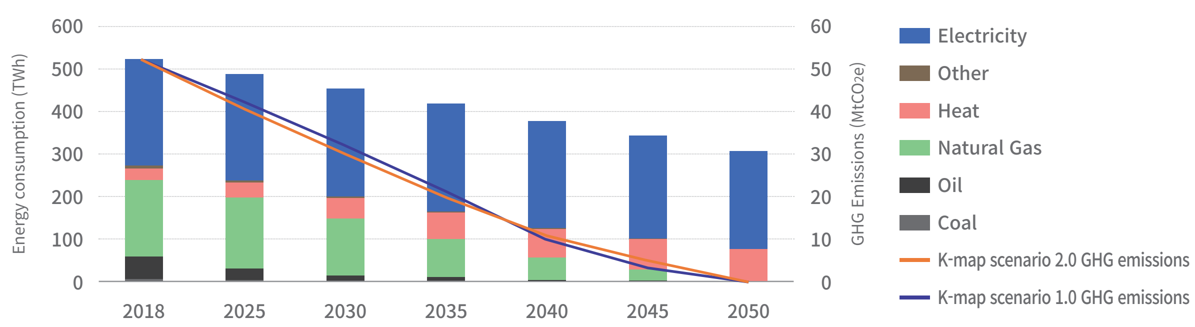
Several changes have occurred since the K-map scenario 1.0 was released in 2022, requiring an update of the GHG emission outlook. The projected gross floor area of residential buildings has increased due to the rapid development of new housing and the Korean government has revised its future household projections.[12] In addition, the decarbonisation of heating has been revised to include a ban on the installation of new gas boilers from 2030, the phase-out of coal and oil heating by 2030, a 2.8-fold increase in district heating by 2050 compared to 2018 and the replacement of other heating needs with electricity.

As a result, the residential building stock (in terms of gross floor area) in 2050 is expected to be split into:

- 6% built before 2010 (before the adoption of insulation standards),
- 22.3% built between 2010 and 2018,
- 71.7% built after 2019.

While increasing energy efficiency in buildings (in line with the previous K-map scenario 1.0) will reduce overall energy consumption in the buildings sector, electrifying heating will increase the overall electricity demand of the residential sector (from 74.0 TWh in 2018 to 92.2 TWh in 2050). Overall, and taking into account the changes in housing floor area and the early retirement of old coal and oil heating, energy demand is adjusted to 451.2 TWh in 2030, 373.7 TWh in 2040 and 305.4 TWh in 2050, reducing the buildings sector's GHG emissions to 29.46 $MtCO_2e$ by 2030 (compared to 2018) and to 10.97 $MtCO_2e$ by 2040, and achieving carbon neutrality by 2050. This pathway is slightly more ambitious than the previous K-map scenario 1.0 up to 2040, due to the enhanced heating transition, but slightly slower afterwards.[13]

[Figure 8] Outlook for energy consumption and GHG emissions of the buildings sector



12 While the K-map scenario 1.0 projected a gradual increase in the gross floor area of residential buildings from 1 894 million square metres in 2025 to 2 001 million square metres in 2050, this K-map scenario 2.0 shows a rapid increase to 1 928 million square metres in 2025, followed by a gradual slowdown to a peak of 1 981 million square metres in 2040, and then a decline.

13 The K-map scenario 1.0 showed 32.3 $MtCO_2e$ in 2030, 10.16 $MtCO_2e$ in 2040 and carbon neutrality in 2050.

4-2. Additional GHG emission reduction potential through a residential rooftop solar programme for Korea

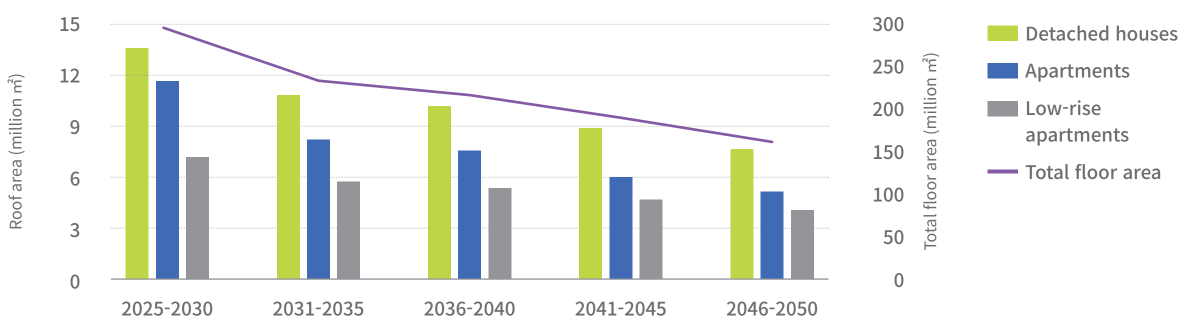
In addition to the updated framework for building stock transformation mentioned in 3-1, this study specifically analyses the potential of mandatory rooftop PV programmes on residential buildings in Korea.[14] Such a policy has been implemented for example in the European Union.[15] Considering the characteristics of Korea's shorter building lifespan compared to other countries and the efficiency improvements in building energy performance and photovoltaic power generation equipment, this study analyses the annual photovoltaic installation potential and the increase in the power self-sufficiency rate in buildings when a mandatory rooftop PV programme is introduced for new builds or retrofits.

Based on the assumptions described in 4-1, the number of new and retrofitted residential buildings and their roof area will continue to decline (see Figure 9).

Despite the declines in new roof area, installed PV capacity will continue to grow with the increased efficiency of solar panels. The cumulative deployment potential of residential rooftop solar in 2050 is 12.6 GW, corresponding to an average annual installation rate of 484 MW.[16] The greatest potential is offered by detached houses with relatively large roof areas at 5.6 GW (44 percent), followed by apartments at 4.1 GW (33 percent) and low-rise apartments at 2.9 GW (23 percent).

Expanding rooftop solar PV will increase residential electricity generation from 0.5 TWh in 2018 to 18.8 TWh in 2050 and see the residential power self-sufficiency rate rise from less than 1 percent in

[Figure 9] Projected total floor area and roof area of newly built/retrofitted residential buildings

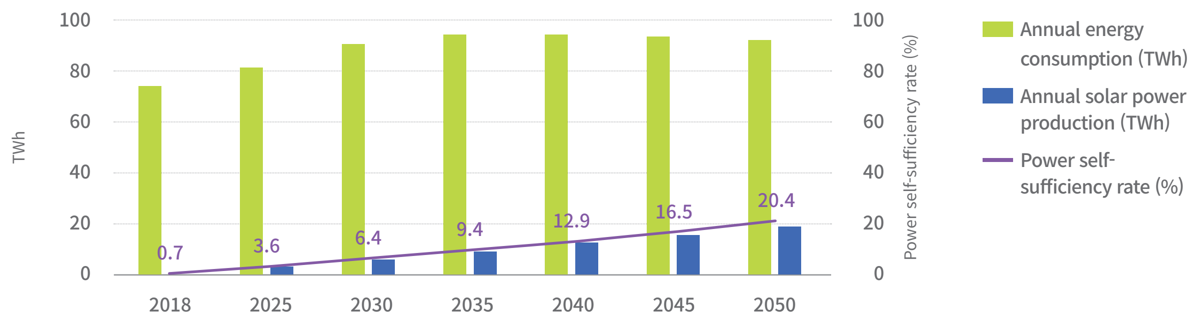


14 As residential buildings account for two thirds of all GHG emissions in the buildings sector and the gross floor area of residential buildings is expected to increase by 2040, this study analyses only the solar installation potential of residential buildings. In the case of commercial buildings, the scope for analysing solar installation potential is limited by the wide variety of roof uses and lack of relevant data.

15 The European Rooftop Solar Package mandates rooftop solar on all new buildings with the goal of generating 25% of total electricity consumption.

16 Residential solar deployment over the past five years has averaged 156 MW per year, which means that about three times more than the current deployment is necessary.

[Figure 10] Projected residential power self-sufficiency rate with rooftop solar expansion



2018 to 20.4 percent in 2050. This will contribute to an additional GHG abatement of 0.65 $MtCO_2e$ in 2030 and 0.18 $MtCO_2e$ in 2040 (these reductions are counted as power sector emissions)[17]. If the solar PV obligation also applies to existing buildings built before 2025, the potential for rooftop solar in 2050 will increase to 28.4 GW (15 GW for detached houses, 8 GW for apartments and 5.4 GW for low-rise apartments), while the power self-sufficiency rate of residential sector will increase to 40.5 percent.

17 These additional GHG emission reductions from rooftop PV are not counted as direct GHG emissions from the buildings sector. However, since the buildings sector (household, commercial and public) accounted for 47.6 percent of total electricity consumption in Korea in 2021, reducing the overall electricity demand by generating the electricity directly in buildings will contribute to the country's overall GHG reduction.

4-3. Policy suggestions for buildings sector decarbonisation

To mobilise the potential for rooftop solar in residential buildings (12.6 to 28.2 GW in 2050, corresponding to 4.2-9.4 percent of the K-map total solar PV target), the following policy measures should be improved accordingly.

4-3-1. Introduce a mandatory rooftop solar programme for new builds and retrofits

Given the slow progress being made with improving public acceptance for ground-mounted PV, installing solar power on building roofs should be prioritised as it allows solar power to be adopted while avoiding conflicts over land use. In addition, since most buildings are located in cities where electricity consumption is quite high, generating solar power on building roofs helps improve a city's energy self-sufficiency, minimising the need for additional transmission grids. Furthermore, if home batteries are increasingly used to store power generated from rooftop solar in the future, this will also play a role in demand response. As electricity consumption in buildings is expected to increase due to the electrification of heating energy, for example using

[Table 4] Mandatory building solar PV programmes in major countries

Jurisdiction	Policies
European Union	- (EU) Mandatory solar PV installation in all new public, commercial and residential buildings (from 2026)
Germany	- (Nine states including Berlin and Baden-Württemberg) Mandatory solar PV installation in new buildings and roof improvements (from 2023)
United States	- (California) Mandatory solar PV installation in newly built residential complexes of ten or more units, multifamily buildings with ten storeys or fewer and non-residential buildings with three storeys or fewer (from 2020) - (New York) Solar or green roof obligation for new-builds or roof improvements in small residential and non-residential buildings (from 2019)
Japan	- (Tokyo) Mandatory solar installation in large new buildings of 2 000 ㎡ or more, detached houses in large new residential complexes of 20 000 ㎡ or more (from 2025) - (Kyoto) Mandatory solar installation in new residential buildings of 300 ㎡ or more (excluding detached houses) (from 2022)

heat pumps, installing solar power on roofs can also reduce consumers' energy bills. Introducing a mandatory rooftop programme such as those already in place in the European Union, Germany, Japan and the United States should be considered (see Table 4).

In Korea, it is mandatory to supply and use renewables (at least to some percentage) in public buildings with a gross floor area of 1 000 ㎡ or more (new-builds and extensions or renovations). This obligation does not yet apply to private buildings. The Renewable Energy Act should therefore be amended to mandate the supply of renewable energy to private buildings with a gross floor area of 1 000 ㎡ or more, as is the case for public buildings. In addition, given that buildings with a gross floor area of less than 1 000 ㎡ account for 93.3 percent of the total building stock in Korea, it is also necessary to expand the obligation to small and medium-sized buildings of 500 ㎡ or more.

4-3-2. Enable surplus PV electricity sales to other homes/buildings through community solar power and decentralised markets

Due to roof space constraints, the amount of solar power that can be generated per household in apartments is limited. By contrast, detached houses and low-rise apartments can generate more solar power than their own electricity demand, and it is possible to create a more economical business model if the surplus power can be traded. Various business models for trading surplus power between buildings already exist in other countries, such as the Community Solar Power and Prosumer schemes. Similar measures should be implemented to activate surplus power trading between households in Korea.

In December 2018, the Electricity Business Act was amended to allow solar power systems of 1 MW or less to trade surplus power with neighbours through aggregators. However, as power sales are still only allowed through KEPCO and new tariff plans are not permitted, no active trading of surplus power takes place. The relevant regulations therefore need to

[Table 5] Surplus power trading business models

Business models	Concepts	Advantages
Community Solar Power	▪ A local utility, special purpose company or nonprofit organisation leases the roof of a building to develop a solar project and sells solar power to local residents. ▪ Residents can initially invest in the solar project and purchase equity in the solar installation, or can purchase solar power without initial investment.	▪ (Expanding consumer choice) Residents who live in rented homes or apartments and cannot install solar themselves can still access solar power. ▪ (Reducing consumer electricity bills) Residents can use community solar contract power first and then use KEPCO power, avoiding progressive tariffs.[18] ▪ (Expanding the spread of solar power) Encouraging the development of solar power businesses that utilise idle sites in the community, including building roofs.
Decentralised market	▪ Residents with solar on their homes sell surplus electricity after self-consumption to neighbours on the same grid who have higher electricity bills.	▪ (Increasing profit) Residents who generate solar power can sell it to their neighbours at a higher price than KEPCO's offset transaction. ▪ (Reducing consumer electricity bills) Power can be purchased at a lower price than the progressive tier.[19] ▪ (Expanding solar penetration) Encouraging solar installations that maximise the use of roof area by generating revenue through surplus power trading.

be improved so that small-scale solar companies or aggregators can trade power and offer various electricity tariffs without going through the wholesale power market.

18 During the first oil crisis in 1974, tiered electricity pricing was introduced to residential electricity bills in order to discourage electricity consumption. Electricity usage is divided into three tiers: tier 1 for 1-200 kWh consumption at 120 Korean won (KRW) per kWh, tier 2 for 201-400 kWh consumption at 214.6 KRW/kWh and tier 3 for over 400 kWh consumption at 307.3 KRW/kWh.

19 According to Paran Energy, which provides neighbour-to-neighbour electricity trading services, households with an average monthly electricity consumption of 500 kWh or more can purchase electricity from neighbours who sell surplus electricity at a lower rate (about 200 KRW/kWh) than the progressive tier 3 rate.

5. Transport sector

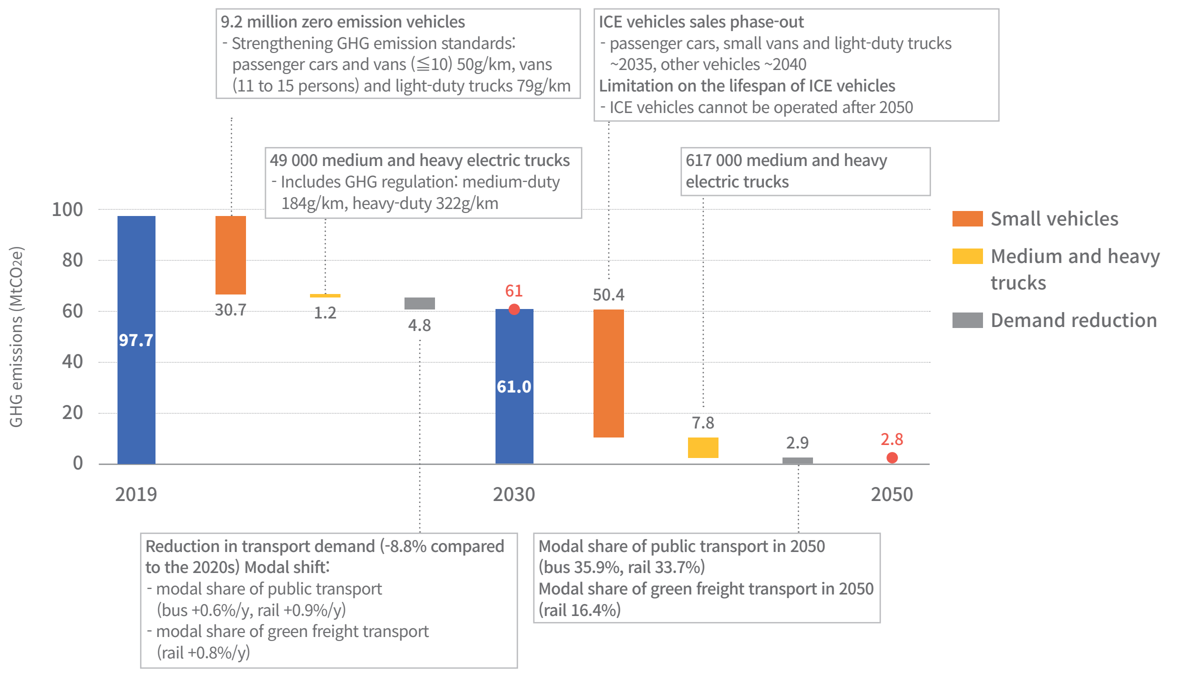
5-1. Recent trends and update of the K-map scenario in the transport sector

The emission reduction pathways in the transport sector that were defined by the K-map scenario 1.0 in 2022 have failed to materialise. Both the number of thermal engine vehicle registrations and overall transport demand have increased in Korea (i.e. insufficient modal shift). Consequently, CO_2 emissions in the sector are stagnating (97.8 $MtCO_2e$ in 2022 versus 97.3 $MtCO_2e$ in 2018). Faster GHG reductions are therefore now needed to achieve climate neutrality by 2050.

Greater policy implementation is necessary to reach the 2050 target. Tougher emission standards for car manufacturers are required to accelerate the switch to electric vehicles (EVs) by 2030 in the case of small cars and after 2030 in the case of medium- and heavy-duty freight vehicles. A ban on the sale of internal combustion engines for all vehicle types should be implemented before 2040, and a roadmap to phase out remaining internal combustion engines should be put in place.

According to this new analysis, the transport sector will emit 78.3 $MtCO_2e$ in 2030, i.e. about 30 percent more than the government's target of 61 $MtCO_2e$, unless vehicle GHG standards are tightened. Achieving the 2030 target will require the aggressive deployment of EVs and a significant decrease in transport demand (8.8 percent reduction in transport demand from 2020 to 2030[20]), brought about in particular by incentivising a modal shift.

[Figure 11] Emissions reduction strategies in the transport sector



20 The government plans to reduce transport demand by 4.5 percent in 2030, compared to the 2018 level, as a means of reducing GHG emissions.

5-2. Diffusion of electric vehicles in Korea

This section analyses in more detail the expected and required pathways for the diffusion of EVs in Korea. The road transport vehicle fleet (which represents 97 percent of national emissions in the transport sector) is analysed through the lens of car manufacturer plans. The projected future production scale of EVs is estimated, taking into account the adoption of different policies[21] by the government (compared to other international regulations).

5-2-1. Small vehicles

The domestic penetration potential of small EVs is analysed on the basis of the market share of domestic car manufacturers. The Hyundai Motor Group (71.1 percent market share in 2020) plans to produce 1.51 million EVs per year in 2030, of which 590 000 will be sold domestically. Renault Samsung (5.1 percent) has announced a goal of 100 percent EVs by 2030, Korea GM (4.4 percent) has no plans to produce EVs in Korea, and KG Mobility (4.7 percent) does not have a clear EV penetration goal, but is also adapting its production line for EVs. In addition, imported cars represent about 14.8 percent of the domestic car market, and their contribution to EV penetration in Korea was calculated on the basis of the EV penetration targets announced by each manufacturer.

The government's EV targets can be exceeded if carmakers' production targets for small EVs are taken into account. At least 1.5 million EVs can be supplied in 2030 alone by expanding the domestic sales of Korean carmakers with domestic production plants, including the Hyundai Motor Group. Furthermore, if imported EVs are included, supply will reach 1.8 million units in 2030 and a cumulative total of 9.2 million units by 2030. This is more than double the government's target of 4.5 million EVs. With such a diffusion of EVs, GHG emissions in the transport sector could be reduced to 2.8 $MtCO_2e$ below the government target (91.8 $MtCO_2e$) in 2025 and to 10.1 $MtCO_2e$ below the government target (78.3 $MtCO_2e$) in 2030.

21 Car manufacturers are required to sell vehicles in compliance with the emission permit standards set forth in the Clean Air Conservation Act. Major countries such as the United States, the European Union, Japan and China have similar fleet average scheme regulations.

5-2-2. Medium- and heavy-duty trucks

Reducing GHGs in freight and logistics is more challenging than in personal road transport: GHG emission intensities are higher and vehicles have a longer lifetime without clear retirement dates (today more than 40 percent of heavy-duty vehicles are 15 years old or older). In addition, the freight and logistics sectors are facing more complex structural and social constraints (in particular regarding vehicle ownership) that make the transition to EVs more difficult.

The GHG reduction potential of medium- and heavy-duty trucks was examined in two steps. First, the reduction potential was calculated by applying the GHG emission regulations (that already apply to small vehicles) to medium and large trucks. Next, a more structural transformation of the freight logistics sector was explored.

The adoption of EVs for medium- and heavy-duty trucks will happen much more slowly than for passenger cars. This is because the technology maturity of medium- and heavy-duty EVs is still low, and it will take time to implement new regulations. Nevertheless, around 49 000 medium- and heavy-

[Table 6] Cumulative forecast of medium- and heavy-duty electric freight truck deployment and GHG savings

		2025	2030	2035	2040	2045	2050
K-Map scenario 2.0 ①	Medium-duty trucks	5 657	20 788	52 682	75 233	81 010	83 064
	Heavy-duty trucks	3 363	19 081	48 115	81 470	96 609	99 058
	Total	9 020	48 889	149 686	306 389	484 008	666 130
	GHG emissions ($MtCO_2e$)	13.7	10.1	7.6	4.8	2.5	0
BAU scenario ②[22]	Penetration targets	3 808	21 287	66 783	142 752	320 370	502 493
	GHG emissions ($MtCO_2e$)	13.8	10.6	9.0	7.6	4.7	0
GHG emission reduction potential (②-①, $MtCO_2e$)		0.1	0.5	1.4	2.8	2.2	0

duty electric freight vehicles could be deployed by 2030, saving around 1 $MtCO_2e$ of GHG emissions. In addition, all new trucks will be EVs from 2040, which is expected to cumulatively supply 660 000 vehicles and reduce emissions by 7 $MtCO_2e$ by 2050.

22 Since the government has not yet set a supply target for medium- and heavy-duty freight EVs, a BAU scenario was created based on the current supply trend to forecast future supply.

5-3. Policy suggestions for transport sector decarbonisation

5-3-1. Tighten regulations to accelerate the transition to electric vehicles

A. Tightening and enforcing regulatory standards

Korea’s emission standards for new personal cars in 2030 are less restrictive (70gCO_2/km) than those in other industrial nations. The EU has some of the toughest CO_2 emission standards in the world (43 gCO_2/km in 2030 in the Fit for 55 package; these are subsequently expected to become even tougher). The US has had less ambitious standards until now, but recently announced a plan to tighten the standard to 57 gCO_2/km in 2030. In addition, both the EU and California plan to ban the sale of new internal combustion engines from 2035.

In order to achieve the K-map scenario 2.0, GHG emission standards need to be increased to 50 gCO_2/km for passenger cars and to 79 gCO_2/km for small vans and freight vehicles in 2030. Since 40 percent of new cars are driven for more than 15 years, the benefits of this tightening of standards on GHG mitigation will be seen in the medium to long term.

[Table 7] Tightening GHG regulation standards for vehicles to achieve K-map scenario 2.0

GHG emissions (gCO_2/km)		2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Government plan	Passenger cars and small vans (fewer than ten persons)	97	97	95	92	89	86	83	80	75	70
	Vans (11 to 15 persons) and light-duty trucks	166	166	164	161	158	158	155	152	149	146
K-map scenario 2.0	Passenger cars and small vans (fewer than ten persons)	97	97	95	89	82	76	69	63	56	50
	Vans (11 to 15 persons) and light-duty trucks	166	166	164	152	140	128	115	103	91	79

B. Expanding the emission standards to include larger vehicle categories

Currently, the GHG emission standard scheme is limited to passenger cars, small vans and light-duty trucks. Indeed, only small-sized EV technologies were commercialised when the scheme was introduced. Since then, alternative technologies have also been developed for medium and large EVs, some of which have already been commercialised. Minimum standards for medium and large vehicles should therefore be increased more quickly now. Based on the EU's GHG emission standard, we propose introducing new standard categories for medium and heavy vehicles that would be set at 45 percent below the 2023 level in 2030. And following the medium and heavy EV penetration target in the US, Korea could target medium-sized EV sales of 80 percent in 2035 and of 100 percent in 2040. The targets would be slightly lower for heavy vehicles (60 percent in 2035 and 100 percent in 2040).

Since medium- and heavy-duty trucks have a longer lifetime than personal cars, achieving the 2050 carbon neutrality goal will require sales of internal combustion engines to be banned after 2035 or the forced scrappage of internal combustion engines above a certain age.

C. Expanded subsidies to promote electric vehicles

As the price of EVs is still higher than that of conventional internal combustion engines, purchase subsidies are needed to encourage consumers to opt for the former. To achieve the GHG reduction targets in this K-map scenario 2.0, about 3.4 trillion Korean won (about 2.6 billion US dollars) in annual subsidies are needed by 2025, which is about 30 percent higher than the 2023 budget (2.6 trillion Korean won). Subsidies for passenger EVs are expected to decrease significantly from 2026 to 2030 as passenger EVs become more price-competitive, and from 2031 onwards, only subsidies for medium- and heavy-duty freight EVs would be required (in addition, those subsidies are expected to decrease rapidly due to the decline in production costs).

[Table 8] Electric vehicle penetration targets and purchase subsidy needs by year

	Number of electric vehicles (thousands)			Purchase subsidy (million Korean won)			
	Passenger cars	Vans	Trucks	Passenger cars	Vans	Trucks	Total
2024-2025	1 607	15	209	4 807 321	177 141	1 791 855	6 776 317
2026-2030	6 472	40	835	765 980	249 145	4 502 225	5 517 350
2031-2035	9 087	32	1 225	-	-	5 179 444	5 179 444
2036-2040	10 350	20	1 414	-	-	1 495 149	1 495 149
2041-2045	11 132	10	1 467	-	-	-	-
2046-2050	11 973	5	1 504	-	-	-	-

5-3-2. A roadmap for phasing out conventional internal combustion vehicles

Even if all new vehicles sales gradually shifted to EVs, it would not be possible to achieve climate neutrality if the existing stock of internal combustion engines remained high. Therefore, in addition to tighter GHG emission standards, a long-term roadmap for phasing out existing vehicles on the road is needed.

According to the K-map scenario 2.0, even if new EVs accounted for 84 percent of new sales in 2030 (based on a total of 1.79 million new EVs sold in 2030), internal combustion engines would still account for a very high proportion of total registered vehicles, namely 66.6 percent. Additional restrictions on vehicle age should therefore be introduced in order to align with the K-map scenario 2.0.

[Table 9] Vehicle age restrictions for new internal combustion vehicles in K-map scenario 2.0

	Passenger cars	Vans		Trucks	
	All	Small	Medium and large	Small	Medium and heavy
2020	Unlimited vehicle age				
2025					
2030	15 years	15 years	20 years	15 years	20 years
2035	10 years	10 years	15 years	10 years	15 years
2040	Sale prohibited	Sale prohibited	10 years	Sale prohibited	10 years
2045	Sale prohibited				

6. Agriculture sector

6-1. Updated K-map scenario in the agriculture sector

The first version of the K-map scenario 1.0 did not consider the possibility of using farmland to generate PV electricity, a concept known as agrivoltaics. This approach – which makes better use of farmland for both agriculture and renewable energy power generation – can help revitalise the rural economy. Agrivoltaics offers the advantage of allowing farmers to simultaneously cultivate crops and generate electricity, preserving valuable farmland. Additionally, farmers can earn extra income – 1.7 to 2 times their regular farming earnings – through electricity sales. There are drawbacks, however, including a potential decrease in agricultural production (12-20 percent for rice), inconvenience during farm work and increased labour involved in agrivoltaic installations. This study aims to calculate the potential of farm-based solar power and propose detailed policies to revitalise its deployment[23].

In 2016, Korea's first agrivoltaic demonstration project was launched, and several bills to revitalise agrivoltaics have been proposed by the National Assembly. However, due to the structure of rural areas in Korea – where 50 percent of farmers are tenants – and the lack of social acceptance of renewable energy overall, the spread of agrivoltaics has remained stalled.

23 This study analysed scientific journal articles, policy reports and newspaper articles related to agrivoltaic projects, in particular in advanced countries such as the EU, Germany, France and Japan. It also examined papers and policy reports related to profit-sharing and rural sustainability to solve social problems through agrivoltaics.

6-2. Potential for agrivoltaics in Korea

6-2-1. Capacity and generation forecast

To analyse the potential of agrivoltaics in Korea, we first looked at the amount of agricultural land available. In 2022, Korea's total farmland covered 1 911 167 hectares, corresponding to about 19 percent of the country's land area. Of this total, 42.8 percent (818 737 hectares) was in what are known as agricultural promotion zones in which non-farm activities are strictly restricted by several laws and regulations.

In agricultural promotion zones, solar power installations are not allowed excepting in an area which contains at least a certain level of salt in the soil among land formed by the reclamation of public waters. On other agricultural land outside these agricultural promotion zones, where it is relatively easy to change the land's purpose, it is not uncommon to find examples of solar power installations in general (not only agrivoltaics) that are installed directly on the farmland. However, given Korea's very low food self-sufficiency rate, the use of agricultural land for anything other than farming has negative consequences for the country's food security. In this context, this study considers only agrivoltaic projects and not any other renewables projects on farmland (such as ground-mounted PV or even wind turbines), since these conflict with farming to a relatively lesser extent. A 100 kW agrivoltaics installation requires about 2 000 square metres of farmland. This study uses agrivoltaic unit cost forecasts to calculate the potential deployment of agrivoltaics over time and the investment required.

Table 10 Agrivoltaic unit cost forecasts

KRW billion / MW	2024	2025	2030	2035	2040	2045	2050
Agrivoltaic unit cost	1.83	1.77	1.56	1.44	1.37	1.31	1.24

In order to calculate the potential offered by deploying agrivoltaics, this study considered various social, economic and structural constraints facing rural areas in Korea. First, to minimise conflicts within rural communities, we assumed that agrivoltaics would be deployed on farmland outside agricultural promotion zones first and then gradually deployed in agricultural promotion zones after 2035, once acceptance of solar in rural areas has improved. We also assumed that farmland owned by farmers would be deployed first, while farmland cultivated by tenant farmers would only be deployed in earnest after 2030. This is because farmers have negative views of solar power due to environmental pollution and damage to the landscape, and renters are concerned that it will reduce their farming income, increase land rent and negatively impact their farming activities. We therefore assume that it will take time to resolve these concerns. Lastly, we took into account food security concerns at the national level, since agrivoltaics does not prevent farming activities but may reduce agricultural output in some cases. We evaluate the installed capacity of agrivoltaics to cover at most 10 percent of total farmland.

Based on various data and the constraints mentioned above, the total potential for solar PV in Korea's rural areas is estimated at 118.6 GW, including 59.3 GW of agrivoltaics. This represents about 20 percent of the total 300 GW of solar PV installations in 2050 projected by this updated K-map scenario 2.0. Installing this capacity of agrivoltaics would require about 118 620 hectares of farmland, corresponding to 6.2 percent of total farmland.

Looking at the timeline, the total agrivoltaic capacity could reach 9.1 GW by 2030 (yearly capacity expansion of 1.3 GW between 2025 to 2030), 30.8 GW by 2040 (yearly capacity expansion of 2.2 GW between 2030 and 2040) and 59.3 GW by 2050 (yearly capacity expansion of 2.9 GW from 2040 to 2050). This development would contribute 15.3 TWh of electricity generation in 2030, 51.8 TWh in 2040 and 106.6 TWh in 2050. This would bring about an additional GHG abatement of 1.53 $MtCO_2e$ in 2030 and 0.95 $MtCO_2e$ in 2040.[24] This agrivoltaic plan would require a total investment of 81.8 trillion Korean won (about 62.9 billion US dollars).

24 Like rooftop PV in the buildings sector, this agrivoltaic deployment does not affect direct GHG emissions from the agricultural sector. The emission factor for Korea's power sector will be zero in 2050 as renewable energy penetration expands, so the GHG emission reduction effect of agricultural solar in 2050 will be 0 tonnes.

[Table 11] Outlook for agrivoltaic capacity, greenhouse gas reductions and farmland use

	2025	2030	2035	2040	2045	2050
Agrivoltaic cumulative installed capacity (GW)	2.6	9.1	17.6	30.8	48.8	59.3
Agrivoltaic annual electricity production (TWh)	4.7	15.3	29.5	51.8	78.2	106.6
Annual GHG reductions from agrivoltaics ($MtCO_2e$)	1.53	2.84	3.81	0.95	0.79	0
Percentage of farmland with agrivoltaics installed (% of total farmland)	0.3	1.0	1.8	3.2	5.1	6.2

6-3. Policy suggestions for supporting the development of agrivoltaics in Korea

6-3-1. Improving the economics of agrivoltaic businesses

In order to generate additional income and create added value in rural areas through the promotion of agrivoltaics, it is necessary to improve the profitability of the agrivoltaic business. According to the current Agricultural Land Act, the temporary use permit period for installing solar energy generation facilities on agricultural land is only eight years at most. The concept of mixed use of agricultural land should therefore be introduced as the basis for using agricultural land for agrivoltaics, and the use period should be extended to ten years. In addition, the Korean feed-in tariff (FIT) system for small-scale solar PV, which ended in July 2023, should be reintroduced, and specific tariffs for agrivoltaics should be designed. Furthermore, additional support schemes for accelerating agrivoltaics should be taken into account, such as those used in countries such as France: raising deployment targets, making mandatory regional allocations or introducing special PV auctions just for agrivoltaics. To motivate low-income farmers in particular to invest, the Ministry of Agriculture, Food and Rural Affairs should introduce a low-interest loan for farmers participating in agrivoltaic projects.

6-3-2. Measures to support farmland and help farmers stabilise food production

As of the end of 2023, agrivoltaics had not yet been defined in Korean laws and regulations. A clear definition should be added to the law to ensure that agricultural output is not reduced by energy production. In addition, specialised organisations should be established in each local municipality to verify that agrivoltaics does not impede crop production (such as the Regional Agricultural Commissions established in Japan). Since food and grain self-sufficiency rates are continuously declining in Korea, measures should be taken to establish yield verification standards for agrivoltaic operations: revoke the approval of agrivoltaics if standard yields are not achieved and provide additional incentives if they are exceeded.

6-3-3. Scaling up participatory agrivoltaic business models for rural sustainability

Non-transparent information sharing and conflicts with external investors are among the barriers to promoting solar PV in rural areas in Korea. To address this, village-level energy cooperatives should be fostered and supported to enable diverse rural populations, including tenant farmers and low-income farmers, to jointly participate in agrivoltaic projects.

6-3-4. Improve environmental performance of agrivoltaics

Unlike conventional solar projects, the environmental impacts of agrivoltaics have not been fully studied, so it will be necessary to establish a separate evaluation system or criteria for agrivoltaics. For example, there are concerns about the installation of structures on farmland, corrosion of equipment by fertilisers and pesticides, and soil erosion. Governments should create guidelines for environmental standards on agrivoltaics to prevent unnecessary controversy.

[Table 12] Key indicators in the updated K-map scenario 2.0

	2018	2030	2040	2050	2018-2030 p. a. net	2030-2050 p. a. net
Greenhouse gas emissions (MtCO₂e)	686	411	144	0	-23	-21
Power sector	270	141	19	0	-11	-7
Industry sector	261	191	84	11	-6	-4
Buildings sector	52	30	11	0	-2	-2
Transport sector	97	58	26	0	-3	-3
Agriculture sector	25	18	15	12	-1	-0.3
LULUCF, waste and others	-19	-14	-19	-24	0.4	0.5
Fossil fuel primary energy consumption						
Oil (million TOE)	114	76	45	16	-3	-3
Coal (million TOE)	50	27	2	0	-2	-1
Natural gas (million TOE)	39	38	20	0.03	-0.1	-2
Power						
Electricity generation (TWh)	571	759	1 043	1 268	+16	+25
Share of renewables in gross electricity consumption (%)	4	28	59	63	2	2
Share of zero-carbon H2 in gross electricity consumption (%)	0	0	17	21	0	1.8
Photovoltaics (GW)	7	67	197	301	5	12
Onshore wind (GW)	1	9	24	24	1	1
Offshore wind (GW)	0	13	70	98	1	4
Electrical energy storage (GW/GWh)	2/19	5/21	74/295	116/466	0.3/0.2	5.6/22.2
Industry						
Steel production with DRI (million tonnes)	0	59.6	69.2	69.2	5.0	0.5
CO_2 absorption with CCUS (million tonnes)	0	0	9.6	23.4	-	1.1
Buildings						
Total floor area of newly constructed/green retrofitted buildings (million ㎡)	0	813	1 372	1 839	68	51
Energy demand for new residential buildings (kWh/㎡a)	123	80	60	40	-3.6	-2
Energy demand for new non-residential buildings (kWh/㎡a)	300	200	140	100	-8.3	-8.3
Number of heat pumps (thousands of units)	0	1 659	1 967	2 107	138	22
District heat supply (million TOE)	2.4	4.2	5.8	6.5	0.15	0.12
Transport						
Number of electric vehicles (thousands of units)	0.13	7.9	20.3	27.3	0.6	1.0
Fossil energy demand in the transport sector (million TOE)	43	20.2	6.1	0	-1.9	-1.0
Agriculture and LULUCF						
Livestock manure fermentation (% share of all livestock manure)	1.7	50	70	90	-	-
LULUCF absorption ($MtCO_2e$)	-41.3	-26.7	-26.0	-25.3	1.2	-
Hydrogen						
Hydrogen turbines (GW)	0	0	61	85	0	4.3
Hydrogen demand (million tonnes)	0	3	11	18	0.3	0.8
Domestic green hydrogen production (million tonnes)	0	0	4	7	-	0.4
Imported green hydrogen (million tonnes)	0	1.6	6.6	11.3	0.1	0.5
Green hydrogen storage (GW)	0	0	17	20	-	1
Macroeconomic indicators						
GDP growth (annual %)	1.9	1.9	1.9	1.0	-	-0.05
Population (millions)	51.5	51.9	50.9	47.7	-	-0.2