Research on Strategy and Policy by Sector for Korea 2050 Carbon Neutrality

10 November 2020

에너지전환포럼

EU-KOREA CLIMATE ACTION

Project funded by the European Union

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CONTENTS

ABBREVIATIONS

ATS	Advanced Transition Scenario
BATs	Best Available Technologies
BAU	Business As Usual (Scenario)
BDI	Federation of German Industries
BECCS	Bioenergy with carbon capture and storage
CCS	Carbon Capture and Storage
DAC	Direct Air Capture
DDP	Deeper Decarbonization Perspective
ETS	Emission Trading Scheme
EV	Electric Vehicle
GDP	Gross Domestic Product
GHG	Green House Gas
GIR	Green House Gas Inventory and Research Center
GW	Giga Watt
ICEV	Internal Combustion Engine Vehicle
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
KEA	Korea Energy Agency
KEC	Korea Environment Corporation
KEEI	Korea Energy Economics Institute
KEI	Korean Environment Institute
KEITI	Korea Environmental Industry & Technology Institute
KEPCO	Korea Electricity Corporation
KETEP	Korean Institute of Energy Technology Evaluation and Planning
K-ETS	Korean Emissions Trading Scheme

ABBREVIATIONS

KoSIF	Korea Sustainability Investment Forum
KRW	Korean Won
LEDS	Low-Emission Development Strategy
LEZ	Low-Emission Zone
LNG	Liquefied Natural Gas
LULUCF	Land use, land use change and forestry
MOE	Ministry of Environment
MOLIT	Ministry of Land, Infrastructure and Transport
MOTIE	Ministry of Trade, Industry and Energy
MTS	Moderate Transition Scenario
NDCs	National Determined Contributions
NRC	National Research Council for Economics, Humanities and Social Sciences
NRVP	National Cycle Path Plan
OECD	Organization for Economic Co-operation and Development
PPCA	Powering Past Coal Alliance
REB	Korea Real Estate Board
R&D	Research and Development
RPS	Renewable Portfolio Standards
TES	Transforming Energy Scenario
TOE	Tonnes of Oil equivalent
TWh	TeraWatt-hour
ULEV	Ultra-Low Emission Vehicle
UN	United Nations
VTS	Visionary Transition Scenario
WTO	World Trade Organization

Purpose

- Develop policy agenda overcoming the limitation of 2050 Low-Carbon Development Scenario
- Envision the future and develop key policy agenda reflecting the technological development and social acceptance in 4 sectors with most GHG emissions - Electricity , industry, building , and transportation
- Form alternative expert group to respond to Low GHG Emission Development Strategy (LEDS) of Korean Government

Major contents

- Comparison between the existing development strategy and scenario
  - Low-carbon development strategy scenario by 2050 Low-carbon Society Vision Forum, Ministry of Environment
  - Long-term energy strategy scenarios for South Korea: Transition to a sustainable energy system (Energy Policy Volume 127) by Professor Jong-Ho Hong's Lab (Graduate School of Environmental Studies, Seoul National University)
  - Sector Coupling Scenario by Green Energy Strategy Institute (Agora Energiewende funding)
  - Global Net-zero Scenarios: IRENA, IEA, etc.
- Develop Net-zero policy agenda by sector
  - Investigate the limitation of current scenario, list-up climate crisis and energy transition related short term policies
  - Review domestic/foreign policy agenda for the realization of Net-zero
  - Identify technological, legal and institutional agenda to be resolved : form advisory group with researchers to discuss comprehensive policy agenda covering even finance and governance

Participants

- Principal Researcher : Lee, Seong-Ho, Senior expert advisor, Korea Institute of Energy Technology Evaluation and Planning (KETEP)
- Researchers
  - Electricity sector (renewable energy 100%): **Lee Seong-Ho**, Senior Expert Advisor, KETEP
  - Industry sector (structure and process): **Seo JeongSeok**, Director, Renewable Energy Green Fund Asia office
  - Building sector (system, related technology): **Lee Mi-Kyung**, Research Professor, Graduate School of Energy and Environment, Korea University
  - Transportation sector (road, air, vessel): **Song Sang-Seok**, Secretary General, Green Transport
  - Advisory Group operation and research coordination: **Yoon Soon-Jin**, Professor, Seoul National University, **Lim Jae-Min**, Acting Secretary General, Energy Transition Forum

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Introduction

1.1 Research Background

- The 10th largest economic and technological powerhouse, Korea, is one of the countries with high level energy consumption and GHG emission. Korea is one of the least converted countries among the OECD Members; coal-fired power generation takes up more than 40%, and the emission has not reached its peak yet. GHG emission in 2017 increased by 1490 million tons compared to the 69410 million tons in 2016, and energy related GHG emission increased as much as 860 million tons.
- Despite the enhanced National Determined Contributions (NDCs) and LEDS requirements to meet the UN's 1.5℃ pathway, NDCs and LEDS by Korean Government are insufficient. The GHG emission in the energy sector is still increasing even with the GHG emission reduction plan and the implementation of an Emission Trading Scheme (ETS). Korea's NDC commitment is to reduce GHG emission by 24.4% from 2017 levels to achieve 536 $MtCO_2eq$ in 2030, which seems to be difficult to achieve considering the slow pace of growth in the renewable energy sourced power plant and insufficient nationwide efforts in improving energy efficiency.
- The '2050 Low-carbon Society Vision Forum', formed by the Ministry of Environment through the Korea Environment Institute with 69 experts in 7 subcommittees including overview, conversion, industry, transportation, building, non-energy (agriculture, farming, and fisheries/waste/forestry), and young adults, submitted the '2050 Long-term Low GHG Emission Development Strategies (LEDS)' report as a result of discussion since March 2019. The forum proposed a 'Transition to a low-carbon society and realization of carbon-neutral economy' as a long-term vision of climate change policy but does not include the Net-zero scenario in 5 recommendations for GHG reduction plans.
- The 2050 LEDS by the Ministry of Environment does not include the Net-zero scenario, mainly because it failed to propose the targets such as reduced energy consumption or 100% renewable energy in the Electricity sector. Not only insufficient awareness in the climate change, but also the pessimistic outlook that current limitation, for example the current energy taxation scheme, electricity market, science and technology, cost of power generation, and regional acceptance, would persist are considered the reason of such a proposal. In particular, Government officials still have a strong perception that the Net-zero scenario will be a threat to the existing industries and economy, and this perception is backed by the mainstream economy experts.
- The important aspect of the 2050 low-carbon generation strategy is not the figures included in the scenario, but the detailed policy agenda required to realize the development strategy, and the detailed

legal and institutional changes for the realization of the agenda.

- This research on devising a detailed policy agenda required to realize LEDS will be launched along with the experts who participated in the 2050 Low-carbon Society Vision Forum by Ministry of Environment, and a draft of the report will be proposed during the time of the P4G Summit. An elaborated version of the report will be submitted to the 21st National Assembly as an agenda and will be taken as a starting point of developing a policy agenda for the presidential election.
- President Moon Jae-in, in his policy speech on the budget at the National Assembly on 28 October 2020, announced the 2050 Carbon neutrality of Korea, and the participation in the global GHG reduction efforts. However, a specific roadmap should be established including detailed methodologies of achieving the goals.

1.2 Research Purpose

- This research focuses on the fact that the LDC and LEDS by Korean Government is insufficient in meeting the UN's 1.5℃ pathway requirements and plans to present the scenario and policy agenda appropriate for meeting the pathway requirements.
- Under the time constraints of submitting the enhanced NDC and LEDS by 2020, we plan to offer the LEDS and relevant policy agenda satisfying the 1.5℃ pathway requirements applicable to Korea, by leveraging the domestic research, and the experience and knowledge from Europe.
- We aspire that this research proposes a scenario satisfying UN's 1.5℃ pathway requirements while enriching the energy transition methodologies in the future.
- At the same time, we hope that this research helps to spread the belief that human civilization can be maintained without dependency on the global warming causing coal, oil, gas and nuclear power.
- We hope the public to understand the maturity of technological and economic readiness to implement UN's 1.5℃ pathway goal, and to understand that transition to an energy-saving and renewable energy-based system from the existing fossil fuel and nuclear based power dependent energy system would facilitate job sharing and resolving inequality.
- The climate crisis is getting worse every minute. To rapidly reduce GHG emissions, nation-wide better awareness and agreement are needed. At the same time, various policies need to be introduced and legislation and revision of relevant laws are needed to reduce GHG emission and to adapt to the climate crisis.
- The Korean Government has been providing cheap and stable energy supply for the economic growth and industrial development, exclusively imported energy (fossil fuel, nuclear power), invested in energy-related infrastructure. While establishing a cheap and stable energy supply structure, such efforts by the government fostered energy-intensive industry.
- As a result, energy-intensive industry has taken up a significant share of the national economy, and people have developed high resistance against rising electricity bills. Korean people's consent on the necessity and methodology of energy system transition is required.
- In other words, transition of energy policy to the direction satisfying UN's 1.5℃ pathway, is an issue that requires Korean people's political will. The response to the climate crisis should be included in the upcoming presidential election as a key pledge, and the process of confirming the will of the people through the election is essential. We hope this research be helpful in the process.
- Lastly the deficiencies of this research, if any exists despite of authors' efforts, are expected to be corrected and supplemented in the future.

1.3 Methodology

- The Energy Transition Forum raised the necessity of a scenario review to check whether it satisfies the global 1.5℃ pathway requirements. It, decided to launch this study which was funded by the EU-Korea Climate Action project, and formed a research team comprised of energy experts from the Energy Transition Forum.

- Dr. Lee Sung-Ho, Professor Yoon Sun-Jin, Dr. Suh Jung-Seok, Professor Lee Mi-Kyung, Secretary General Song Sang-seok were appointed as writers and professor Hong Jong-ho, Jeon Young-Hwan, Dr. Lee Chang-Hun, and Director Kwon Pil-Seok were appointed as advisory members.

- This research aims to identify Korea's 2050 GHG Net-zero emission scenario (pathway) satisfying 1.5℃ pathway requirement by UN and the international society, and to propose the relevant policy agenda.

- Numerous presentations, discussions and advices were made during a series of seminars, workshops, and meetings with domestic and international experts on long-term low carbon scenario and GHG reduction plan by sector. As a result, the policy agenda for Korea was identified and the final report was written after the internal discussion among the research participants has been completed.

- Existing low carbon scenarios developed by advisory members including Professor Hong Jong-Ho, Dr. Lee Chang-Hun, Director Kwon Pil-Seok and 2050 GHG zero emission plans by Europe, Germany, UK, and France were reviewed.

- Sector level experts' review for the scenario and policy agenda development was divided into Electricity , industry, building, and transportation.

- Two workshops to enhance the understanding on the long-term low GHG emission scenarios in Europe were held and reviewed the 2050 GHG reduction plans made by Europe, Germany, UK, and France. Furthermore, criteria of classifying green technologies, industry sector's GHG reduction plan, Electricity system stabilization protocol responding to the expansion of renewable energy, economics, and changes in employment subsequent to progression to long-term low carbon society in Europe were reviewed.

[Seminars/Workshops]

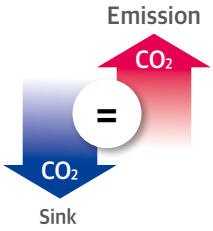
Schedule	Advisory
Prior Advisory Meeting 13 May (Wed)	**(Presentation) 2050 Energy Strategy for Korea** - Hong Jong-Ho, Professor, Graduate School of Environmental Studies, Seoul National University **(Presentation) Accelerating Energy Transition in Korea** - Kwon Pil-Seok, PhD, GESI
Transition Sector Workshop 26 May (Tue)	**(Presentation) Decarbonization energy transition scenario** - Lee Chang-Hun, Senior Researcher, KEI **(Presentation) New/Renewable energy system acceptance and expansion** - Kwak Eun-Seop, Senior manager in Systems, KepCo **(Advisory)** Jeon Young-Hwan, Professor, Hongik University
Industry/ Building Sector Workshop 9 June (Tue)	**(Presentation) Industry sector GHG emission status and reduction strategy** - Kwon Dong-Hyuck, Division Head, Eco-Partners **(Presentation) Agenda on building energy in achieving Net-zero** - Park Deok-Jun, Head of KCL TF **(Advisory)** Lee Seung-Eon, Senior Researcher, KICT, Lim Sung-Jin, Professor, Department of Public Administration, JeonJu University
European Green Deal Workshop 23 June (Tue)	**(Presentation) 2050 Net-zero goal for EU** - Miles Perry European Commission **(Presentation) Electricity Grid system for EU's energy transition** - John Lowry, Project Director of EirGrid **(Presentation) Industrial transition for 2050 Net-zero in Europe** - Yeen Chan, Consulting Director Energy at ICF Consulting

Open Seminar 21 July (Tue)	**(Presentation) Importance of Korea's 2050 zero emission planning, challenges and opportunities** - Lee Seong-Ho, Senior Researcher, KETEP **(Presentation) Green financing to achieve Korea's 2020 zero emission** - Lim Dae-Woong, Representative, Eco-Partners **(Presentation) Europe's Green Deal and sustainable finance** - Helena Viñes Fiestas, Global Management Strategy, BNP Paribas **(Presentation) Europe's Energy transition tasks and opportunities** - Dolf Gielen, Director IRENA Innovation and Technology Centre

1.4 Developments in LEDS

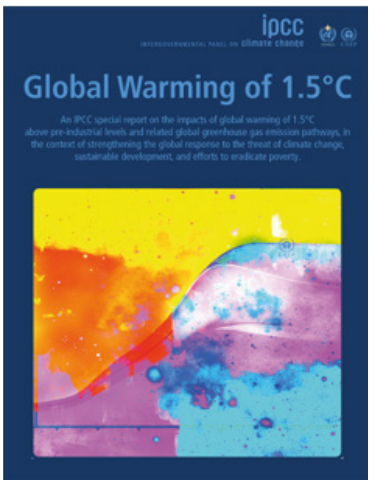
1.4.1 International developments

- Paris Agreement aims to keep a global temperature rise to 1.5~2℃ above pre-industrial levels. Not only advanced countries but also developing countries committed to submission and implementation of the NDCs.
- UN IPCC Recommended 1.5℃ goal, the target of the Paris Agreement, and reduction of Net CO_2 emissions by 45% from 2010 levels by 2030, and Net Zero by 2050.



By 2030
Carbon emission to 45% of 2010 level

By 2050
Carbon net emission to Zero



IPCC SPECIAL REPORT, GLOBAL WARMING OF 1.5 DEGREES (2018)

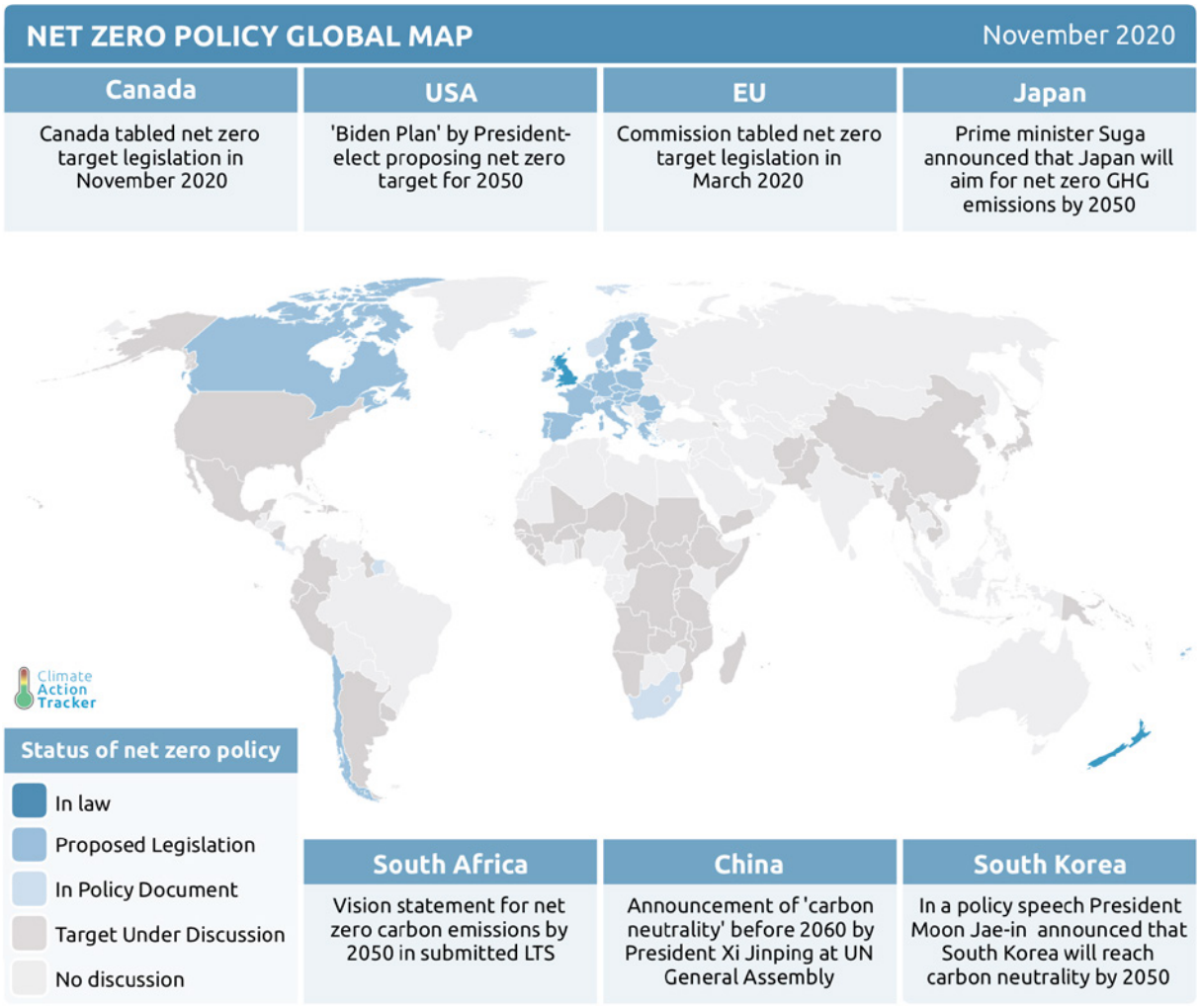
- Europe declared Zero GHG emission by 2050 and is preparing relevant legislation. The US President-elect Biden declared zero carbon emission from electricity sector by 2035, and zero GHG emission before 2050.
- President Xi Jinping of China committed zero GHG emission before 2060 at the virtual UN General Assembly, newly elected Prime Minister of Japan, Suga announced zero GHG emission by 2050.
- Currently, 121 countries announced zero GHG emission by 2050, and 9 countries passed relevant law.

[Table 1-1] Number of countries with carbon neutrality announcement

Type		Country		Major content
Type 1	Climate Ambition Alliance member	120 + EU	UK, Japan, Canada, Germany.	Climate Ambition Alliance : Group of countries committed to achieve Net-zero by 2050 (Organized by UNFCCC)
Type 2	Proposed legislation or in law	9	UK, France, etc.	(proposed legislation) EU, Spain, Chile, Fiji (in law) UK, Denmark, France, Sweden, New Zealand

Source : UNFCCC[1]

<Figure1-1> Status of carbon neutrality statement countries



1) https://climateaction.unfccc.int/?coopinitid=94#CA

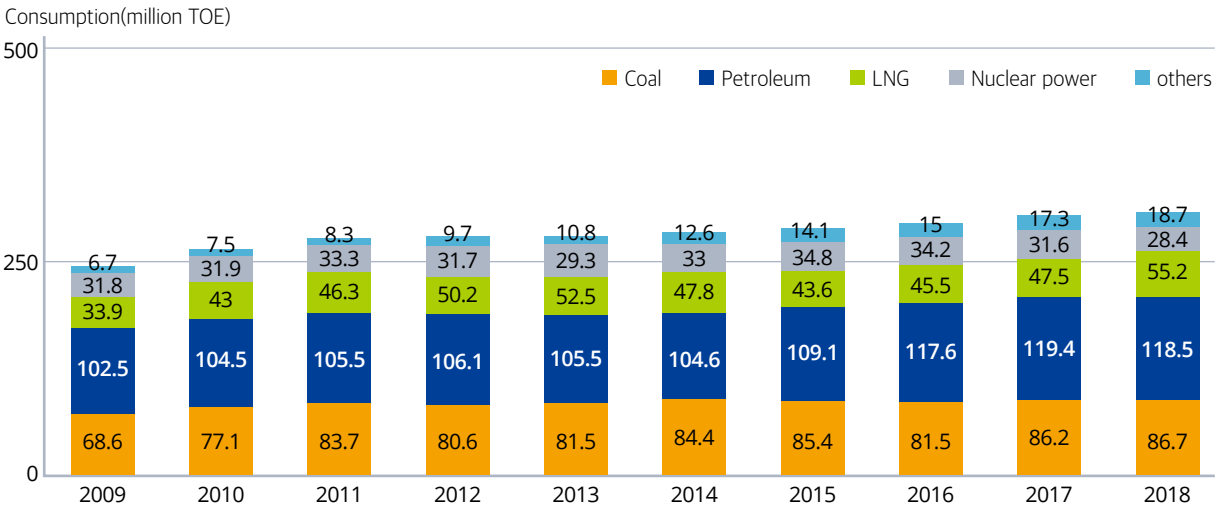
- RE100 campaign : As of October 2020, 264 global companies are implementing 100% use of renewable energy, and carbon footprint became one of major criteria for product and service transaction.
- G20, OECD, WTO, IEA, Powering Past Coal Alliance are materializing global transition away from coal power.
- Global Carbon Budget 2019 by Global Carbon Project reported that 86% of global GHG emission is from the use of fossil fuel, 14% from land use. The movement is being expanded into the fossil fuel (coal, petroleum, gas) phase out movement.
- Europe introduced GHG minimum price system for ETS, strengthened carbon tax, and announced the introduction of Carbon Border Tax.

1.4.2 Developments in Korea

1) Energy consumption in Korea

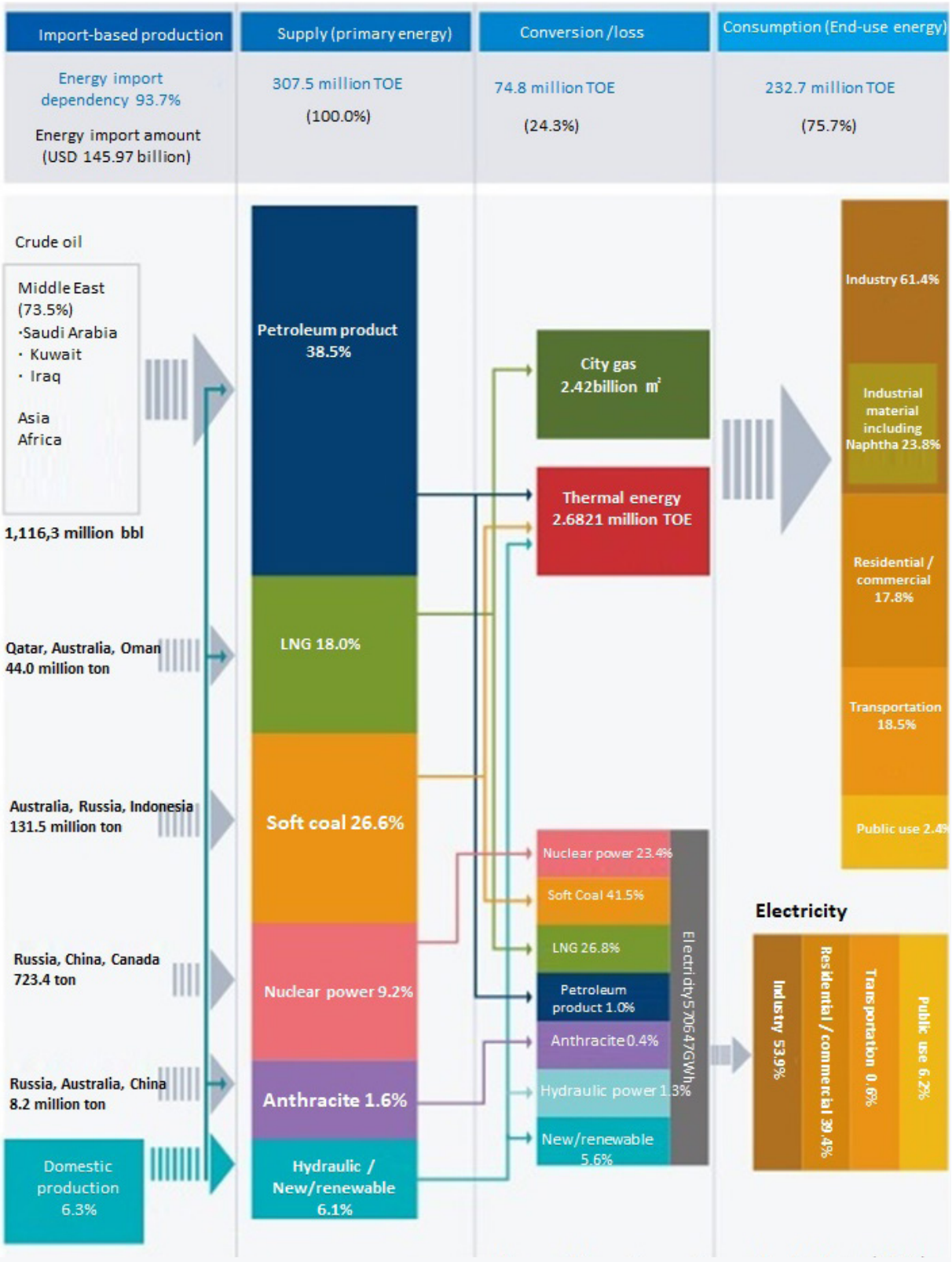
- As of 2017, Korea, with 51.48million population which is 0.69% of global population, is the 28th largest country.
- Korean economy is the 10th biggest in terms of GDP (USD 1.6421 trillion) as of 2019, with the 22nd largest GDP per capita of USD 31,682. Korean Economy is highly dependent on trade, which takes up about 65% of the economy.
- Energy consumption continuously increased, reaching total energy consumption of 307 million TOE in 2018. Petroleum took the biggest portion in the primary energy consumption, which is followed by coal, LNG, and nuclear power.

<Figure 1-2> Status of Primary Energy consumption volume



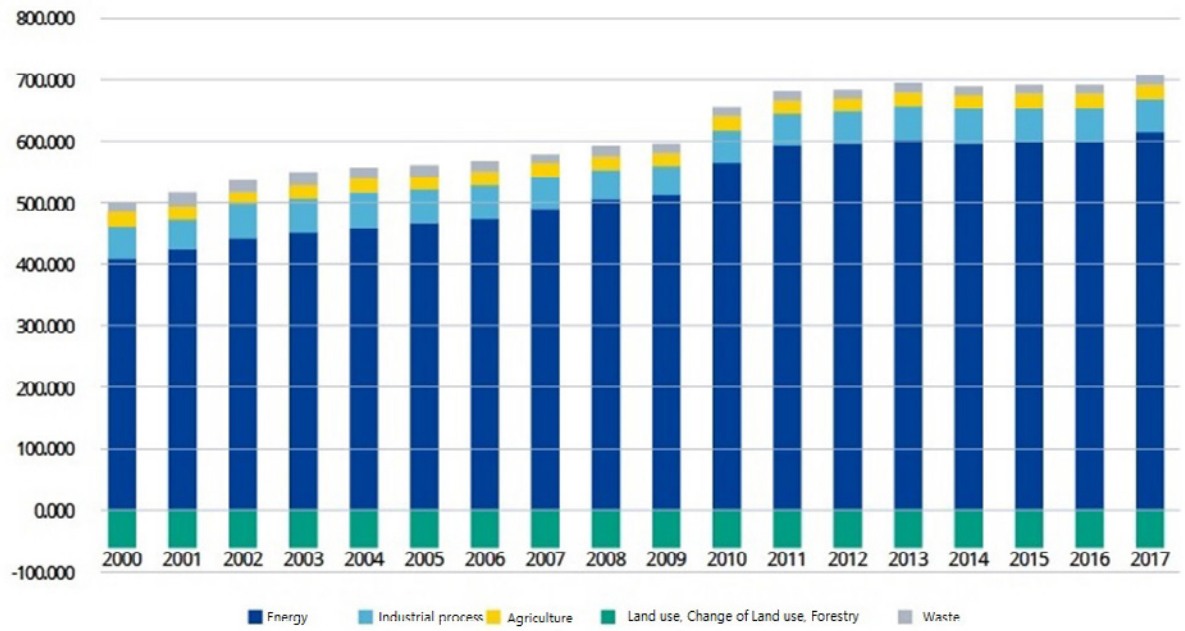
Source : e-statistics Korea

<Figure 1-3> Energy Balance Flow in 2018



Source : Korea Energy Economics Institute (2019)

<Figure 1-4> GHG Emission status of Korea (1990-2017)



Source : Re-charted based on the data from Greenhouse Gas Inventory and Research Center

2) Korea's GHG emission

- CO_2 emission also continuously increased. Over the period of 1990 to 2017, the emission volume more than doubled from 292.2million tons to 709.1million tons. As of 2017, Korea recorded a world emission share of 1.71%(9^{th}), accumulated emission share of 1%, and 11.8ton of annual per capita emission.

[Table 1-2] Annual GHG emission trend (unit : million ton CO_2eq)

Sector	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017
Total emission (YoY variance)	292.2	435.9 (7.9%)	503.1 (7.1%)	561.8 (0.8%)	657.6 (10%)	697.0 (1.4%)	691.5 (-0.8%)	692.3 (0.1%)	692.6 (0.03%)	709.1 (2.4%)
Net emission	254.4	405.0	444.8	507.7	603.8	652.8	649.3	649.9	648.7	667.6
Energy	240.4	352.2	411.8	468.9	566.1	605.1	597.5	600.8	602.7	615.8
Industry process	20.4	45.2	51.3	55.7	54.7	54.8	57.3	54.4	52.8	56.0
Agriculture	21.0	22.8	21.2	20.5	21.7	21.2	21.3	20.8	20.5	20.4
Waste	10.4	15.7	18.8	16.7	15.0	15.9	15.4	16.3	16.5	16.8
(LULUCF)	(-37.7)	(-30.9)	(-58.3)	(-54.0)	(-53.8)	(-44.2)	(-42.2)	(-42.4)	(-43.9)	(-41.6)

Source : 2019 National GHG Inventory report

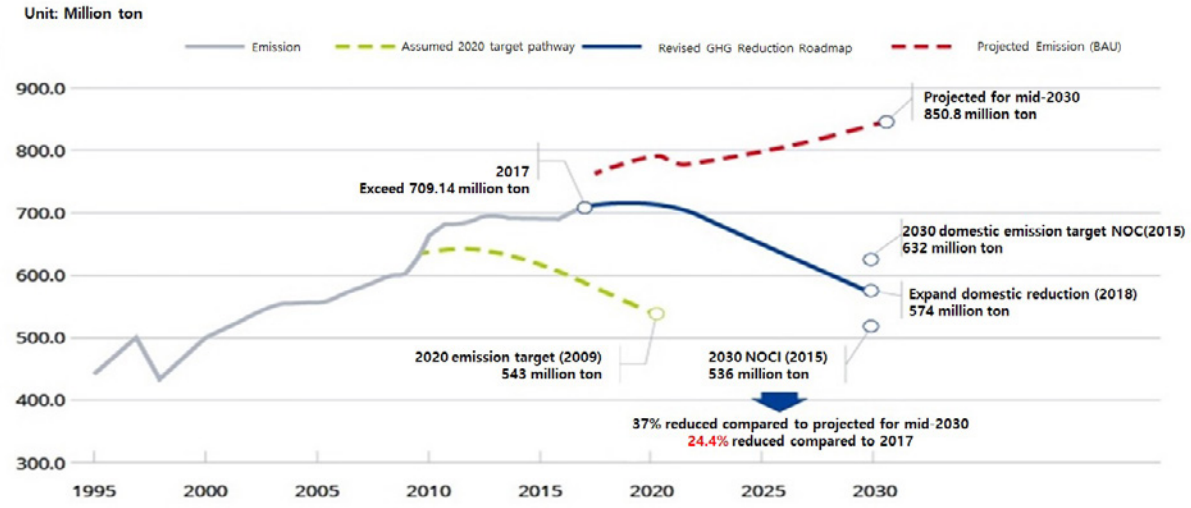
[Table 1-3] CO_2 emission volume by country (based on 2016 fuel combustion)

Emission index	Korea	Rank	Note
CO_2 emission	594 million tons CO_2	7th	1st China (9.1B), 2nd US (4.83B)
Variance ('90~'16)	156%	59th	1st Benin (2,121), 2nd Vietnam (976)
Per capita CO_2 emission	11.6 tons (CO_2 / person)	18th	1st Qatar (30.8), 2nd Curacao (25.9)
Variance ('90~'16)	115%	28th	1st Benin (908), 2nd Vietnam (667)
GHG Intensity (CO_2 emission / GDP)	0.45kg (CO_2 /$)	60th	1st Libya (2.31), 2nd Curacao (2.24)
Variance ('90~'16)	-29%	78th	1st Benin (616), 2nd Libya (287)

Source : The 2nd Basic plan for coping with climate change

- Total emission as of 2017 was 709.1 million (Mn) CO_2 ton (tCO_2), which is composed of energy 615.8 Mn tCO_2 (86.8%), industrial process 56.0Mn tCO_2 (7.9%,), agriculture 20.4 Mn tCO_2 (2.9%), and waste 16.8 Mn tCO_2 (2.4%).
- Korea's 2030 GHG emission goal in the NDC submitted to UN is 536 Mn tCO_2.
- UN requested submission of enhanced NDC and 2050 LEDS (Long-term low greenhouse gas emission development strategies), and Korea is in the process of developing 2050 LEDS under the lead of the Ministry of Environment.
- 2050 Low Carbon Society Vision Forum's scenario suggests as much as 75% reduction of GHG emission from 2017 level by 2050.

<Figure 1-6> GHG Emission Pathway of Korea



Source : re-graphed by author

[Table 1-4] 2030 GHG reduction goal

Sector		Emission volume (2017)	Emission projection (2030 BAU)	Reduction goal		
				Target emission	Reduction against BAU (rate)	Key measures for reduction
Domestic goal per sector		**-**	**850.8**	**574.3**	**△276.4 1 (32.5%)**	
Reduction at source	Industry	392.5	481.0	382.4	△98.5 (20.5%)	√Enhance efficiency √ Replace refrigerant √Transition of fuel / material √Use of waste heat
	Building	155.0	197.2	132.7	△64.5 (32.7%)	√ Better insulation (new / existing) √facility enhancement √BEMS expansion
	Transport	99.7	105.2	74.4	△30.8 (29.3%)	√ Expand eco-friendly vehicle √ improve fuel efficiency √Eco-friendly vessel √Bio-diesel
	Waste	16.8	15.5	11.0	△4.5 (28.9%)	√ Expand recycle √ Methane recovery
	Public (others)	20.0	21.0	15.7	△5.3 (25.3%)	√LED light √Expand renewable energy
	Agriculture / Farming	20.4	20.7	19.0	△1.6 (7.9%)	√Energy from excreta √rice field irrigation management
	Omission, etc.	4.8	10.3	7.2	△3.1 (30.5%)	
Use of reduction tool	Transition	(253.1)	(333.2)2	(192.7)	(△140.5)3 (42.2%)	√Improve Electricity supply mix √Demand management
	E new biz, CCUS		-	-	△10.3	√Carbon capture, usage, storage
Reduction at overseas			**-**	**-**	**△38.3 (4.5%)**	**Forest sink + global market**
Use of reduction tool	Forest sink	(-41.6)	-	-	△22.1	√Create economic forest √Expand urban forest
	Reduction at overseas		-	-	△16.2	√bilateral cooperation √SDM
Total		**709.1 4**	**850.8**	**536.0**	**△314.8 (37%)**	**Domestic (32.5%) + overseas (4.5%)**

Source : Revised 2030 national GHG reduction roadmap

[Table 1-5] Review on national 2050 emission target by Low Carbon Society Vision Forum

- Target emission volume and reduction (rate) by country / sector

Item			2017 status	2050 goal				
				Plan 1	Plan 2	Plan 3	Plan 4	Plan 5
Country	Emission (Million ton CO_2eq)		709.1	178.9	222.0	279.5	355.9	425.9
	Reduction rate (from 2017)		-	75%	69%	61%	50%	40%
By sector	Transition	Emission	252.3	24.8	28.9	71.4	75.6	125.3
		Reduction rate		90.2%	88.6%	71.7%	70.0%	50.3%
	Industry	Emission	259.9	89.7	124.1	132.2	200.7	211.1
		Reduction rate		65.5%	52.3%	49.2%	22.8%	18.8%
	Building	Emission	52.8	17.5	18.8	20.3	21.4	22.5
		Reduction rate		66.8%	64.4%	61.6%	59.5%	57.3%
	Transport	Emission	98.3	26.3	28.8	33.8	36.0	40.0
		Reduction rate		73.3%	70.7%	65.7%	63.4%	59.4%
	Waste	Emission	16.8	9.1	9.4	9.6	9.8	10.0
		Reduction rate		46.1%	43.9%	43.2%	41.9%	40.7%
	Agro/farming/ fishery	Emission	24.1	21.8	22.2	22.5	22.8	22.8
		Reduction rate		9.5%	7.8%	6.6%	5.5%	5.4%
	Omission*, etc.	Emission	4.8	7.3				
	Forest	Sink	-	17.6	17.6	17.6	17.6	13.0
Source of emission unit	Per GDP (Ton/KRW Mn)		0.46	0.07	0.08	0.10	0.13	0.16
	Per capita (Ton/person)		13.8	3.6	4.5	5.7	7.2	8.6

Source : Low carbon Society Vision Forum reviewed (2020)

* Omission: GHG leaked during the mining/production/processing/refining/storage/distribution of fossil fuel such as coal/petroleum/natural gas, not through the combustion

[Table 1-6] Low carbon Society Vision Forum reviewed

- Key social images in 2050, by sector

Sector	Option 1	Option 2	Option 3	Option 4	Option 5
Energy supply	• Coal-fired generation ratio 4% • Renewable energy 60% • Hydrogen economy era	• Coal-fired generation ratio 4% • Renewable energy 60% • Hydrogen Economy era	• Coal-fired generation ratio 8% • Renewable energy 50% • Hydrogen economy generalized	• coal-fired generation ratio 8% • Renewable energy 50% • Hydrogen economy generalized	• Coal-fired generation ratio12% • Renewable energy 40% • Hydrogen economy visualized
Industry	• Complete transition and expansion of conversion • Maximum material reuse, ground-breaking process innovation	• Fully supply of smart energy management system • Material reuse and gradual process improvement	• Expansion of smart energy management system supply • Material reuse and gradual process improvement	• Expansion of smart energy management system supply • Introduction of high-efficiency energy reduction system for industrial process	• Partial application of smart energy management system • Energy efficiency improvement for motor, boilers
Building	• Settlement of green building • Maximized consumption of renewable energy including unused heat, etc.	• Settlement of Green building • Strengthened supply of new / renewable energy	• Generalized green building, strengthen expanded supply of new / renewable energy	• Generalized green building • Pursued supply of new / renewable energy	• Strengthened Green building management • Pursued supply of new / renewable energy
Transportation	• Drastic decrease of ICEV (internal combustion engine vehicle) (ratio 7%) • Popularized green vehicle (ratio 93%) Expansion of automated driving, AI	• Drastic decrease of ICEV (ratio 7%) • Popularized green vehicle (ratio 93%) • Full -scale road-network change	• Gradual decrease of ICEV (ratio 18%) • Generalization of green vehicle (ratio 82%) • Full -scale road-network change	• Gradual decrease of ICEV (ratio 18%) • Generalization of green vehicle (ratio 82%) • Materialization of road-network change	• Decrease of ICEV (ratio 25%) • Expansion of Green vehicle (ratio 75%) • Materialization of road-network change
Agro/ Farming/ forestry/ waste	• Diversification of smart farm • Natural virtuous cycle of the circular economy • Eco-friendly environment	• Expanded supply of smart farm • Natural virtuous cycle of the circular economy • Eco-friendly environment	• Expanded supply of smart farm • Expansion of aerobic operation and bio-plastic ratio for landfill • Eco-friendly environment	• Commercialization of smart farm • Expanded collection of methane, enhanced reuse / reduction of waste • Eco-friendly environment	• Commercialization of smart farm • Enhanced reuse / reduction of waste • Eco-friendly environment

Source : Low carbon Society Vision Forum reviewed (2020)

3) Developments in Korea's response to climate change

- To actively participate in the global GHG reduction movement and to enthusiastically respond to international agreements, various climate crisis movements and think-tanks are developed, mostly by civic groups. Since the General election in April 2020, the National Assembly has actively proposed legislation on decarbonization, carbon neutrality, and Green New Deal. The Government and the President office announced 'Korean New Deal', and are actively pursuing relevant policies.

- President Moon Jae-in, during his speech at the National Assembly in October 2020, announced Korea's commitment to carbon neutrality by 2050. Since then, Korea witnessed a full-scale movement for decarbonization in various aspects of the economic and social front.

- More than 80% of respondents in various surveys stated that the climate crisis is a critical issue. However, many people still consider the climate crisis as a lower priority compared to other social/economic/political matters. Change of the general public's awareness on the climate crisis, led by the civil society, needs to be more actively induced.

- Most representative civil movement and policy development process in Korea are as below
  - 2018 - launch of Energy Transition Forum
  - 2019 - launch of Climate Crisis Emergency Action
  - 2019 - launch of public/private joint 'LEDS Society Vision Forum' composed of 69 representatives from academia, industry, civil movement, and youth for 7 sub-committees of overall, transition, industry, transportation, building, non-energy (agriculture, farming, and fisheries/waste/forestry), and young adults
  - 2020 - From around the General election, 2050 Net-zero discussion activated
  - Reviewed 2050 Low Carbon Society Vision Forum

- Changes in response to climate crisis after the 2020 General Election are as below.
  - 5 June: All basic local governments (226) announced climate crisis emergency
  - 7 July: All regional local governments (17) announced carbon neutrality
  - 24 September: National Assembly adopted 'Resolution on call for Climate crisis emergency response'
  - 28 October: President Moon Jae-in announced 2050 Carbon neutrality in his policy speech at National Assembly

Research on Strategy and Policy by Sector for Korea 2050 Carbon Neutrality

2

Electricity Sector

2.1 GHG Emission Status and Key Characteristics in Electricity Sector

2.1.1 GHG emission status in power sector

- As of 2017, the final energy was 230,019(unit : 1000 TOE), which was composed of coal 33,36, petroleum 117,861, natural gas 795, urban gas 23,258, electricity 43,666, thermal 2,441, and new/renewable energy 8,638. Power sector and new/renewable energy constituted 19% and 3.8%, respectively.[2)]
- GHG emissions in 2017 from energy transition (generation/thermal) was 252 million CO_2 ton[3)] which is 40.9% of energy sector emission, which is 615 million CO_2 ton.
- GIR (Greenhouse Gas Inventory and Research Center) does not issue the GHG emission volume per source of power generation. Hence, Yearbook on Energy Statistics by the Korea Energy Economics Institute (KEEI) was referenced to calculate the GHG emission per fuel for the transition sector and the below table is produced.
- GHG Emission from coal-fired generation in 2017 was 213.81 million CO_2 ton, taking up 84.8% of 252million CO_2 ton of transition sector emission. The energy consumed in the coal-heat conversion providing the heat to the industrial complex and the amount of GHG were not confirmed.
- In 2017, 47.495million CO_2 ton and 5.129 million CO_2 ton of GHG was emitted during the gas-electricity conversion and gas-heat conversion processes, respectively.
- 3.575 million CO_2 ton of GHG was emitted during the petroleum-power generation conversion in 2017.
- Despite the termination of fossil fuel subsidy and call for phase-out of coal-fired power generation since the G20 meeting in 2009, new coal-fired power plants (CFB) were built, and coal-based energy production continuously increased in Korea.
- An anomaly for fuel cell is that CO_2 is generated during the process of producing hydrogen from LNG. 2,256,560MWh of power is generated from the fuel cell in 2019, and it is estimated that a significant amount of CO_2 is emitted. However, the GIR does not specify the CO_2 volume from the LNG used for fuel cell power generation. The CO_2 emitted from the process of hydrogen production from LNG for Hydrogen Fueled Car is not identified, either.

2) 2018 Yearbook of Energy Statistics

3) GIR, Greenhouse Gas Inventory and Research Center

- The Electricity emission factor for Korea is not formally announced through the GIR. The Electricity emission factor indirectly confirmed through government documents[4] is 440kg/MWh; 830kg/MWh for coal-fired generation and, 350kg/MWh for gas-fired generation.

[Table 2-1] GHG Emission per during energy conversion (electricity, heat) per fuel 2000~2017[5]

Year	Emission from energy conversion ($ktCO_2eq$)				
	Coal-generation	Petroleum -generation	Gas -generation	Petroleum -heat	Gas -heat
2000	86,480	17,090	13,258	1,204	1,020
2001	93,981	18,421	14,184	1,415	1,919
2002	102,138	16,147	17,970	1,502	1,855
2003	106,060	16,245	17,827	1,703	1,873
2004	114,497	12,325	25,103	1,906	1,754
2005	120,089	12,131	25,459	1,967	2,086
2006	125,708	12,054	30,031	1,567	1,885
2007	138,579	12,498	34,404	1,425	1,922
2008	156,265	6,993	34,036	1,058	1,837
2009	176,479	9,676	29,559	1,023	1,596
2010	189,149	8,857	43,456	1,066	1,983
2011	196,262	6,403	44,952	758	5,360
2012	193,586	9,935	49,133	577	6,232
2013	194,753	10,185	54,887	565	6,420
2014	192,002	4,890	49,660	460	5,038
2015	197,284	5,701	44,376	340	4,684
2016	192,048	8,564	47,230	555	4,739
2017	213,810	3,575	47,495	525	5,129

Source : prepared by author

- Korea aims at 20% power generation from renewable energy by 2030 and the 3rd Energy Master Plan targets 30-34% of power generation from renewable energy.
- The LEDS Forum by the Ministry of Environment suggests 5 LEDS scenarios for 2050. The most aggressive scenario suggests 60% power generation through renewable energy with the GHG

4) The 3rd Energy Master Plan

5) (Referenced data) Yearbook on Energy Statistics, data regarding consumption per energy source in energy conversion sector, 2000~2017

reduction goal of 75% by 2050. However, the linkage between the 60% power generation from renewable energy and 75% GHG reduction is not clear. It may be possible to achieve the goal if the final energy consumption is drastically reduced, but if a significant amount of renewable energy is imported, it may cause problems in energy security or stable energy supply.

2.1.2 Key characteristics

1) Continued increase of GHG from energy conversion (electricity, heat)

- Electricity consumption consistently increased, but slowdown in growth recently
- Unlike other major OECD countries, the decoupling between GDP growth and electricity consumption isn't significant.
- New investment in existing sources of power generation (coal, gas, nuclear power) continued. As of February 2020, facilities for nuclear power 5.6GW, coal 7.26GW, combined cycle power 5.86GW, and Integrated energy 3.6GW are under construction.
- Coal-fired power generation takes up over 40%, which is 85% of GHG emission in the power sector.

2) Insufficient supply of renewable energy

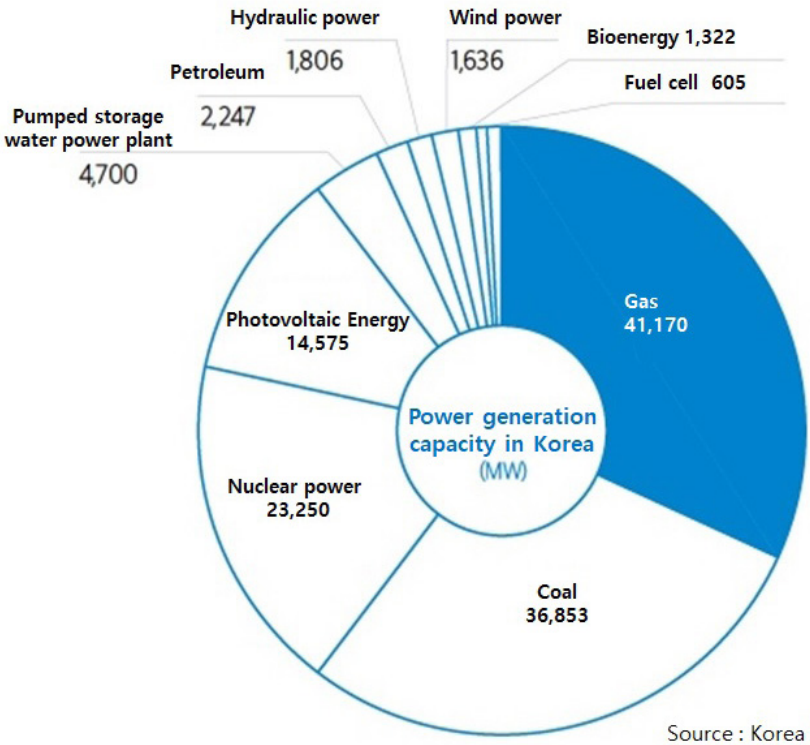
- Speed of renewable energy supply lags further behind compared to that of OECD countries. As of 2019, only 3.5GW and 0.25GW worth of new solar photovoltaics (Solar PV) and wind power plants were built, respectively.
- The 8th Basic Plan for Long-term Power Supply and Demand is a power supply plan still based on the legacy source of power, not stretched out to the power supply system based on renewable energy.

[Table 2-2] Power plants under construction in Korea

Power plant under construction			As of September, 2020	
Type	Name	Capacity (MW)	Construction period	Note (Name of company)

Nuclear power plant (5,600MW)	Shin-Hanul #1 Shin-Hanul #2	1,400×2	'10. 04 ~ '21. 08	Korea Hydro & Nuclear Power co. (KHNP)
	Shin-Gori#5 Shin-Gori#6	1,400×2	'16. 06 ~ '24. 06	KHNP
Combined cycle power (5,680MW)	Nam-Cheju combined	GT : 55×2 ST : 63×1 GT : 50×2 ST : 50×1	'19. 02 ~ '20. 12	Korea Southern Power Co. (KOSPO)
	Yeoju Natural gas power plant	GT : 321.3×2 ST : 361.4×1 GT : 327.2×2 ST : 349.6×1	'19. 12 ~ '22. 07	Yeoju Energy Service KOSPO
Coal-fired (7,260MW)	Shinseocheon thermal	1,000×1	'15. 11 ~ '21. 03	KOSPO
	Goseong Hai Thermal #1,2	1,040×2	'15. 10 ~ '21. 10	Goseong Green Power
	Gangneung Anin Thermal #1,2	1,040×2	'17. 05 ~ '23. 03	Gangneung Eco Power
	Samcheok Thermal #1,2	1,050×2	'19. 08 ~ '24. 04	Samcheok Blue Power

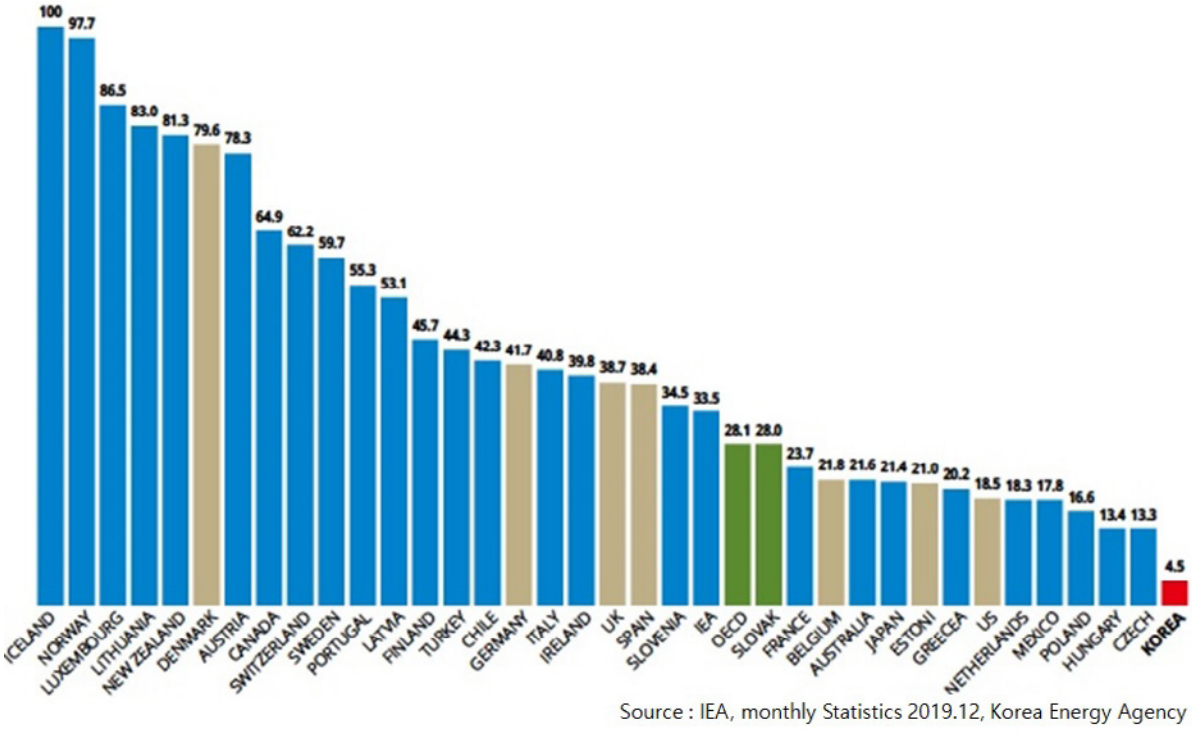
<Figure 2-1> Power generation capacity Korea (MW)



Source : Korea Power Exchange (As of 4 January)

Ratio of renewable energy generation is the lowest among the OECD countries

<Figure 2-2> New/renewable energy share in OECD Countries



Source : IEA, monthly Statistics 2019.12, Korea Energy Agency

3) Lack of national awareness regarding the climate crisis and energy transition

- General public and politicians remain indifferent to the climate crisis and energy transition.
- Renewable energy options required to reduce fossil fuel use in response to the deepening of the climate crisis has been linked to nuclear phase-out movement and overflowing fake news. As a result, the negative perception on renewable energy has increased.
- The local governments with low level of awareness on climate crisis and renewable energy introduced stricter regulations on renewable energy facilities, which resulted in the deteriorated economic feasibility of renewable energy.
- Green vs Green discord remains regarding the introduction of renewable energy facilities, due to the negative perception by certain environment groups.

2.2 GHG Reduction Scenario and Methodology in Korea and Other Countries

2.2.1 Scenario and reduction methodologies in foreign countries

1) International trend

- Countries around the world are pursuing fossil fuel generation reduction and decarbonization in the power sector.
- Countries are introducing renewable energy not only in the power sector but also in industry, transportation, and building sector.
- As post -carbon power source, renewable energy is preferred over nuclear power. Solar PV/ wind-power/ hydraulic power generation, bio energy and geo-thermal energy are supplied in pursuing the post-carbon power policy.
- Assessment and projection on CCS (Carbon Capture and Storage), and DAC (Direct Air Capture) technology differs among national governments and international agencies.
- IEA considers nuclear power and CCS as major tool, while IRENA considers nuclear power plant only, considering CCS is not meaningful.
- Among the world major countries, China, US, Japan, and the UK included nuclear power and CCC as core of the post- carbon strategy.
- EU, on the other hand, excludes nuclear power from the green technology classification criteria. CCS is used only upon the consumption of biofuel, and CCS upon fossil fuel is not applied.
- To achieve the Paris Agreement 1.5℃ goal, the goal of CO_2 emission reduction to 45% of 2010 levels by 2030, and net zero emission by 2050 is suggested. Hence, the Green hydrogen production has become a necessary option for decarbonization in industries where carbon reduction is difficult, such as vessel, airplane, heavy chemical, and petrochemical sectors. Renewable energy facility plan is increasing for the green hydrogen production.
- A number of countries are announcing or enacting a net zero emission goal by 2050, by reducing energy consumption and increase renewable energy usage.

IRENA energy conversion scenario (IRENA, 2020, Global Renewable Outlook)

- TES (Transforming Energy Scenario) is a GHG reduction scenario satisfying Paris agreement. TES contribution to energy related CO_2 reduction is 52% in Renewable energy, 27% in energy efficiency, and 21% in fuel transition etc.
- Compared to each countries' NDC based reduction plan, TES holds 2.4% higher contribution to economic development by 2050. Renewable energy, efficiency, electrification accompany extensive socio-economic benefits.
- Renewable energy industry will create 42 million jobs, which is 4 times higher than current level, 21 million more jobs in energy efficiency, and 15 million jobs in system flexibility by 2050.
- TES articulates the need of reduction technology, business model, and behavior adaption, which is the last part of the in-depth reduction within the industry.
- Decarbonization in energy use, to prevent the catastrophic climate change, requires an international cooperative framework. Together with the awareness on necessity of reduction, as investment in Green energy accompanies increase in stranded assets, attention should be paid not to make short-sighted decisions.
- Policies to overcome COVID-19 need to include flexible power system, efficiency, EV charging stations, energy storage, interlinked hydraulic generation, green hydrogen, and investment in other technology that satisfies the energy and climate sustainability.
- It includes industrial policy, intervention in labor market, development of training programs, and social protection programs, to maximize the positive function of the energy transition.

5 core policies of TES for future energy system transformation

1) Electrification

- The cost of the renewable energy is, despite decreasing subsidies, continues to fall at record prices.
- In the TES, electricity will become the central energy carrier and will grow from 20% of the current final consumption to 50% by 2050. With the electrification in industry, transportation, and building sectors the electricity consumption will more than double.

- Annual growth of the renewable electricity share should increase from current 0.25%/year to 1%/year. 1,000TWh of renewable electricity generation should be added per year, which can be translated into addition of new generation capacity of 520GW/year. Renewable electricity share that only recorded 26% in 2019 should increase to 57% in 2030, and 86% in 2050, which can be achieved considering the dropping renewable electricity price. Power generation cost at 4/5 of the Solar PV and wind energy facilities constructed in 2020 is lower than the cost from existing facilities (IRENA).
- Electrification of final consumption should be filled by renewable electricity.
- TES projects the number of Electric Vehicle (EV) would increase from 8 million in 2019 to 1.1 billion in 2050, and the heat pump with 2~4 times higher energy efficiency than existing heating system would increase by more than 10 times.

2) Enhanced power system flexibility

- Flexibility of the power system is the backbone of the future power system, and a key enabler of accepting renewable energy with high variability.
- A climate-friendly energy system can be achieved through electrification, digitalization and decarbonation.
- Currently, when power generation volatility exceeds 30% per year, the total amount of electricity generated temporarily approaches or exceeds the total electricity demand. Such electricity surplus would create new business opportunities, which will again accelerate the electrification. Within the TES scenario, solar PV and wind power, the variable energy sources are responsible for 73% of facility capacity and 60% of energy generated (currently 10%) by 2050.
- Power system flexibility should be maximized by leveraging the current and developing innovations to reform the business model, market design, and system operation.
- Storage technology is important in the short- and long-term perspectives. Storage capacity should increase from currently 30GWh to 9,000GWh by 2050. As for the EV, storage systems are important for both power system stability and power storage. TES projects the storage capacity for EV to reach 14,000GWh ~ 23,000GWh by 2050.
- However, most of the flexibility is secured through grid expansion and operation, such as flexibility in demand or sector coupling. Smart storage for EV requires both the flexibility in

demand and improvement in storage capacity and is judged to have significant potential for system flexibility.

- TES argues that the investment in Smart Power System should increase from USD 13 trillion to USD 26 trillion by 2050.

3) Traditional role of renewable energy

- Potential volume of hydropower, bioenergy, solar thermal and geothermal renewable energy should be maximized, covering 1/4 of the GHG reduction in TES. Hydropower and bioenergy especially play significant roles.

- Hydropower is critical in TES, and the capacity should increase by 25% till 2030, and by 60% till 2050. The capacity of the pumped hydro storage power plant is expected to double. When two types of power generation facilities are added, 850 GW worth of facility should be added by 2050, which is equivalent to the total generation capacity of Europe as a whole. Hydropower is important as it can cope with the variability of solar or wind power generation, complement the seasonality, and is useful for water resource management such as flood control effect.

- Hydropower generation can be increased by building new dams, upgrading existing dams , or using existing dams. New hydropower generation plans require environmental impact studies and discussion with the local community. Operational plans including response to intermittency of renewable energy, variable speed power generation, and low storage management needs to be changed. Policy makers need to establish comprehensive plans as the construction requires a longer time horizon, and to modernize the facility to achieve new level of power system performance from existing facilities.

- Bioenergy will play a bigger role in final energy sector. It is currently one of the major sources of renewable energy in industrial heat, power generation, and transportation.

- Under the current scenario, the ratio of modern primary bioenergy excluding the biofuel should increase from the current 5% to 10% level. Under the planned scenario, bioenergy will play a significant role as process heat supply and fuel in sectors such as marine and air transportation as well as industry sectors where the electrification is difficult. Ultimately, bioenergy is expected to take up to 23% in those sectors. The traditional bioenergy should be replaced by modern bioenergy, which needs to be developed in an environmentally, socially, and economically sustainable way.

- Bioenergy has enormous potential. Without destroying the forest, and leveraging the existing farmland and meadow, bioenergy will generate economic and green energy. There is great room for the bioenergy generation, without threatening the food production.

4) Green hydrogen

- Hydrogen is required to supply the energy for the sectors where electrification is difficult. However, the IEA reported that of the 70MTon hydrogen produced in 2018, most of them are from fossil fuels, and that Green hydrogen is less than 1%.

- In early 2020, Japan started operating a green hydrogen production plant with 10MW capacity electrolysis facility, and the cost is expected to fall fast. Green hydrogen produced in locations with favorable renewable electricity production would soon gain a competitive edge against the blue hydrogen (fossil fuel-based hydrogen combined with the CCS). If the renewable cost further drops, green hydrogen will become cheaper than the blue hydrogen in many locations. Energy-intensive industries including steel and ammonia manufacturing may relocate looking for cheap sources of green hydrogen.

- First ammonia produced using green hydrogen will be launched in 2020. Hydrogen can be processed into hydrocarbons and ammonia, contributing to reducing the GHG emission from shipping, aviation, iron making and petrochemical industries.

- Gas industry considers hydrogen as an opportunity to extend the life of the existing infrastructure, but the idea should be reviewed whether it would really contribute to the reduction of GHG remission, and also the potential lock-in of carbon-intensive infrastructure.

- A Hydrogen commodity trade is nascent, but hydrogen could become the clean energy vector. Production of hydrogen at a location that is wide, remote, that allows low cost, would have geopolitical implications. TES projects that about 160 Mton of green hydrogen would be manufactured, which is the same as 5% of current energy consumption.

- For the green hydrogen manufacturing, the electrolysis technology should be upgraded. By 2050, new renewable energy facilities about 50GW~60GW of capacity need to be added per year by 2050.

5) Foster innovation to address challenging sectors

- As TES aims to electrify 50% of the final energy, the remaining 50% should also be considered for electrification. Of the remaining 50%, 1/3 is supplied with renewable energy, and 2/3 is supplied by fossil fuel. To reduce the use of fossil fuel, solar thermal, bioenergy, geothermal must be enhanced together with the energy efficiency. At the same time, the structural change to reduce the demand and the electrification are required.

- Measures to reduce the energy consumption by shipping, air transport, and heavy industry, that emit the 3/4 of the remaining GHG are required, and it is explained in the DDP (Deeper Decarbonization Perspective). DDP is a challenging sector dealing with freight, shipping, air transport, and heavy industry, which can be reduced through biofuel, synthetic fuel, new materials and the circular economy. In countries like China with high energy intensive industries 50% of the energy is consumed in such sectors. Solutions for industries consuming bulk of energy including iron and steel making, cement and petrochemicals should be identified. Also, it is urgent to find solutions to reduce the GHG emitted from these processes.

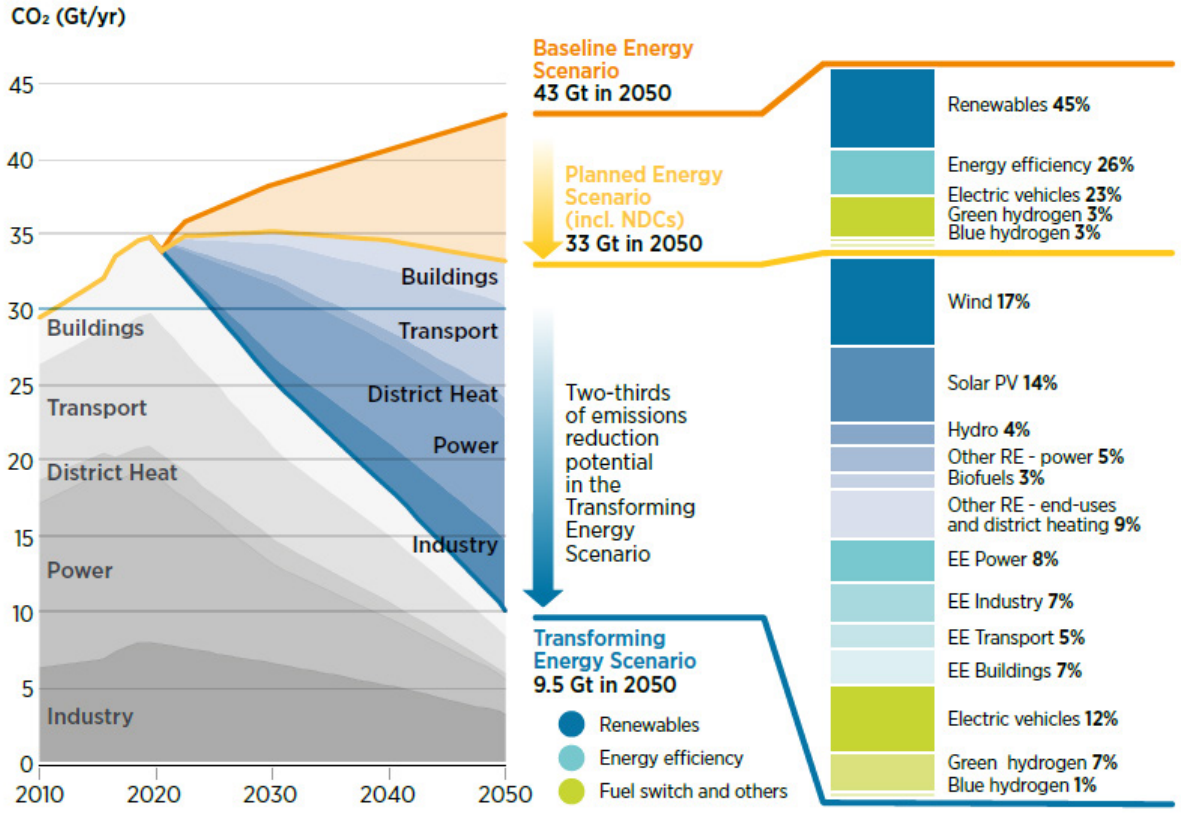
- Under the DDP, 60% of the GHG can be reduced by use of renewable energy, 37% by energy efficiency and structural and behavioral changes, and 3% by CCUS and nuclear power. In the Baseline Energy Scenario targeting zero emission from energy and industrial processes 43% of reduction is from renewable energy, 26% from energy efficiency, 12% from EV, 9% from green hydrogen, 7% from CCS/CDR, 2% from behavioral changes and 1% from nuclear power.

- To achieve as in the ETS (Energy Transformation Scenario), CO_2 emissions need to fall by 3.8% per year till 2050, and energy related CO_2 emission should be reduced by 70% by 2050.

- TES Scenario projects that over 50% of GHG emission is reduced by use of renewable energy (electricity and end-use), and 1/4 by energy efficiency. When direct and indirect electrification (green hydrogen, EV) is included, over 90% of GHG remission reduction is by renewable energy. For the reduction of GHG emission from the sectors identified as challenges under the DDP, such as shipping, air transportation, and heavy industry, additional renewable energy, electrification, energy efficiency, carbon management, structural and behavioral changes are required.

- Efforts need to be exerted in the non-energy sectors, as well. Land use, land use change and forestry (LULUCF), coal, petroleum, gas industry's efforts to reduce the fugitive gas emission are also required.

<Figure 2-3> GHG emission reduction under IRENA, TES scenario

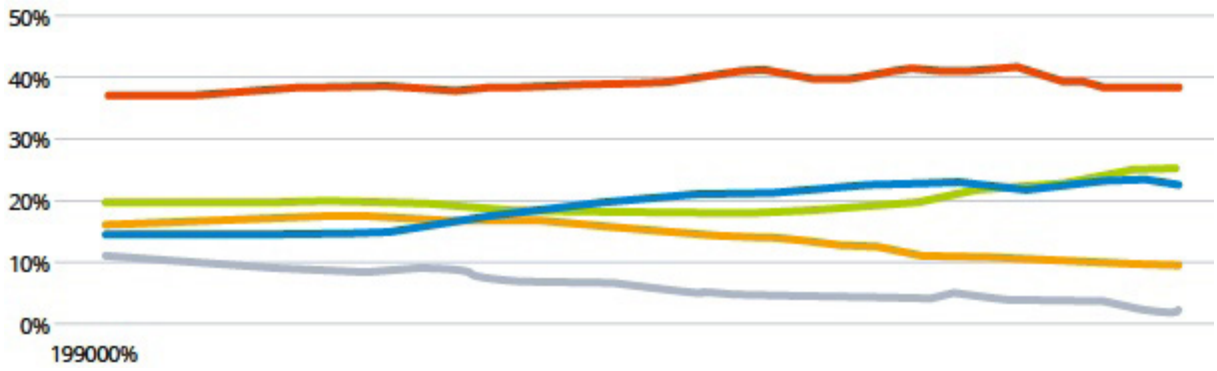


Source : IRENA (2020), Global Renewable Outlook

<Changes in ratio per source of global power generation (IEA, World Energy Balances 2019)>

- Electricity from renewable energy has secured competitive edge over existing source of energy in many countries and regions.
- As the figure below illustrates, the ratio of coal/nuclear/petroleum-fired power generation decreases while the ratio of renewable energy / natural gas increases.
- Even the IEA using a conservative projection on renewable energy highly assesses the price competitiveness of renewable energy.

<Figure 2-4> Changes in share of global power generation per source



Source : IEA (2019), World Energy Balances 2019

2.2.2 Scenario and reduction plan in Korea

Hong, Jong-Ho. Korea 2050 Energy Strategy

1) Why do we need energy transition?

- Energy security : 9th biggest energy consumer, 95% of energy is imported.
- Overcoming economic crisis : potential growth rate lowered to 2% level, 4th Industrial revolution and energy innovation, post-COVID19 economic recovery.
- Safe and clear energy : Highest nuclear power plant density in the world, lowest ratio of renewable energy power generation among OECD countries, highest fine dust density among OECD countries.
- GHG reduction : 7Th biggest CO_2 emission from fuel combustion, global warming, climate change, climate crisis.

2) 2050 Energy Scenario

[Table 2-3] 2050 energy scenario for sustainable future

Scenario	BAU	Moderate (MTS)	Aggressive (ATS)	Visionary (VTS)
Policy / technology condition	Based on Government funded research center's 「2016 long-term energy projection」	Demand management for reduction of per capita energy consumption, gradual reduction of centralized power plant	Aggressive demand management to limit the average temperature increase to 2℃	100% of end-use energy demand supplied by renewable energy
End use energy demand (as of 2014)	35.4% increase by 2050	7.0% reduction by 2050	24.0% reduction by 2050	24.0% reduction by 2050
End use energy electricity generation ratio	Increase from 31.9% in 2014 to 34.0% in 2050	Expand from 31.9% in 2014 to 45.8% in 2050	Expand from 31.9% in 2014 to 45.6% in 2050	Significantly expand from 31.9% in 2014 to 75.9% in 2050
Ratio of renewable energy	Increase from 2.1% in 2014 to 6.1% in 2050	Increase from 2.1% in 2014 to 67.7.1% in 2050 (5070 scenario)	Increase from 2.1% in 2014 to 60.4% in 205060.4% (5060 scenario)	Achieve 100% in 2050from 2.1% in 2014 (5000 scenario)

Source : Hong, Jong-Ho, et al. (2017), 2050energy strategy for sustainable future of Korea. WWF

- Under the BAU, the generation volume increases by 29% from 480TWh in 2014 to 675TWh in 2050, which is broken down to nuclear 42%, coal 29%, gas 19%, and renewable energy 4%.
- Under the Moderate Transition Scenario (MTS), the projected generation volume in 2050 is 626TWh, which is broken down to Solar PV 265TWh (42%), Wind 105TWh (17%), Natural gas 78TWh(13%), Nuclear 80TWh (13%), and Coal 43TWh (7%).
- Under the Advanced Transition Scenario (ATS), end-use energy is projected to decrease by 24% from 129.5Mtoe in 2014 to 98.4Mtoe in 2050.
- Visionary Transition Scenario (VTS) projected end-use energy consumption decrease by 24% from 129.5Mtoe in 20 to 98.4Mtoe in 2050, and it is broken down to 71.8Mtoe (75%) electricity; 10.7Mtoe (11%) heat (RR); and 7.3Mtoe (8%) bioenergy, 5.9Mtoe (6%).

Kwon, Pil-Seok(2020, Accelerating Energy Transition in South Korea)

1) Purpose

- Research on GHG emission reduction alternative scenario for power sector (goal of 150MTCO$_2$ in 2030)

2) Factors in the CO_2 reduction scenario

- Carbon Tax (on the CO_2 emission), (KRW 10~100K per ton)
- Design Life condition for early exit of coal-fired power generation (30, 25, 20 years)
- Expansion of renewable energy (Maximum supply without limitation by the Government Plan)

3) Scenario analysis

❶ **Introduction of carbon tax - coal-fired power generation, which covered 45% of the power generation without the carbon tax would be replaced by the gas-fired power generation if the carbon tax rate is high. If the Carbon tax is set at KRW 100K per ton, then the share of coal-fired generation will be only 8% and 151MtCO$_2$ of CO_2 emission will be achieved, but with excessive cost.**

❷ **If coal-fired power plant design life is set at 30, 25, 20 years, then the share of coal-fired generation could drop to 22.5%. This scenario assumes the 7 stations currently under construction to be redirected to gas fired power plants. With the shorter design life, achieving the reduction goal in the power sector becomes easier.**

❸ **Competitiveness of the renewable energy increases when external cost increases. The share of renewable energy under the maximum scenario is 32%, or 92GW (Solar PV 42GW, wind 50GW). Expansion of renewable energy could lead to maximum 90Mt CO_2 reduction of GHG emission.**

❹ **Modeling result leads to the conclusion that the combined approach is required to achieve 150Mt CO_2 goal by 2030.**

❺ **When heavy carbon tax of KRW 100K per ton and exit of coal fired power plant station after 20 years design life combined, the goal can be achieved.**

❻ **Most economical way of achieving the goal is to combine the expansion of renewable energy and the early exit of power plant stations.**

4) Challenges in decarbonization in Korea

① Land use and public receptivity

- Land use, complicated licensing process
- Negative perception on renewable energy

② Electricity market and renewable energy price

- Concurrent subsidy to non-renewable and renewable energy power generation
- Lack of policy for prosumer, slow drop of renewable energy price
- Lack of long/short term power market

③ Insufficient flexibility in power grid and power system

- Excessive inflexibly power supply
- Delayed expansion of transmission lines

Lee, Chang-Hun, 2019, Decarbonization Energy Transition Scenario - Sustainable Development and Transitions in Energy and Industry : focusing on the climate change policy goal of meeting 1.5°C pathway

1) Carbon budget regarding meeting 1.5°C pathway

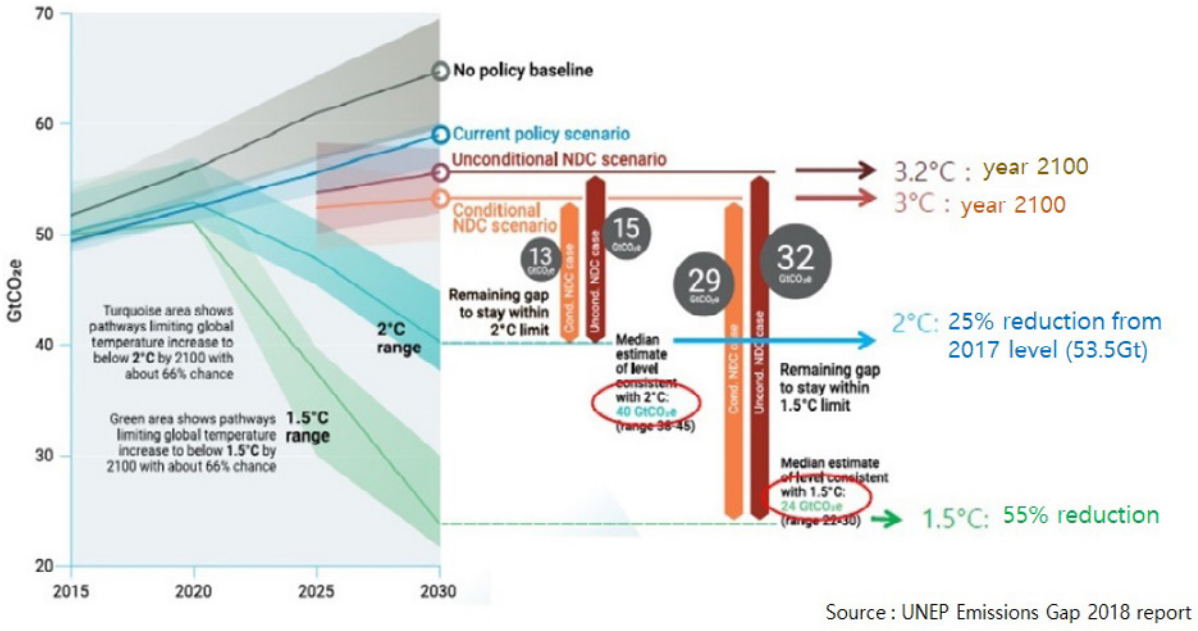
- 1.5°C pathway GHG Emission (Global Carbon Budget)
- CO_2 emission pathway in IPCC 1.5°C report (2018)
- When to reach Net zero
- Targeting 1.5°C : 45% reduction compared to 2010 level on around 2050, 2030
- Targeting 2°C : 20% reduction compared to 2010 level on around 2070, 2030
- 1.5°C Energy transition scenario (ratio of 2030, 2050 compared to 2010 level)
- CO_2 emission : 58%, 93% reduction
- End-use energy demand : 15%, 32% reduction
- Ratio of renewable energy in electricity : 60%, 77%
- Ratio of renewable energy in primary energy : 49~67% ('50)
- Ratio of electricity in end-use energy : 34~71% ('50)

2) 1.5℃ pathway GHG emission in Korea (National Carbon Budget)

- Principle of sharing the reduction burden in International Treaties : Fairness (Fair Sharing of Burden)
- Equity : GHG per capita
- Responsibilities : Accumulated GHG emission (1850~, 1950~, or?)
- Respective Capabilities : National income, GDP per capita, HDI, income

* Article 3-3 of the treaty articulates the Cost-Effectiveness as a principle, which can also be achieved through Emission Trade (Certified Emission Reduction). Certified Emission Reduction is a secondary principle as it may facilitate the sustainable development of the developing countries.

<Figure 2-5> GHG Contribution per scenario (Lee Chang-Hun, recited)



Source : UNEP Emissions Gap 2018 report

3) In-depth energy transition scenario

- Innovative improvement of energy efficiency, increase ratio of electricity with higher potential for decarbonization, drastic increase of renewable energy use would lead to CO_2 emission in Korea by 91.5% from 592Mt CO_2e in 2017 to 50Mt CO_2e in 2050, and provide support to developing countries' GHG reduction to achieve net zero.

4) 1.5°C pathway scenario strategy

❶ Innovative improvement of energy efficiency

- Improve energy efficiency by 3.0% per year from 2018, reduce the energy intensity (TOE/KRW Million) from 0.114 in 2017 to 2018, and the end-use energy consumption by 33.7% from 172.6 MTOE in 2017 to 114.4 MTOE in 2050.

❷ Electrification of energy demand

- Increase the generation volume by 68.9% from 553.5TWh in 2017 to 935.1TWh, ratio of electricity in end-use energy from 25.3% in 2017 to 63.7% 2050.

❸ Expansion of renewable energy in Power generation

- Together with the electrification, expand the use of renewable energy such as solar PV and wind power and minimize the carbon intensity in power generation.
- Enhance the ratio of renewable energy up to 85%, and secure power system flexibility through LNG generation and energy storage technology (e.g. battery, hydrogen, P2G).
- Complete the coal/petroleum phase out by 2040, guarantee 40 years or 60 years of designed life for the nuclear power plant, reflecting the current government's policy (Generation of 12.4GW by 2050).

❹ In-depth energy transition strategy for power generation

- Reduce the power generation CO_2 emission from 223MTCO_2 in 2017 to 16MTCO_2 in 2050 through decarbonization, improve the carbon intensity (tCO_2e/MWh, User-end) of Electricity from 0.4046 in 2017 to 0.0194.
- Continuously reduce coal-fired generation with high carbon intensity continuously from the power generation options and replace it with the renewable energies including solar PV and wind power.

❺ Potential of securing renewable energy generation capacity

- When renewable energy power generation for 2050 is achieved by onshore solar PV and offshore wind farm (including floating type) 50% each,
- With the assumption of capacity factor of 15% and 30%, 305GW, 152GW are required.
- If 3/4 of facility to cover the solar PV generation required in 2050 takes the farming solar PV, 1.5 larger land is required compared to the vacant land solar PV, representing about 20% of total farming area, or 3,050km2.
- It is with the assumption that the Solar PV average efficiency is improved to 30%. If the efficiency still remains at the 20% level, then 30% of total farming area is required for farming solar PV.

- According to Lee, Chang-Hun et al. (2014, page 81), area of the sea that is less than 50m deep, within 50 km from the shore with over 300W/ m^2 wind density is 88,829km^2. When the wind turbine of 88GW is installed on 20% of the region, and floating type offshore wind turbine is installed in deep East Sea, the offshore wind power for 2050 can be secured.
- Onshore solar PV and offshore wind turbine installment demand can be achieved technologically and economically. However, such huge installation would fundamentally change the rural and maritime scenery. Change of perception and adaptation to new scenery are required.

⑥ Overcoming intermittency of renewable energy

- Electricity cannot be artificially controlled because of its natural characteristics, and as the capacity factor is low, when the ratio of renewable energy becomes high, the energy surplus is inevitable.
- Redesigning of Electricity operation system complementing the intermittency of the renewable energy generated power is required. In particular, the efficient storage (pumped-storage hydroelectricity, battery, production of hydrogen and methane) and use of renewable energy surplus are required.
- Considering the conversion loss from the use of the storage facilities, the required renewable energy generation volume in 2050 may increase.

2.2.3 Recommendation on 2050 renewable energy supply scenario in Korea

1) Basic strategy

- UN requires 45% CO_2 reduction by 2030 and net zero by 2050 for 1.5°C pathway.
- UN requires enhanced NDC submission to each country (every 5 years since the first NDC in 2015).
- UN also requires each country to submit 2050 LEDS by the end of 2020.
- Korea has to develop implementation plan for CO_2 Net Zero by 2050.
- Strategy for GHG zero emission by 2050 is composed of First, reduction of the end-use energy consumption, Second, electrification of industry, transportation, and building energy Third, use of renewable energy for electricity generation.

- In other words, the GHG zero emission can be achieved by minimizing energy consumption and maximizing the renewable energy supply.
- The scenario suggested is based on the reduction of end-use energy consumption of 2017 by 35~50%, electrification of 80% of end-use energy, and 90% power supplied using the renewable energy.
- The end-use energy in 2017 was set at 176 MTOE (excluding industrial resources) in the 3rd Energy Master Plan.

2) Renewable energy power 2050 target

- **<Condition>**
  - End-use energy in 2050 would be 30~50% less than in 2017
  - Electrification ratio of end-use energy in 2050 is 80%
  - Ratio of renewable energy-based electricity is 90% of total electricity in 2050
- **<Calculation of renewable energy generation facility for 2050>**
  - 50% reduction of end-use energy 176 MTOE (excluding consumption as resource) in 2050 is 88MTOE
  - 80% electrification of end-use energy 88MTOE in 2050 is 70.4MTOE = 819TWh
  - 90% of 70.4MTOE in 2050 is 63.36MTOE
  - 63.36MTOE equals to about 737TWh (1MTOE = 11.63TWh).
  - 30% reduction of end use energy 176MTOE (excluding consumption as resource) in 2050 is 123.2MTOE
  - 80% electrification of end-use energy 123.2MTOE in 2050 is 98.56MTOE
  - 90% of 98.56MTOE in 2050 is 88.704MTOE
  - 88.704MTOE equals to about 1,0.3TWh (1MTOE = 11.63TWh).

3) 2050 renewable energy facility capacity : solar PV 400GW, wind power 100GW, pumped storage power plant 50GW

- With capacity factor of 15% and 27.5% for solar PV and Wind power, respectively, 766.5TWh is produced
- Solar PV 400GW per year = 400GW*8760h*0.15=525,600GWh=525.6TWh of electricity
- Wind power 100GW per year = 100GW*8760h*0.275=240.9TWh of electricity

- Pumped storage power plant 50GW per year = 50GW*8760h*0.3=131.4TWh of electricity
- If pumped storage power plant efficiency is 80%, 131.4TWh/0.8 = 164.25TWh, in other words,
- With annual electricity consumption for pumping of 164.25TWh, 131.4TWh is generated (32.85TWh consumed)
- The 8th Basic Plan for Long-Term Power Supply and Demand assumes an average 1.0% increase of consumption per year, to reach 579.5TW in 2030, with peak electricity increase reaching 100.5GW in 2030 (winder season).
- Renewable energy-based electricity generation volume is set as below for year 2030, 2040, and 2050 based on the above plan.

[Table 2-4] Mid/Long term solar PV, wind power generation facility volume

	2030		2040		2050	
	Facility capacity	Capacity	Facility capacity	Capacity	Facility capacity	Capacity
Solar PV	80GW	105.12TWh	220GW	289.08TWh	400GW	525.6TWh
Wind power	30GW	72.27TWh	60GW	144.54TWh	100GW	240.9TWh
Solar PV + Wind Power	177.39TWh (30% of total 600TWh)		433.63TWh (60% of total 700TWh)		766.5TWh (90% of total 819TWh)	

- 2030 : solar PV 80GW (105.12TWh), Wind power 30GW (72.27TWh), 177.39TWh (29.5% of total 600TWh)
- 2040 : solar PV 220GW (289.08TWh), Wind power 60GW (144.54TWh), 433.62TWh (61.9% of total 700TWh)
- 2050 : solar PV 400GW (525.6TWh), Wind power 100GW (240.9TWh) 766.5TWh (93.6% of total 819TWh)

4) Solar PV installation area, expected impact, and economics

❶ **Solar PV installation area** : 1kw=Module (18%, 340W, 1m*2m) 3 panels, 6㎡installation interval considered, 10㎡ 1MW (1000kw), 1000*10㎡=1ha

- Of 400GW, facility for 100GW is installed in city space, 300GW is installed in designated site (3% of land) required.

❷ **Job creating impact** : the total installation cost of 1MW of PVcosts KRW 2billion, which will create20.6 jobs, This estimation is based on the study of 1 billion investment impact in Korea's construction sector by Korea Institute for Industrial Economics and Trade: 10.3 jobs per billion.

③ **CO_2 Absorption through Solar PV** : 65.88 times than pine grove, 1,314MWh*(540kg/MWh)/ha, year
=709.56ton/ha,year (National institute of Forest Science) CO_2 absorption of 30 year old pine grove: 10.77ton/ha,year

④ **Solar PV and Wind power generation replace coal-fired generation and nuclear power plant, with better economics.**

⑤ **Solar PV and Wind power generation are more environment-friendly than the city, industrial complex, road, or farmland.**
- Solar PV and Wind power generation does not pollute air, land, or water, with minimum impact on other environment.

5) Wind power generation installation area, methodology, and economics

① **Onshore Windfarm turbine Unison, 4.2MW model with the blade diameter (D) 151m, installation interval between towers 2D, 3D assumed.**
- Total 25 in square format (5 turbines in 5 rows) requires minimum area, 3D applied
5*5 square (0.453km*4) =1.812, 1.812*1.812=3.28㎢, hence, 1GW area is 32.8㎢
- For 1 line format, 2D applied 1*(0.302*24) = 7.248㎢, hence 1GW area is 72.5㎢

② **GE offshore turbine 6MW, with diameter 150m, installation interval 3D standard is applied**
- Square format (0.15*3*4) + 1=2.8, 2.8*2.8=7.84㎢,
6MW 25 turbines,150MW, hence 1GW area is 7.84*1000/150=52.27㎢
- For 1 line format 0.15*3*24+1=11.8, 11.8*1=11.8k ㎡
1GW area is 11.8*1000/150=78.67㎢
- Area required for 1GW : 30㎢ (interval 3~5 times of the diameter, 3.3MW blade diameter 140m)
- Installation location : onshore 30GW, offshore 70GW

③ **Installation region**
- Baekdudaegan Mountains, level 2 of ecological naturalness regions
- Southwest coastal plains (150m tower, 100m blade)
- Offshore : Government led location planning, construct transmission line, and bid for the lowest price

④ **Cost for land** : KRW 90trilion, KRW 30K/m2

⑤ **Wind power turbine installation cost** : KRW 100~200 trillion, KRW 1 ~2billion/MW

⑥ **Annual income from wind farm** : KRW 24.09trillion (Capacity factor : 27.5%, onshore 20%, offshore 30%)

5) Means of securing flexibility

① Expansion of transmission and changes in the Electricity market

- For the expansion of renewable energy, extensive investment in the Electricity system is necessary. The ratio of investment between the power generation : transmission is 1:1
- Economic energy conversion is enabled with the construction of large-scale renewable energy power plant. (requires comprehensive plan)
- System flexibility can be improved through 2-way flow of Electricity , real-time monitoring and control.
- Changes in the Electricity market
  - Develop climate and power generation volume projection program,
  - Introduce volume-based charging system to maintain Electricity balance,
  - Divide the market into contract market (year/month/week/day) and real-market market (day/hour/15 minutes / 5 minutes),
  - Strengthen the right of choice by consumer, allow direct trade between the producer and consumer.
  - Introduce time-based charges for DR.
  - Build connected line with overseas (10~20GW) : Enhance domestic electricity system and strengthen connection with the neighboring countries.

② Pumped storage water generation

- Status of hydraulic generation (New and Renewable Energy Whitepaper, Korea Energy Agency, 2018)
- Pumped storage water generation : Produced 4,700MW (2GW added at the 8th Basic Plan for Long-term Power Supply and Demand), 4,088GWh (9.9% capacity factor)
- Large scale hydraulic power generation : generated 1 GW by K-Water, 595MW, 3,561GWh by Korea Hydro & Nuclear Power Co., (25.5% capacity factor)
- Small scale hydraulic power generation : generated 188MW (237sites), 662GWh (40% capacity factor)
- Maximum volume of pumped storage water generation using the mountain terrain:10~20GW
- Even distribution across the city, Gun, Gu is required, and economics can be secured through all day use.

- Pumped storage water generation is the local governments' energy self-sufficiency project and is developed through budget support, in the form of profit-making project.
- As much hydraulic and tidal power as possible needs to be secured : Use Saemangeum tidal barrage, dam, reservoir, river, fish farm, sewage treatment plant, etc.

③ Bioenergy generation

- As biogas is flexible source power generation, maximum level of energization is required.
- An-aerobic digestion power generation using organic wastes including woods, grain by-products, livestock manure, and food waste.
- London Convention bans disposal at sea and direct landfill, which necessitates the energization. Paris Agreement mandates reporting to UN on the generation and treatment of GHG.
- As organic waste generates Methane, which has high GHG index, the entire quantity needs to be transitioned into energy.
- Potential volume of organic waste resources ranges 310K toe/year ~980K toe/year (New/Renewable Energy Whitepaper).
- MoCIE (Ministry of Commerce, Industry and Energy) targets 1.2M toe/year from organic waste resource, biomass, and landfill gas in 3020.

Issue : ① Ban on importing pellet, ② at domestic level, support bio-crops growing technology and guarantee purchasing price ③ introduce proof system for livestock manure treatment at farms

④ Battery

- EV (100kwh, 600km) 10million cars, counting in 10~20% V2G, the storage volume is 50kwh* 1 ~2 million cars

=50~100GWh

- After use battery (80% of initial capacity) from EV (100kwh, 600km) can be used for ESS , 1milion batteries per year 100kwh*0.8*1 million

=8GWh. When ESS reusable battery is used for 10 years it becomes 80GWh

- ESS 500GWh = $5billions . ESS price is $50/kwh, can be used for 5000 cycles. When PV price is $50/MWh, price of PV+ESS electricity is $60/MWh(pv50+ess10).

⑤ Demand Response : 20GW

- Usage time of deferrable load (freeze, air conditioning, heat storage, heat pump, etc) can be adjusted using the timed charging system (Time Of Use).
- Not only huge scale deferrable load but also small-scale deferrable load and ESS can play a role collectively in the Electricity market through an intermediary.
- Emergence and spread of Prosumer will require a market to sell the Electricity surplus, which will be the fundamental change of Electricity market.

- For Demand Reponse (DR) market to grow, a market environment that enables 2-way monitoring and control is a necessity.
- Electricity platform will change into the direction allowing free trade between the Electricity producer and consumer.

2.3 Implication and Policy Agenda

2.3.1 Implication from studies on scenario by Korea and other countries

- Consensus on phase-out of coal-fired generation in power generation is expanding.
- Emission intensity of Coal-fired generation is 2.7 times higher than that of Gas-fired generation. GHG reduction in power generation should start from the Coal-fired generation.
- Approach and strategy on the phase-out speed of Gas-fired generation are different per country.
- Heavy oil-fired generation takes up 2% of total electricity generation globally but is currently on decrease with the spread of micro-grids using renewable energy and battery.
- Europe, US, China, India, Japan chose to expand renewable energy, with priority on reducing the coal-fired generation.
- Importance of investment in flexible electronic power system to better respond to variability of renewable energy is emerging.
- Energy transition creates trade-offs. It may accompany political and social conflicts such as sunken asset, so the political/social consensus is critical, and creation of righteous transition fund is also important.
- Awareness on climate crisis and energy transition in Korea is relatively low compared to other major countries. Awareness and understanding on this issue is a precondition for full-scale response to climate change and required legislation.

2.3.2 Korea’s renewable energy supply strategy and policy agenda

1) Strategy of supplying renewable energy

- **Understanding global situation**

  - As shown in the RE100, the international trend to achieve 1.5℃ goal of Paris Agreement focuses on economics, trade and technology standard.

  - Korea should actively cope with the climate change, especially considering our export-driven economy.

  - Efforts to achieve 45% reduction by 2030 and zero emission by 2050 requested by international community (IPCC) to achieve 1.5℃ pathway is a must.

  - The end-use energy consumption reduction, efficiency improvement, renewable energy provision goal should be suggested, war against reducing fine dust and GHG announced, and ultimately the people’s efforts should be unified for the net zero emission of GHG by 2050.

  - Minimum level of renewable energy 4040, 5060 is an essential requirement to meet for the sustainable development of the country as a responsible member of the international society and a country with export-driven economy.

- **2050 GHG reduction target and strategy for Korea**

  - President Moon, Jae-In clearly suggested ‘Carbon neutrality by 2050’ as the goal of climate crisis management and goal at the National Assembly on 29 October. Subsequent detailed and practical roadmap and policy are required.

  - 2050 target should be clearly defined so that the goal of energy-saving and provision of renewable energy are set clearly as well.

  - Potential volume of renewable energy is over the energy consumption volume, at each country level.

  - Countries pursue decarbonization and energy independency through supply of renewable energy.

  - Korea selected solar PV, wind power, hydraulic power, and bioenergy as solution towards decarbonization and energy independency.

- Reduction of GHG should be clearly set as the top priority in government policies.
- Reduction of GHG is a process of setting new order in the transition from the fossil fuel to renewable energy, inevitably accompanying political and social conflicts.
- To create consensus, the direction of the national policy should be correctly set even through a national poll.
- 2050 goal level : 1.5℃ by UN, zero emission in 2050.
- 2030 goal level : Reduction by 45% (current goal of 3020 renewable energy is too low).
- Methodology (IRENA) : Energy saving, enhanced supply of renewable energy (6~7times faster than current speed).
- Ultimate end-use energy saving goal by 2050:30~50% reduction of end-use energy than 2017 level.
- Principle : Market principle, tax and subsidy are the tools to create the market.
- Priority : 1) withdraw fossil fuel energy subsidy, 2) normalize electricity price, 3) expand use of renewable energy.
- Achieve 90% by renewable energy supply by 2050.
- Develop detailed action play on scale of supply per renewable energy sources in Korea needs to be developed.

2) Policy agenda in electricity power sector

● **Upward adjustment of renewable energy-based electricity supply**

- Increase renewable energy-based electricity share to 30% by 2030, 60% by 2040, and 90% by 2050.
- Introduce government-led site planning and transmission line construction and private party's participation in power plant construction and operation.
- Restructure Electricity industry, nurture energy related new businesses (smart grid, DR, Prosumer, RD100).

- **Improvement of supply system**

  - Bidding for large-scale renewable energy (1MW and over) generation, and generation cost difference support system for small-scale (lower than 1MW) generation.

- **Location plan**

  - Establish public (central government/local government) renewable energy site plan, and electricity transmission plan.

  - Strengthen role of local governments in establishing energy policy : energy efficiency, licensing renewable energy.

  - Private party participate in competitive market of power generation and sales.

- **Expand electricity system flexibility**

  - Expand electricity system, power generation flexibility (pumped storage, bioenergy power plant), enhance flexibility in consumption (DR), and expand storage capacity (ESS).

- **Restructuring of Electricity market**

  - Principle : Renewable energy, provided by the nature should be open to anyone to produce and sell.

  - For the new business in energy sector (PPA, RE100, prosumer, V2G, DR, smart grid) market is to function, real-time electricity market, 15 minutes /5 minutes unit electricity trade should be allowed.

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Research on Strategy and Policy by Sector for Korea 2050 Carbon Neutrality

3

Industry Sector

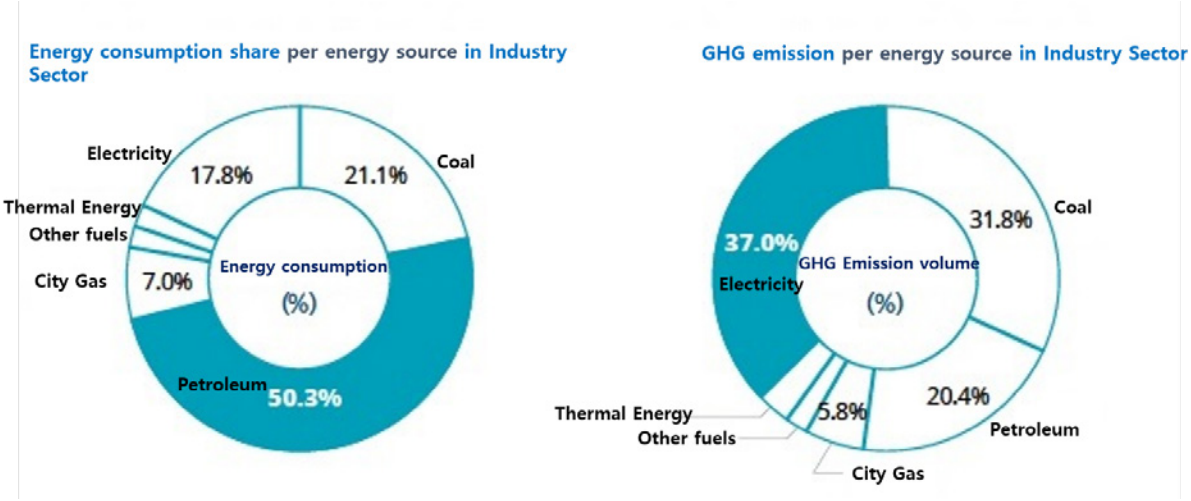
3.1 GHG Emission Status and Key Characteristics in Industry Sector

3.1.1 Status of GHG emission

1) Based on statistics on energy consumption and GHG by industry sector by MoTIE and Korea Energy Agency[6)7)]

- As of 2017, the share of energy consumption in industry sector by source of energy can be listed in the order of petroleum (50.3%), coal (21.1%), electricity (17.8%), and city gas (7.0%). On the other hand, the share of GHG emission is listed in the order of electricity (37.0%), coal (31.8%), petroleum (20.4%), and city gas (5.8%) (Figure 3-1).
  - By detailed source of energy, Naphtha accounted for the highest portion of the total energy consumption at 43.4% (86.2% of the petroleum use), followed by soft coal at 20% (95.7% of coal use).

<Figure 3-1> Status of energy consumption and GHG emission by source of energy in industry sector



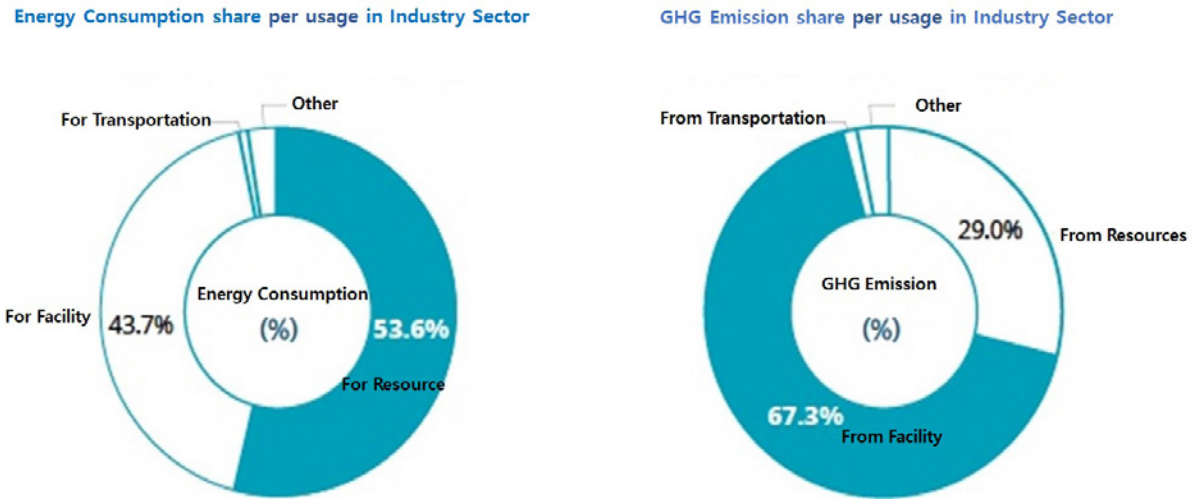
Source : MoTIE, 2018 Industry sector energy use and GHG emission statistics, recharted from figures on page 57-59

6) MoTIE, 2018 Industry sector energy use and GHG emission statistics, page 56-75

7) Annual study by MoTIE and Korea Energy Agency. Statistics for year 2017are estimated based on the sample survey (23.9% of population). 2017 energy consumption is estimated to 129.4M toe, GHG Emission to 332.3M CO_2-eq.

- Energy consumption usage can be roughly divided as for resource (53.6%) and for facility (43.7%). More than double of GHG is emitted when energy is consumed for facility (67.3%) than as material (29.0%) (Figure 3-2).

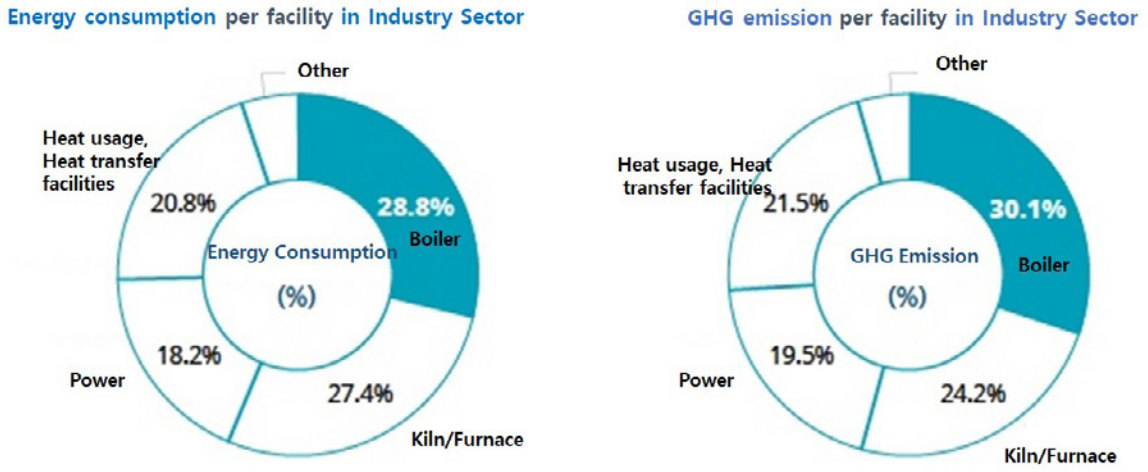
<Figure 3-2> Status of energy consumption and GHG emission by usage in industry sector



Source : MoTIE, 2018 Industry sector energy use and GHG emission statistics, re-charted from figures on page70-71)

- Both energy consumption volume and GHG emission show the same order of share when used for facility : For boiler, kiln/furnace, heat usage and heat transfer facilities, and power. (Figure 3-3)
  - When used for boiler, main sources of energy are Petroleum (39.1%), coal (38.2%), City Gas (19.2%), and the main sources of energy with most GHG Emission are coal (53.2%), petroleum (36.6%), and City gas (8.0%).
  - When used for kiln/furnace, main sources of energy are Petroleum (43.4%), City gas (17.8%), and Coal (13.6%), while the main sources of energy with most GHG Emission are Petroleum (59.9%), Coal (12.2%), and City gas (8.7%).

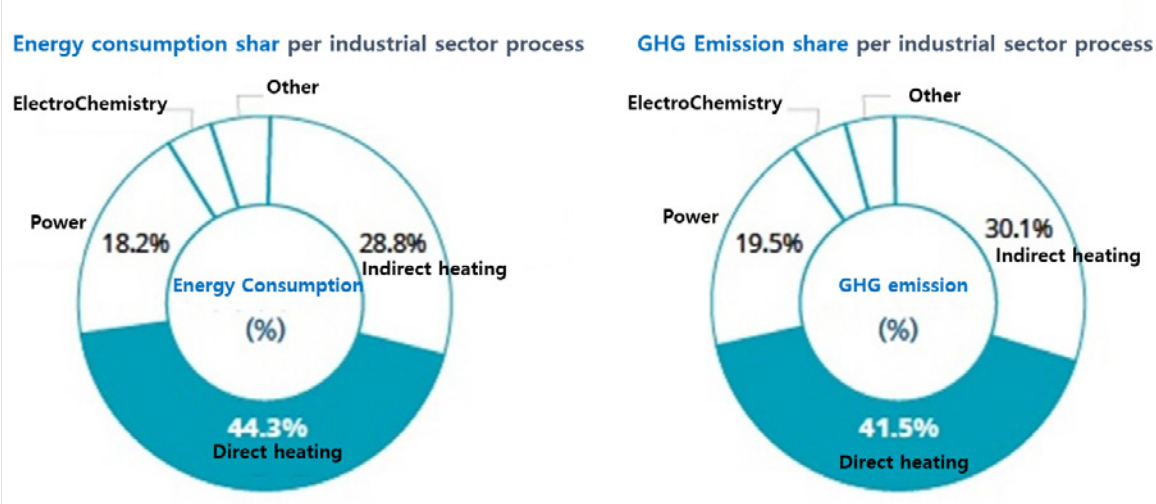
<Figure 3-3> Status of energy consumption and GHG emission by equipment in industry sector



Source : MoTIE, 2018 Statistics on industry sector energy use and GHG emission, re-charted from figures on page 72-73

- Both energy consumption volume and GHG emission show the same order of share from the process perspective : direct heating, indirect heating, and power (figure 3-4).
  - When used for direct heating, main sources of energy are petroleum (44.1%), Electricity (21.1%), City gas (14.0%), and coal (8.3%) while for indirect heating the main sources of energy are petroleum (39.1%), coal (38.2%), and city gas (19.2%). As for the power, more than 90% of energy consumption and GHG emission is from Electricity .

<Figure 3-4> Status of energy consumption and GHG emission by per process in industry sector



Source : MoTIE, 2018 Industry sector energy use and GHG emission statistics, re-charted from figures on page 74-75

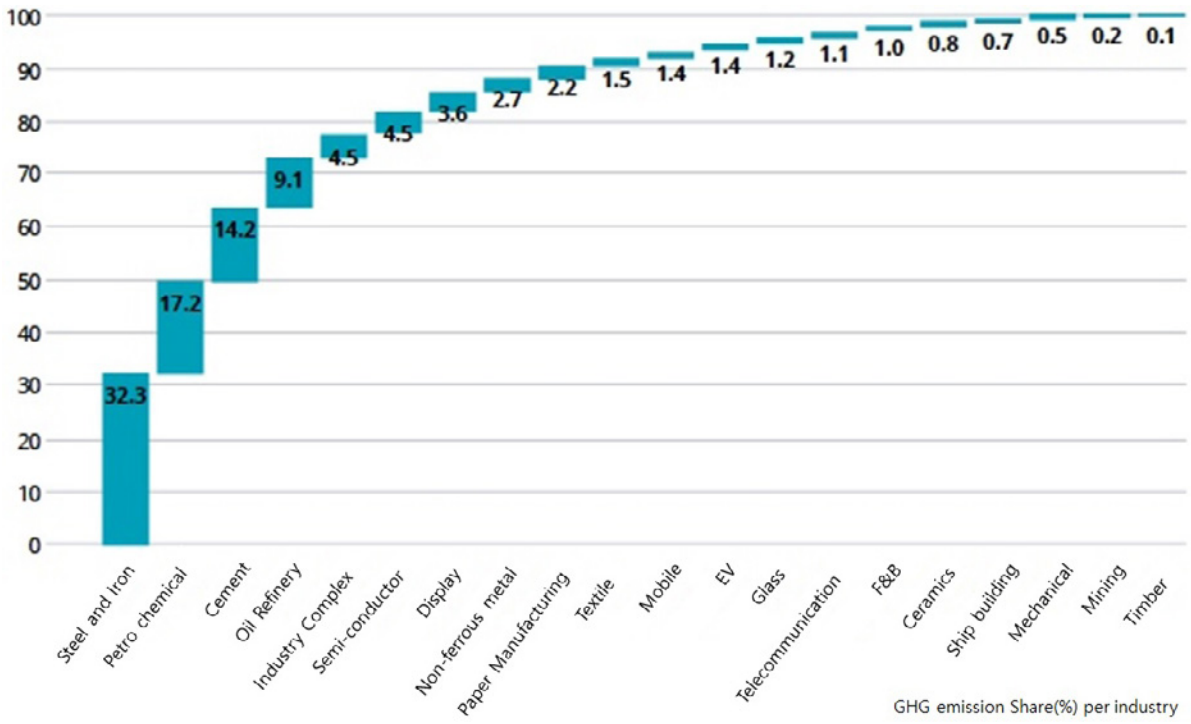
2) Based on emission volume statistics in GHG Emission Trading Scheme(K-ETS) statement by National GHG Management System (NGMS)[8)]

- As of 2017, gross GHG emission from industry sector (381.3 M CO_2-eq.) represents 54% of the national gross emission (709.1 m CO_2-eq. ton).
- Total emission volume by the business entities eligible for allocation of K-ETS stands at 317.2 million CO_2-eq.[9)] which is about 45% of National gross emission, and 83% of total industry sector emission.
    - Steel and Iron (32.3%), petrochemical (17.2%), cement (14.2%), oil refinery (9.1%), industrial complex (4.5%), and semiconductor (4.5%) are the businesses with most emission. Petrochemical (28.1%), Steel & Iron (18.8%), oil refinery (9.7%), cement (6.7%), semi-conductor (6.3%), industrial complex (5.0%) are the businesses that consume most energy (Figure 3-5).
    - GHG emission from 6 major businesses account for about 37% of national gross emission, 68% of industry sector emission, and 82% of emission by companies eligible for allocation of K-ETS.
- 25 companies with most GHG emission (2015-2018 average) recorded about 220million ton, which is equivalent to about 31% of national gross emission in 2017, 58% of total industry sector emission, or about 70% of business entities eligible for allocation under K-ETS (Figure 3-6).
    - POSCO and Hyundai Steel in Steel and Iron business were the biggest emitters, taking up about 13% of national gross emission, 24% of industry sector emission, or 29% of K-ETS allocation eligible companies.
    - Emission from the 10 biggest emitters (POSCO, Hyundai Steel, SsanYong CNE, Samsung Electronics, GS Caltex, S-Oil, LG Chem, SK Energy, Sampyo Cement, LG display) represents 22% of national gross emission, 41% of industry sector emission, or about 50% of K-ETS allocation eligible companies.

8) The weakness of K-ETS is that the scheme does not count the emission not included in the list of 'Business entities eligible for Allocation' (GHG emission was over 125K ton past 3 years' average or over 25K ton). However, the information is highly reliable in that the emission from the companies on the list consist 83% of the Industry sector, and that the emission information is validated by the third-party institution and reviewed by the Government.

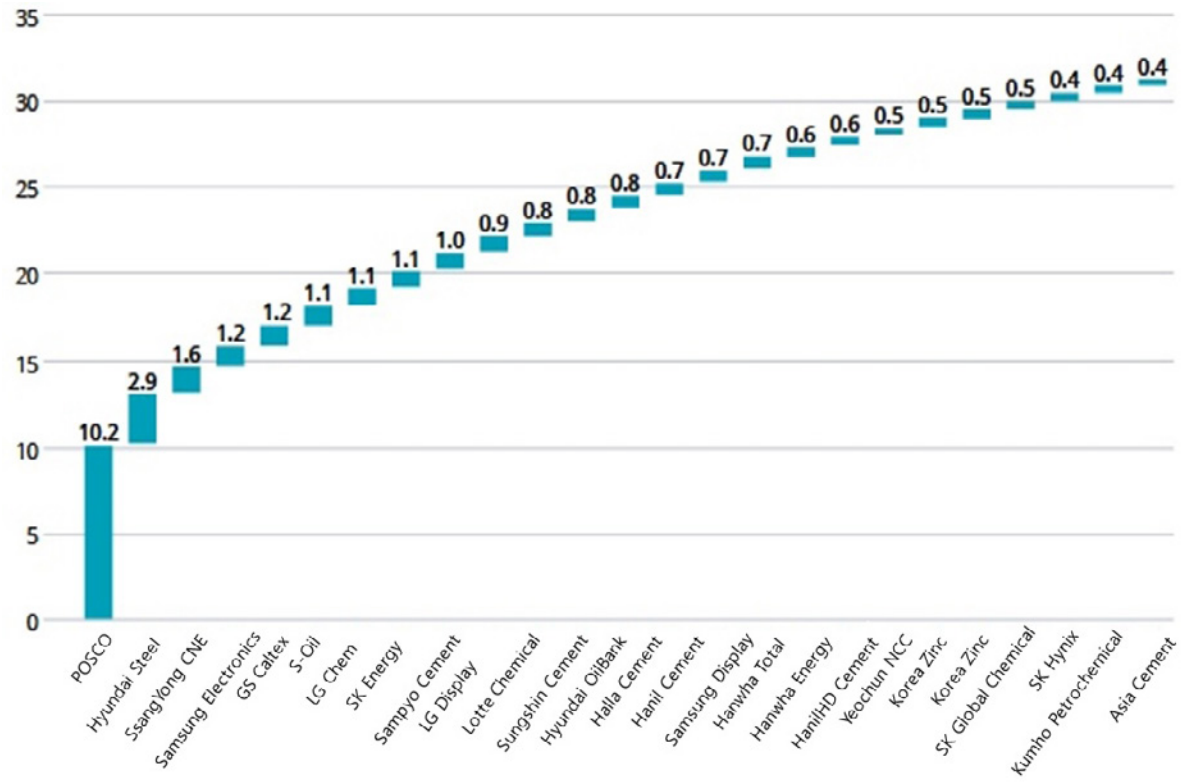
9) 2050 Low Carbon Society Vision Forum (2020), 2050 LEDS report page 67

<Figure 3-5> GHG emission share by business (as of 2017)



Source : Re-charted from key information on 2017 NGMS statement

<Figure 3-6> GHG emission share by 25 biggest emitters in National Gross GHG Emission



Share by company in National Gross GHG Emission (%)

Source : Re-charted from key information on 2017 NGMS statement

3.1.2 Key characteristics

● Continued increase of GHG emission

- The main reason is, during the period of 2000~2017, the national end-use energy consumption recorded average increase of 2.7% per year, while the industry sector recorded average increase of 3.2% per year.
  * Commercial (2.7%/year increase), Transportation (1.9%/year increase), Residential (0.4%/year increase)

● Emission concentrated in certain industry and company

- Emission from 6 businesses represents about 37% of national gross, or 68% of national industry sector.
- 2 biggest emitters, POSCO and Hyundai Steel in Steel and Iron business emitted about 13% of national gross emission, or 24% of total industry level emission.
- Total emission from 10 biggest emitters is about 22% of national gross emission, or 41% of industry sector emission.

● Emission concentrated in certain activity and facility

- More than 70% of GHG emission is from energy usage, and most of the remaining emission is from processing (about 26%).
- In terms of energy usage, 45% of emission is from stationary combustion, while about 25% is from external electricity.[10]
  ☞ When external electricity (25%) is excluded, the share of emission from stationary combustion becomes quite high in the Industry Sector ⇒ by-product gases (18%), by-product fuel oil (11%), coal (10%), and LNG (5%)
- More than 90% of process related emission is from 5 businesses : Steel and iron (41%), cement (29%), oil refinery (12%), semi-conductor (5%), and display (4%)
  ☞ The ratio of emission from process at each business of the total industry sector emission is high in steel and iron (11%), cement (7%), oil refinery (3%), semi-conductor· display (2%).[11]

10) By-product gases mostly used at Steel and Iron business represents the highest emission share (about 39%) among the stationary combustion source of energy, followed by by-product fuel oil consumed about 93% by Refinery/petrochemical (about 25%), coal used for cogeneration facility supplying heat to industrial complex, cement and petrochemical industry (about 22%), and LNG (11%).

11) 94% of GHG emission from Steel and iron industry is from integrated steel mill process by POSCO and Hyundai Steel using soft coal as source of energy. From the cement industry, most of emission is generated from the process of limestone calcination. 8 cement producers represent 95%, 12 limestone producers represent the remaining 5%. As for the refinery business, GHG is mostly emitted from hydrogen manufacturing or catalytic regeneration process. (However, in case of oil-refinery, the GHG emission is not included in the National gross emission, as IPCC guideline does not include the calculation formula for the process.

- As of 2017, industrial engines, fans, pumps, etc. consumed over 25% of gross Electricity demand (MoTIE, 2019).[12]

High ratio of energy usage in end-use energy consumption

- The ratio of energy consumed as industry sector material of the total end-use energy consumption was 48.8% (as of 0215), which is significantly higher than the OECD average of 29.5% (MoTIE, 2019).[13]
- (As of 2017), Naphtha takes up 53% of total petroleum consumption, and is used as material for industry sector. (MoTIE, 2019).[14]

12) MoTIE (2019), The 3rd Energy Master Plan (Page 35)

13) MoTIE (2019), The 3rd Energy Master Plan (Page 21)

14) MoTIE (2019), The 3rd Energy Master Plan (Page 58)

3.2 Review of Long-Term LEDS Scenario and Reduction Measures in Korea and in Other Countries

3.2.1 Korea' s scenario and reduction measures

1) 2050 LEDS (Long-term low greenhouse gas emission development strategy)

- **5 scenarios covering all sectors through bottom-up approach[15)]**
  - Classify 35 reduction measures in 8 sectors (transition, industry, transportation, building, farming, waste, omission, forestry) into 3 groups (High, Medium low)
  - Develop 3 national scenarios with simple sum, using 3 criteria (Plan 1, 3, and 5)
  - Develop 1 scenario by selecting 35 reduction tools from medium and high (Plan 2)
  - Develop 1 scenario by selecting 35 reduction tools from low and medium (Plan 4)

- **Scenario for industry sector ranges from minimum 11.1% (Plan 5) to maximum 65.5% (Plan 1), which is relatively lower reduction rate target compared to national goal or other sectors.**
  - 2050 LEDS suggested industry sector GHG emission reduction from 2017 industry sector, ranging from maximum of 170.3 million ton (Plan 1) to minimum of 48.9million ton (Plan 5) (Table 1).

[Table 3-1] 2050 LEDS industry sector reduction target plans

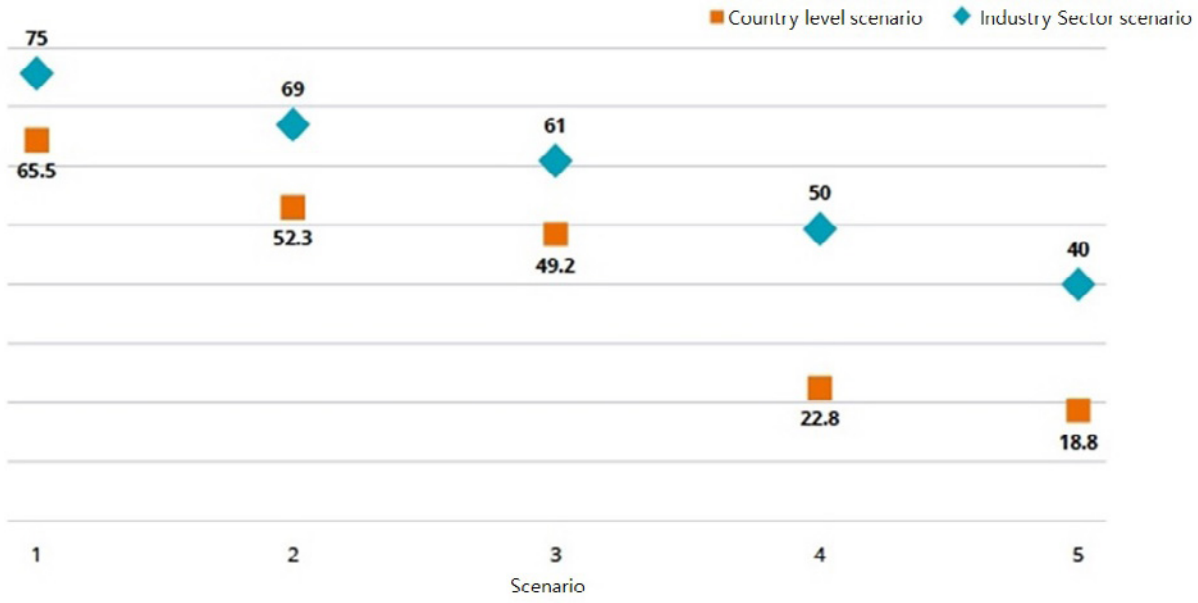
Item		2017 status	2050 goal				
			Plan 1	Plan 2	Plan 3	Plan 4	Plan 5
Nation-wide	Emission	709.1	178.9	222.0	279.5	355.9	425.9
	Volume	-	530.2	487.1	429.6	353.2	283.2
	Rate	-	75%	69%	61%	50%	40%
Industry sector	Emission	259.9	89.7	124.1	132.2	200.7	211.1
	Volume	-	170.3	135.8	127.8	59.3	48.9
	Rate	-	65.5%	52.3%	49.2%	22.8%	18.8%

Source : 2050 Low carbon society vision forum (2020), 2050 LEDS page 23 reproduced into a table

15) 2050 nation-wide reduction target is: Plan 1 (75%), Plan 2 (69%), Plan 3 (61%), Plan 4 (50%), and Plan 5 (40%).

- Compared to nation-wide reduction goal, the industry sector's target reduction rate is lower by 9.5% (Plan 1) ~ 27.2% (Plan 4) (Figure 3-7).
- Reduction target is lower than other sectors (transition, transportation), considering the industrial structure with emphasis on exporters with large energy consumption and low assessment on current political support for GHG emission reduction technology and maturity of the technology.
- This is in line with the significant difference between national reduction target and industry sector reduction rate in Plan 4 and 5.

<Figure 3-7> Comparison on 2050 LEDS national scenario and industry sector scenario



Source : 2050 Low Carbon Society Vision Forum (2020), re-charted from page 23, 2050 LEDS

● Reduction measures

- There are largely 7 measures for industry sector GHG emission reduction.
- Feasibility of 7 measures are compared based on policy index, and projection index (reduction impact, technological maturity, reduction cost) (Table 2).
- Measures with higher feasibility are grouped into measures for equipment efficiency improvement and reduction of emission from the industry process.

[Table 3-2] Comparison on 2050 LEDS industry sector GHG emission reduction measures

GHG Emission reduction tool	Policy index	Projection index		
		Reduction impact	Technology maturity	Reduction cost
Hydrogenation technology and recycle of resources	None	High	Medium	Unfavorable
Transition to new material and expansion of high value-added products	None	High	Low	Unfavorable
Equipment efficiency improvement	Core	High	High	Favorable
Smart plant and industrial complex	Core	Medium	High	Average
Use of CCS	General	Medium	Low	Low
Use of low carbon fuel / material	General	Low	High	Favorable
Reduction of emission from industry process	Core	High	High	Favorable

Source : 2050 LEDS p.68 reformatted

* Policy index is to illustrate the level of supports available in terms of policy, system, and budget, classified as core / general / none, with the core classification having higher possibility of being realized. Reduction impact and the technological maturity of the projection index are classified as high/medium/low, while the reduction cost is classified as favorable/unfavorable/average. Even though the reduction measure is classified as general or none in terms of policy index, if all three projection indices are assessed to be high, then it would be classified to have high feasibility. Reduction measures with general policy index general, and with 2 high projection indices are also classified to have high feasibility.

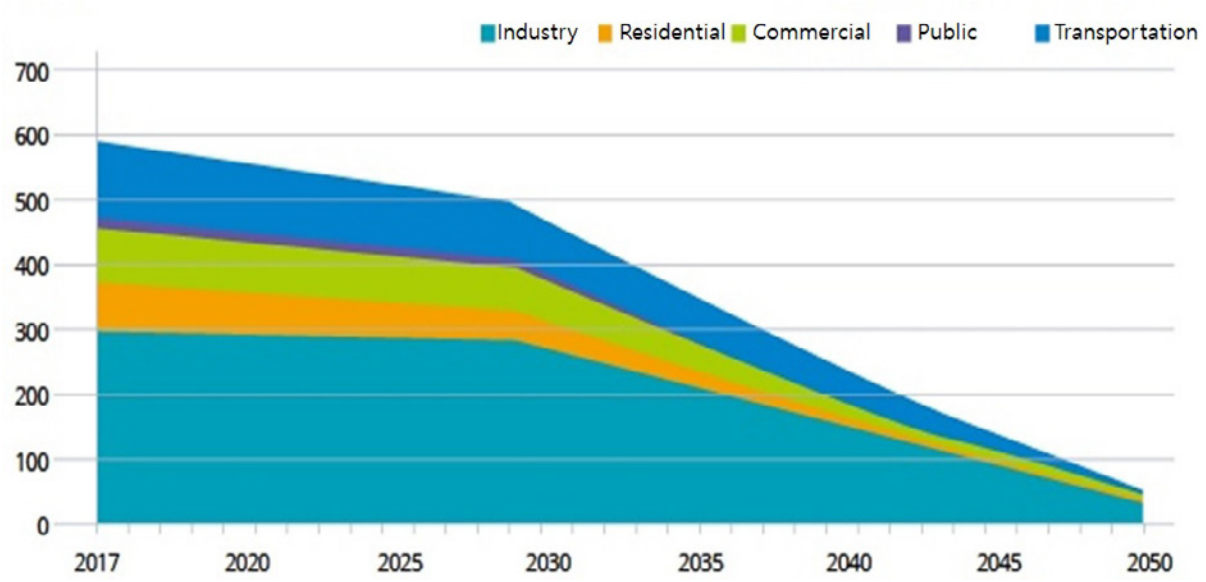
2) Study by Lee Chang-Hun et al. (2019)[16)]

- **Suggested 'In-depth energy transition' scenario, setting zero CO_2 emission by 2050 to achieve 1.5℃ goal (Figure 3-8)**
  - The goal is to reduce CO_2 emission of 592milion ton (as of 2017) by 9.5% to 5million ton in 2050, and offset the 50millin ton through GHG reduction support projects to the developing countries.
  - Industry Sector should reduce the CO_2 emission by 88.4%, from 298.2 million ton in 2017 to 34.7mili ton in 2050.

16) Lee, Chang-Hun et al. (2019), Sustainable development and transitions in Energy and Industry: focusing on the climate change policy goal of meeting 1.5oC pathway, NRC collaborative research series

- **The study suggests the reduction methodology that can be applied to overall Industry processes, challenges to in-depth reduction focusing on the steel & iron and petrochemical business, and 2050 vision.**
  - Replace low-temperature boiler or fuel for power engine, commonly used for industry processes with renewable energy-based electricity.
  - Suggest decarbonization in steel and iron business, and petrochemical industry (Table 3-3).

<Figure 3-8> 2050 In-depth transition scenario



Source : Lee, Chang-Hun et al. (2019), Sustainable development and transitions in Energy and Industry: focusing on the climate change policy goal of meeting 1.5oC pathway, NRC collaborative research series, p.63

[Table 3-3] Challenges against transition in Korea's steel & iron and petrochemical business, and key initiatives to achieve 2050 goal

	Steel & Iron	Petrochemical
Challenges	• Insufficient room for additional energy efficiency improvement • Introduction of New technology/process is difficult considering remaining service life of already invested GHG reduction facility. • Manufacturing facility and process are integrated steel mill structure, making partial replacement impossible. • Risk of introducing unvalidated facility is too high, considering the long investment recovery period.	• Insufficient room for GHG reduction capability from inside. • High investment risk for incomplete commercialization of reduction technology • Marginal abatement cost of applicable technology is high, but • the reduction capacity of the applicable technology is low.
Key initiatives	• Lay foundation inducing the introduction of bold decarbonization process technology, considering 30 years from now. • Consistent and enhanced Government's commitment on applying GHG external cost. is required, considering the characteristics of process industry requiring large scale, irreversible investment. • Large scale R&D projects for technology that will lead the future Steel & Iron market need to be developed and reflected in the national R&D roadmap • Incentives including tax benefit for voluntary investment in decarbonization technology by companies should be provided regardless of the size of the company. • Green hydrogen development related collaboration between the public and the private sectors should be enhanced so that decarbonization technology including hydrogen reduction Iron and steel making process.	• Policies focusing on 'reusing the high-temperature from the facility, 'use of high energy-efficient equipment', 'process efficiency improvement' are effective. • Consistent and enhanced Government's commitment on applying GHG external cost, etc. is required, considering the characteristics of process industry requiring large scale, irreversible investment. • Bio-fuel transition technology developments need to be actively monitored and reflected in the national R&D Roadmap. • Tax benefit on technology investment and R&D investment in high energy efficiency facility should be expanded.

Source : Lee, Chang-Hun et al. (2019), page 101-104 reformatted.

3.2.2 Other countries' scenario and reduction measures

1) DG CLIMA (2019)[17)]

- **ICF and Fraunhofer ISI (Institute for Systems and Innovation Research) suggested 2050 emission scenario for EU-28 industry sector using the bottom-up model FORECAST**

  - Using technological innovation as a criteria, differentiated scenarios with less than 80% reduction (2 scenarios) and with more than 80% reduction scenarios (6 scenarios) are developed (compared to 1990).
  - 2 scenarios with less than 80% reduction are based on the use of best available technologies; and they are reference scenario (Ref) and BAT scenario (BAT), which applied enhanced conditions compared to that of the reference scenario (100% use of best available energy efficiency technology and rapid application of recycling).

    ※ Reference Scenario is to reduce 12% compared to 2015 (45% over 1990), while BAT Scenario is to reduce 35% compared to 2015 (59% over 1990)

  - Total 6 scenarios with over 80% reduction composed of 4 scenarios with 4 or more levels of technology maturity of 4 additional reduction technology applied to BAT scenario, and 2 scenarios where the 4 technologies are combined considering the cost and reduction level.

    ※ 6 scenarios with over 80% reduction consists of CCS, CleanGas, BioCycle, Electricity , Mix80, and Mix95.

[Table 3-4] 2050 Industry GHG emission reduction scenario by DG CLIMA

Scenario	GHG Emission (mT CO_2e)		Reduction ratio (%)	
	2015	2050	Compared to 2015	Compared to 1990
1 Ref	761	665	-12	-45
2 BAT	761	493	-35	-59
3a CCS	761	157	-79	-87
3b CleanGas	761	216	-72	-82
3c BioCycle	761	245	-68	-80
3d Electric	761	255	-66	-79
4a Mix80	761	221	-71	-82
4b Mix95	761	63	-92	-95

Source : DG CLIMA(2019), Industrial Innovation: Pathways to deep decarbonization of Industry.
Part 2: Scenario analysis and pathways to deep decarbonization, page 44 Table 3.1

17) Report titled 'Industrial Innovation: Pathways to deep decarbonisation of Industry. Part 2: Scenario analysis and pathways to deep decarbonisation' submitted to Directorate-General for Climate Action (DG CLIMA) under EU by ICF Consulting Services Limited and Fraunhofer Institute for Systems and Innovation Research (ISI)

● 6 scenarios with over 80% reduction (compared to 1990)

- CCS is added to BAT Scenario for the CCS Scenario.

  ※ It is reasonable in terms of cost, but potential for commercialization is not clear. Without any system changes, significant amount of locked-in risk exists.

- Green gas Scenario is the combination of BAT Scenario technology and Green Hydrogen, synthetic methane.

  ※ The risk is the potential for high energy cost.

- Bio-economy and Circular economy scenario is the combination of BAT technology using biomass as fuel and material, comprehensively adding the circular economy model.

  ※ This could be relatively cheaper than other scenarios, but it is unclear whether the required amount can be secured.

- Electric Scenario is developed by adding overall electrification to technologies used in the BAT Scenario.

  ※ This scenario requires significant amount of change in manufacturing system, and poses great burden to power generation sector.

- By combining the GHG emission reduction technologies applied in the above 4 scenarios, two scenarios targeting 80% and 95% reduction compared to 1990 level are suggested (Figure 3-9).

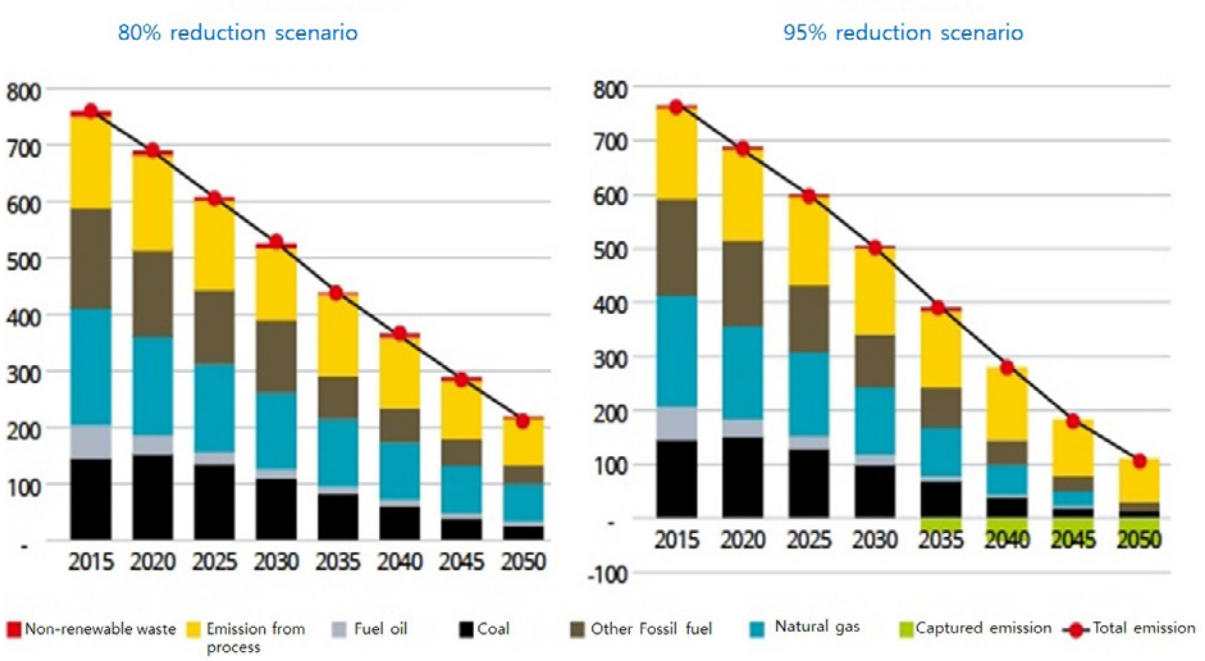
  ※ Maximum potential rate of 80% reduction scenario is 82%, assuming the exclusion of CCS and current level of biomass usage. (This scenario is better in terms of cost and lock-in effect than other 4 scenarios focusing on specific technologies.)

  ※ 95% reduction Scenario allows CCS in the remaining process emission, uses synthetic methane in the gas network, and adds early phase-out of fossil fuel-based steam generation and 100% process innovation (more cost added than the +80% reduction scenario). Energy cost in 2050 is estimated to be EUR 60billion per year, through intensive transition to synthetic methane, hydrogen, and electricity.

  ※ 95% reduction scenario assumes reduction in steel & iron (96%), petrochem (91%), and cement (86%).

<Figure 3-9> EU-28 industry sector 2050 GHG reduction scenario

- **Major reduction tools (Table 3-5)**



Source : Industrial Innovation Part 2: Scenario analysis and pathways to deep decarbonization by Fleiter et al (2019), Re-charted from p.41~43 Figure 3.7, Figure 3.8

- In case of Energy efficiency, measures with less than 10 years of investment recovery are used.
- Carbon cost should meet EUR100 /ton in 2030, EUR 200 /ton in 2040. Carbon price is applied to induce the fuel transition in the industries and companies not included in the Emission Trading Scheme.
- Financial support of EUR20/MW, and EUR100/MW for the electrification of heat is required for heat pump and electric steam boiler, respectively.
- All fossil fuel-based generators to be phased out irrespective of remaining equipment life between 2040 -2050.
- R&D and commercialization of low carbon-based new processes (low carbon-based cement, hydrogen-based steel & iron) are required.
- Raw material efficiency and circular economy need to be improved.

[Table 3-5] Reduction options required for 80% reduction scenario and 95% reduction scenario by major business

Businesses	Reduction rate	Process improvement	Fuel transition	CCS	Recycle and reuse	Raw material efficiency improvement and replacement
Steel & Iron	80%	Innovative energy efficiency (TRL level 4 or more) - NNSC* - Top gas recycling	H-DR, plasma, electrolytic iron (80%)**	N/A	Increase flat steel product share by using high-performance electric furnace	- Replace Steel & Iron to biomass based product - Use high efficiency material
	95%		H-DR, plasma, electrolytic iron (100%)**			
Petrochem	80%	Innovative energy efficiency (TRL level 4 or more) chlorine: ODC Naphtha catalyst decomposition, elective membrane	Electric boiler Use of hydrogen from ethylene, ammonia, methanol (80%)	N/A	Rapid increase of plastic reuse rate	Replace plastic with bio-plastic at a rapid rate, reduce fertilizer demand, enhance material efficiency
	95%		Electric boiler Use of hydrogen from ethylene, ammonia, methanol (100%)			
Cement	80%	Innovative energy efficiency (TRL level 4 or more) Low carbon cement carbonized cement / concrete	Price-based fuel transition	N/A	Recycle / reuse concrete in cement manufacturing	Efficient use of concrete, biomass based concrete replacement, carbon steel concrete
	95%		Clean gas	Applied to limestone and existing clinker		

* Thin slab casting (Near net shaping casting)
** Based on crude steel production capacity

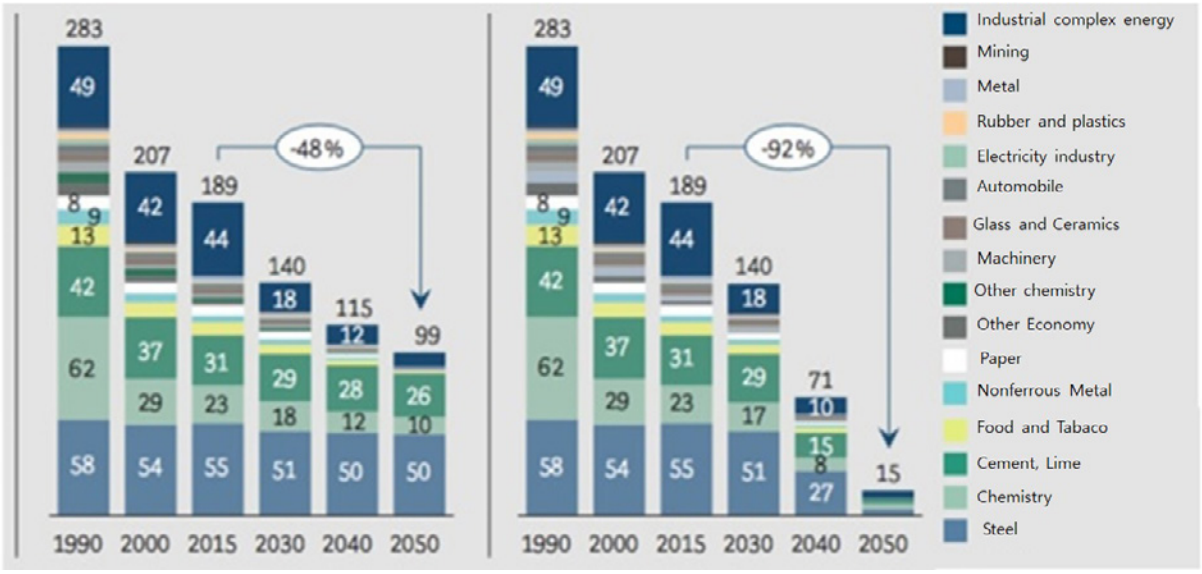
Source : Industrial Innovation: Pathways to deep decarbonisation of Industry. Part 2: Scenario analysis and pathways to deep decarbonisation by DG CLIMA(2019), re-tabled by author based on Figure 1-4, 1-5, 1-6 on pages 7-8

2) Germany's BDI (2018)

● Overview

- The report (titled: Klimapfade für Deutschland) was issued in 2018, as a result of analysis by The Boston Consulting Group and Prognos on the project launched by the Federation of German Industries (BDI) and recommends the 2050 Emission reduction scenario and reduction methods for overall economy and for each business in the industry sector of Germany.
- Industry sector GHG emission in Germany is 189 million ton (as of 2015), taking up 21% of national emission.
- Steel & Iron, Cement, and Petrochemical are high GHG emitters, recording 29.1%, 16.4%, 12.2% of industry total emission, respectively. (Emission from 3 businesses represents 57.7% of industry sector GHG emission).
- At country level, there are 2 reduction scenarios targeting 80% and 95% reduction compared to 2015 level by 2050.

<Figure 3-10> 2050 GHG reduction scenario by industry sector in Germany



Source : Klimapfade fürDeutschland by Gerbertet al (2018), recharted from p.134

● Industry sector scenario

- Industry sector reduction of 48% (80% reduction scenario), or 92% (95% reduction scenario) of 2015 level by 2050 are projected (figure 3-10).

  ※ Baseline scenario projected for 22% reduction

- 80% reduction scenario targets to reduce 48% (of 2015 level) in industry sector GHG emission

by 2050 (189 million ton CO_2 equivalent ⇒99 million ton CO_2 equivalent), composed of relatively achievable reduction tools in terms of cost and technology.

※ **End-use energy consumption is assumed to decrease by 20% from 2.5 EJ to 2 EJ over the same period.**

- Under the 95% reduction scenario, 92% GHG emission reduction (of 2015 level) by industry sector is required by 2050. (189 million ton CO_2 equivalent ⇒15 million ton CO_2 equivalent).
- Under the 80% reduction scenario, it is assumed that Petrochemical achieves more than industrial average reduction (56%), but the Steel & Iron (9%) and Cement (16%) reduction potential is projected to lower level.

● Major tools of reduction

- Energy efficiency, minimum use of coal (replaced with low-carbon electricity), use of biomass for mid/low temperature heat (<500℃) source were recommended for major tools of 80% reduction Scenario (48% reduction in industry sector).
- CCS of process emission residuals, use of recycled energy gas using the PtG (Power to Gas) technology, and use of bio-gas such as Natural gas from fossil fuel for high temperature heat (>500℃) are assumed necessary for 95% reduction scenario (92% reduction in industry sector).

※ **Level of energy efficiency assumed to the same level as used in 80% reduction plan.**

3) Department of Energy and Climate Change in UK (2015)

● Overview

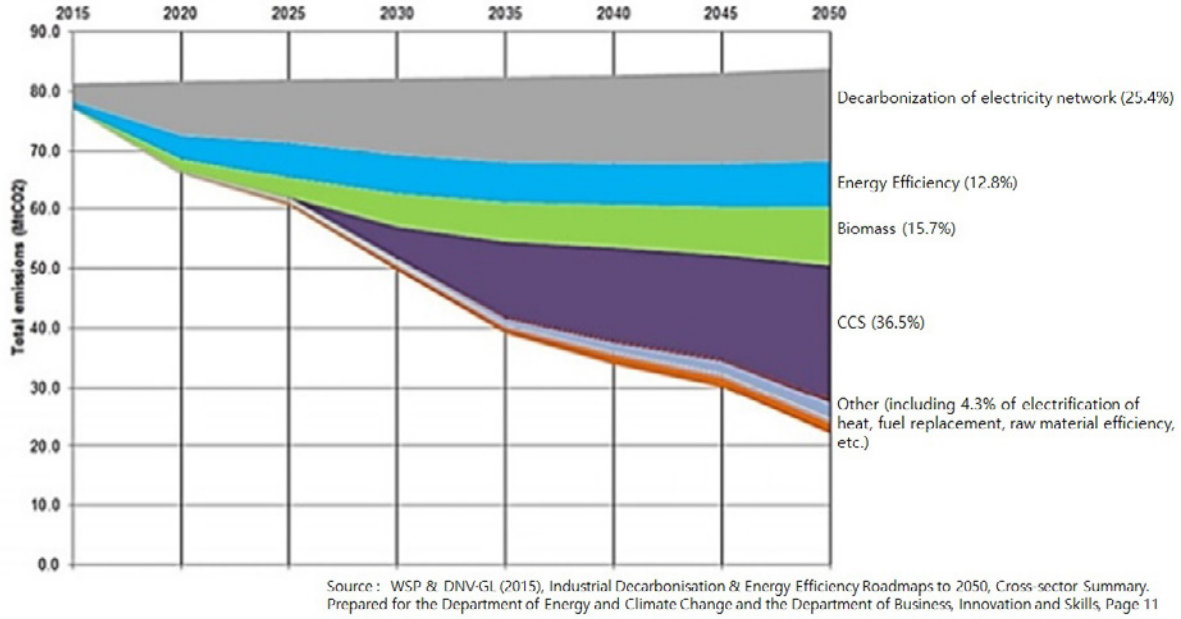
- The report is issued jointly by the WSP and DNV·GL, for the project sponsored by Department of Energy and Climate Change and Department of Business, Innovation and Skills of UK in 2015. The report suggests the decarbonization scenario and reduction tools for industry sector of UK. (report title: Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050).

● Reduction scenario and major tools

- Based on the combination of reduction tools, coverage and level, (1) BAU pathway, (2) intermediate pathway, and (3) Max Tech pathway are recommended.
- BAU pathway is a scenario for 28.4% reduction of CO_2 from 81milion ton in 2012 to 58 million ton in 2050. Drastic decarbonization of electricity network, energy efficiency, increased use of biomass, CCS represents 61.6%, 23.0%, 7.3%, 2.6% of reduction.

- Intermediate pathway is a scenario for 48.1% reduction of CO_2 from 81milion ton in 2012 to 42 million ton in 2050. Decarbonization of electricity network (37%), energy efficiency and heat recovery technology (23%), CCS (18%), and use of biomass as fuel and material (13%) composes the scenario.
- Max Tech pathway is a scenario for 72.8% reduction of CO_2 from 81milion ton in 2012 to 22 million ton in 2050. CCS (37%), decarbonization of electricity network (25%), use of biomass as fuel and material (16%), and energy efficiency and heat recovery technology (13%) are suggested as major tool for reduction (Figure 3-11).

<Figure 3-11> Max Tech reduction scenario for 2050 GHG reduction for UK industry sector



Source : WSP & DNV-GL (2015), Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050, Cross-sector Summary. Prepared for the Department of Energy and Climate Change and the Department of Business, Innovation and Skills, Page 11

● Reduction plan and reduction rate for businesses with high emission

- Reduction tools that can be commonly used for Steel & Iron, Cement, Petrochemical are improvement of energy efficiency, and raw material efficiency, which would reduce only 15% (Steel & Iron), 12% (Cement), and 31% (Petrochem), respectively.
- For drastic increase of reduction volume, CCS and increased use of biomass are suggested to be critical, with the expectation of 60%, 62%, and 88% reduction in Steel & Iron, cement, and petro chemical businesses, respectively (Table 3-6).

[Table 3-6] Reduction plan and reduction rate for businesses with high emission

Business	Reduction plan and reduction rate (%)	Total reduction rate (%)[18]
Steel & Iron	Plan A: Energy and raw material efficiency, fuel replacement	15%
	Plan A + CCS Max Tech (45%)	60%
Cement	Plan A: Energy efficiency, alternative cement	12%
	Plan A + biomass (28%), fuel replacement, CCS Max Tech	33% (CCS not included) 62% (CCS included)
Petrochem	Plan A: Energy efficiency, biomass, fuel replacement, CCS	31%
	Plan A + biomass (37%), CCS (43%) Max Tech	79% (biomass not included) 88% (biomass included)

Source : reformatted from this report p.14~19

18) Total reduction rate does not include the volume through decarbonization of electric network. When it is included additional 6.5Million ton CO_2 reduction will be possible.

3.3 Implications and Recommendation

3.3.1 Implications from the review of scenarios in Korea and in other countries

1) Net zero GHG emission in industry sector by 2050 is difficult but not impossible!

- Global consulting companies analyzed the reduction scenarios of the EU, Germany, and UK, and projected that industry sector GHG emission can be reduced by 90% by 2050. (Table 7)
  - Global consulting firms, ICF Consulting Services Limited and Fraunhofer Institute for Systems and Innovation Research (ISI) that submitted report to Directorate-General for Climate Action (DG CLIMA) under EU covering all of the EU member countries analyzed that 92% of GHG reduction would be achieved by 2050.
  - The Boston Consulting Group and Prognos, in performing a project by the Federation of German Industries (BDI), analyzed that 92% of GHG emission can be reduced in Industry sector of Germany by 2050.

[Table 3-7] Summary of 2050 industry sector reduction scenario

Research team	Region	Scenario		Note
		BAU(Min)	Max	
2050 Low Carbon Society Vision Forum (2020)	Korea	18.8% (of 2017level)	65.5% (of 2017level)	
Korea Environment Institute (2019)	Korea	-[19]	88.4% (of 2017level)	Included CO_2 only
ICF & Fraunhofer ISI (2019)	EU	12% (of 2015 level)	92.0% (of 2015 level)	
Boston Consulting Group & Prognos (2018)	Germany	22% (of 2015 level)	92.0% (of 2015 level)	Included CO_2 only
WSP & DNV·GL (2015)	UK	28.4% (of 2012 level)	72.8% (of 2012 level)	

Source : Developed by author

19) Lee Chang-Hun et al (2019) suggested in-depth energy transition scenario that combined methodologies that are feasible in terms of technology and policy to achieve net 0 CO_2 emission by 2050. In particular, the study has exceptionally suggested industry sector energy transition strategy for business with large emission (Steel & Iron, Petrochem), and maximum reduction target for Industry sector, that is required to achieve 205 goal. In other words, the study did not suggest multiple scenarios based on variables such as reduction tool and scope.

- In particular, ETC(2018)[20] suggested that even the Steel & Iron, Cement, and Petrochemical business, the biggest GHG emitters can achieve the carbon neutrality by 2050 in technological / economic way.

- Due to the difference in business composition and macroeconomic trend of each country, and in the baseline year of scenario analysis, scenarios developed in other countries cannot be directly applied to Korea. However, other countries' scenarios have implication to Korea's Industry Sector reduction scenario development, in that they formulated the maximum reduction scenario using the applicable technologies and reduction options judged to be economically and technologically feasible.

2) Various reduction options exist! We need to actively use the currently available options and make R&D investment in mid/long term options!

- Most of research papers articulate that reduction options can be grouped into common options (particularly for Steel & Iron, Cement, Petrochemicals) and by-business options, and both of the options are required for effective GHG reduction.
    - Example of commonly applicable reduction options are enhanced circularity / demand management and energy efficiency, and the maximum reduction impact from these options are projected to range from 44%~ 71% by business. (Table 6)
    - Certain technologies (green hydrogen, electrification of process, biomass, use of natural gas as transition fuel) are applied also on the decarbonization option by business leading to the projection of significant GHG reduction. Reduction potential of business specific technology is also projected to be significant. For example, if non-cement concrete becomes viable on around 2040, maximum 100% of related GHG emission can be reduced. We expect that about 50%~ 100% of GHG emission reduction from petrochemical business can be achieved if we can replace existing fossil fuel with recycled plastic or biofuel.

- Various reduction options are expected to secure technological/economic feasibility before 2050.

20) Energy Transitions Commission is a committee composed of experts in energy, industry, transportation, building, climate change sharing the need of 2050 carbon neutrality. In 2018, the Commission issued a report titled Mission Possible: Reaching Net-zero Carbon Emissions from Harder-to-Abate Sectors by Mid-Century and suggested reduction tools required for 2050 Carbon Neutrality for biggest GHG emitters (Steel & Iron, Cement, Petrochem) and transportation sector (Truck, Maritime, Air transport). This report is produced by the Commission members based on the analysis by Material Economics, McKinsey & Company, University Maritime Advisory Services, and SYSTEMIQ.

We need to actively leverage currently available and cost-effective options as much as possible, and make R&D investment in reduction options that are applicable in mid/long term.

- Applicable timeline by business on [Table 3-8] is the result of technological / economic feasibility analysis, considering the cost associated with each option. For example, Green hydrogen and CCS are projected to be applicable to Steel & Iron, Cement and Petrochemical businesses at around 2040 and 2050, respectively.
- Options are projected to be technologically / economically applicable to each business at a different schedule. For example, recycled plastic and biofuel are used as raw material for production in petrochemical business already, but the use of non-cement concrete in Cement business will only be achieved at around 2040.

[Table 3-8] Potential reduction rate and projected timeline for large GHG emitting businesses by reduction tool[21)]

Reduction tool		Large GHG emitting businesses		
		Steel & Iron	Cement	Petrochem
Enhanced circularity and demand management	Major tool for reduction	- Increased recycling of scrap - Redesign product for circularity improvement - Reuse Steel & Iron based products (e.g. sharing, etc)	- Efficient building design - Reuse of unhydrated cement and concrete	① Ban on use of the disposables ② Chemical and mechanical recycle
	Maximum reduction potential (projected timeline)	38% (2020-2050)	34% (2020-2050)	56%* *Based on whole cycle emission volume ① (2020-2050) ② (2020-2032)

21) The table is reformatted from Mission Possible by Energy Transitions Committee (2018) pages 40-42

Energy efficiency		Major tool for reduction	- Use high pressure gas from iron furnace exhaust as power source of other equipment - Coke Dry Quenching equipment (CDQ)[22]	- Replace to dry sintering furnace - Multiplex cyclone heating furnace - Reduce Clinker - cement ratio	Enhanced energy efficiency during the monomer manufacturing process Naphtha catalytic cracking
		Maximum reduction potential (projected timeline)	15% (2020-2050)	10% (2020-2050)	15%* (2020-2050) *Based on production emission
Decarbonization technology	Green hydrogen	Major tool for reduction	Hydrogen reduction steel making	Sintering at hydrogen atmosphere	High temperature and material
		Maximum reduction potential (projected timeline)	100% (2040-2050)	100%* (2040-2050)	100% (2040-2050)
	Biomass	Major tool for reduction	Use charcoal for BF or BOF[23]	Heat production using biomass	Heat production using biomass
		Maximum reduction potential (projected timeline)	100% (2020-2040)	50% (2020-2050)	100%* (2020-2050) * Based on production emission
	Electrification of process	Major tool for reduction	① Scrap based EAF[24] ② Electrolysis of iron or	Electrification of sintering furnace	Replace electric furnace
		Maximum reduction potential (projected timeline)	① 100% (2020-2050) ② 100% (2045-2050)	50%* (2042-2050)	100%* (2040-2050) * Based on production emission

22) Coke Dry Quenching

23) Blast Furnace, Basic Oxygen Furnace

24) Electric Arc Furnace

Decarbonization technology	CCS	Major tool for reduction	Capture BF/BOF generated GHG	Capture and storage of emission from production and process	Capture by-product gas
		Maximum reduction potential (projected timeline)	90% (2025-2050)	90% (2025-2050)	90%* (2025-2050) * Based on production emission
	Use of Gas	Major tool for reduction	Gas reduced iron (use as transitional fuel)	Use as transitional fuel	Replace coal with gas
		Maximum reduction potential (projected timeline)	50% (2020-2042)	25% (2020-2035)	50%* (2020-2038) * Based on waste phase emission
	Other	Major tool for reduction	-	① Pozzolan based concrete ② non-cement concrete	① Use of recycled plastics ② Use of biofuel
		Maximum reduction potential (projected timeline)	-	① 70% (2025-2050) ② 100% (2040-2050)	① 50% (2020-2050) ② 100% (2020-2050)

Source : Mission Possible, by Energy Transitions Committee, p.40~42

3.3.2 Strategy and policy recommendation

1) Need of study on GHG net zero emission scenario of industry sector and achievement methodology

- Many countries and institutions (ICF & Fraunhofer, The Boston Consulting Group & Prognos, WSP & DNV·GL, Energy Transitions Commission) continued business-specific studies. Certain number of institutions and researchers studied carbon neutrality[25], but not business-specific studies.[26]

- Considering the share of Industry Sector in Korean Economy and GHG emission, study to achieve net zero emission is the most urgent and critical. For example, as seen in Table 3-9, different research institutions have different perspectives on technological/economic feasibility and actual impact of certain decarbonization technology such as CCS, systematic and comprehensive research on portfolio of most effective reduction options for Korea is required.

[Table 3-9] Comparison of status by research team on CCS

Research team	Region	Position on CCS
2050 Low Carbon Society Vision Forum (2020)	Korea	• To reduce the remaining 178.9 million ton of emission after achieving the Plan 1 (Maximum reduction), CCUS, DAC are required for Industry sector • Government led roadmap for materializing validation / implementation and foundation for legalization need to be developed.
KEI (2019)	Korea	• CCS/CCSU development is excluded in the In-depth Energy Transition Scenario, considering the development feasibility is not high.

25) 「2050 LEDS」of 2050 Low Carbon Social Vision Forum (2020), Hong, Jong-Ho et al. (WWF)의 「2050 Energy strategy for sustainable future of Korea (2017), 의 「2050 LEDS studies to cope with new climate 」(2017) by Lee, Sang-Yeop et al. (KEI).

26) Sustainable development and transitions in Energy and Industry: focusing on the climate change policy goal of meeting 1.5oC pathway (2019) by Lee, Chang-Hun et al.(KEI) introduces 2050 GHG net zero emission scenario and reduction tools. In particular, it suggests the challenges and reduction tool in Steel & Iron and Petrochemical businesses. However, the limitation is that the analysis was limited to the Steel & Iron and Petro-chemical businesses, and scenario analysis per reduction plan was not performed.

ICF & Fraunhofer (2019)	EU	• CCS is reasonable in economic perspective, but commercialization is very uncertain. • If changes in other system is insufficient, significant amount of lock-in risk may occur. • 80% of reduction in Industry Sector is achievable without the application of CCS • Even for 95% reduction, CCS is not applied in Steel & Iron and Petrochemicals and is limited to capturing residual process emission such as limestone and existing clinker in Cement business. • CCS is not considered mandatory for 95% reduction.
Boston Consulting Group & Prognos (2018)	Germany	• 80% reduction plan does not include CCS. • CCS is necessary in 95% reduction plan.
WSP & DNV·GL (2015)	UK	• CCS is applied in all 3 pathways (BAU, intermediate, Tech Max). • CCS is expected to contribute by 2.6%, 18%, and 37% for BAU, Intermediate and Tech Max pathway, respectively.

Source : Developed by author

2) Need of maximizing the use of reduction options technologically / economically feasible including circular economy / demand management and energy efficiency improvement

- Effort for transition to circular economy and energy efficiency improvement based on 3R (Reduce, Reuse, Recycle) principle is accelerated, especially in the EU.
- ETC (2018) estimates CO_2 emission reduction per year by 38%, 56%, and 34% through circular economy and by 15%, 15%, and 10% through energy efficiency improvement for Steel & Iron, Petrochemicals, and Cement industry, respectively.[27]
- All three scenarios by other countries analyzed as part of this study considered energy efficiency improvement as most accessible reduction tool in terms of technology/economy. ICF &

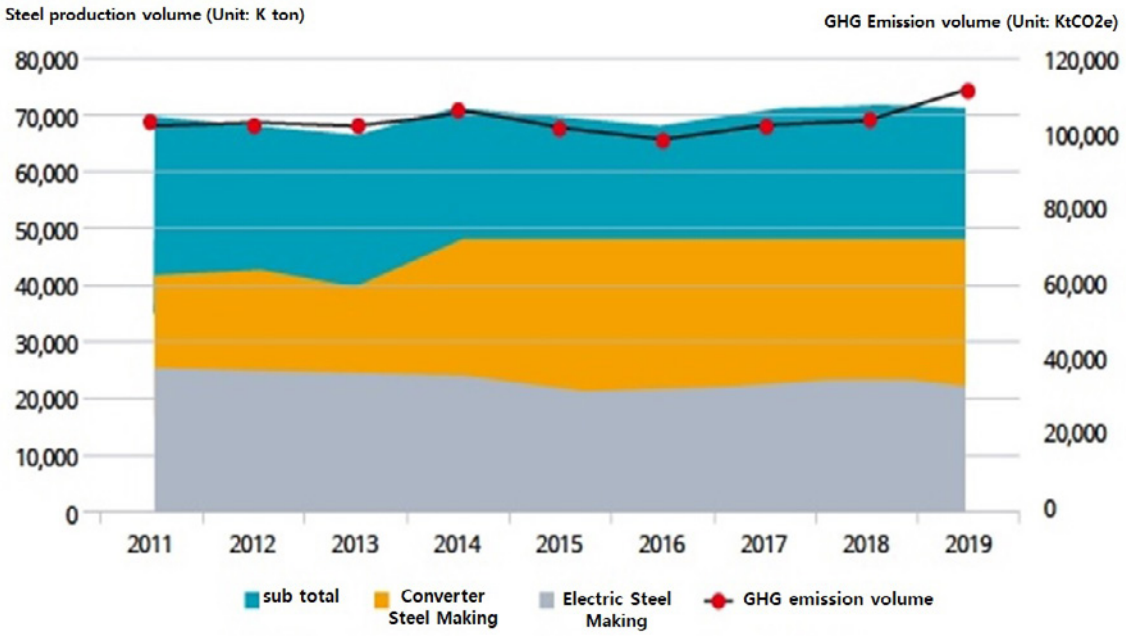
27) Currently, MoTIE is leading the energy efficiency improvement measures in Industry sector. Energy Intensity saving agreement is an agreement to reduce energy intensity by 1% per year, when a business achieves the target incentives will be offered (Outstanding business site certificate, exemption from Energy diagnosis, etc.) Another project is to support replacing an old industrial boiler with high efficiency boiler. As of 2017, energy consumption by boiler represented 18.3% in Industry Sector, and as of 2018 about 30% of 13.5K industrial boilers were old ones and replacing the old boilers would realize significant amount of GHG emission reduction. Lastly, for the introduction of FEMS, it will become mandatory for large energy consumers (100K TOE and over) to install FEMS (planned for 2025). As the 157 businesses with over 100K TOE as of 2007 represents 57.7% of gross energy consumption, GHG reduction impact is expected with the introduction of FEMS. However, additional measures such as systematic measurement of energy efficiency and development of validation standards require further development. For businesses with less than 100K TOE, FEMS supply will be expanded by linking to smart industrial complexes and smart plants (over 3000 new FEMS by 2040).

Fraunhofer (2019) estimates that the investment for energy efficiency improvement measures can be recovered within 10 years. WSP & DNV·GL (2015) projects emission reduction of 15%, 31%, and 12% in Steel & Iron, Petrochemicals, and Cement businesses through energy and raw material efficiency improvement, respectively.

3) Need to exert society-level efforts for the GHG emission reduction in 3 biggest GHG emitting businesses (steel & iron, petrochemical, cement)

- Steel & iron, petrochemical, and cement business represent 64% of industry sector GHG emission, which is 29% of National gross emission.[28]
- Steel & Iron gross production has been 70K ton level per year over the past 10 years. Production using electric furnace remained at 25K ton per year, but integrated steel mill production increased by 14% (Figure 3-12). GHG Emission decreased in 2016 over 2011 (about 4%) but returned to increase in the period of 2016 - 2019 (about 13% increase). In particular, production in 2019 reduced by 1.5%, while GHG emission increased by 7%.

<Figure 3-12> Domestic steel & iron production and GHG Emission (2011-2019)



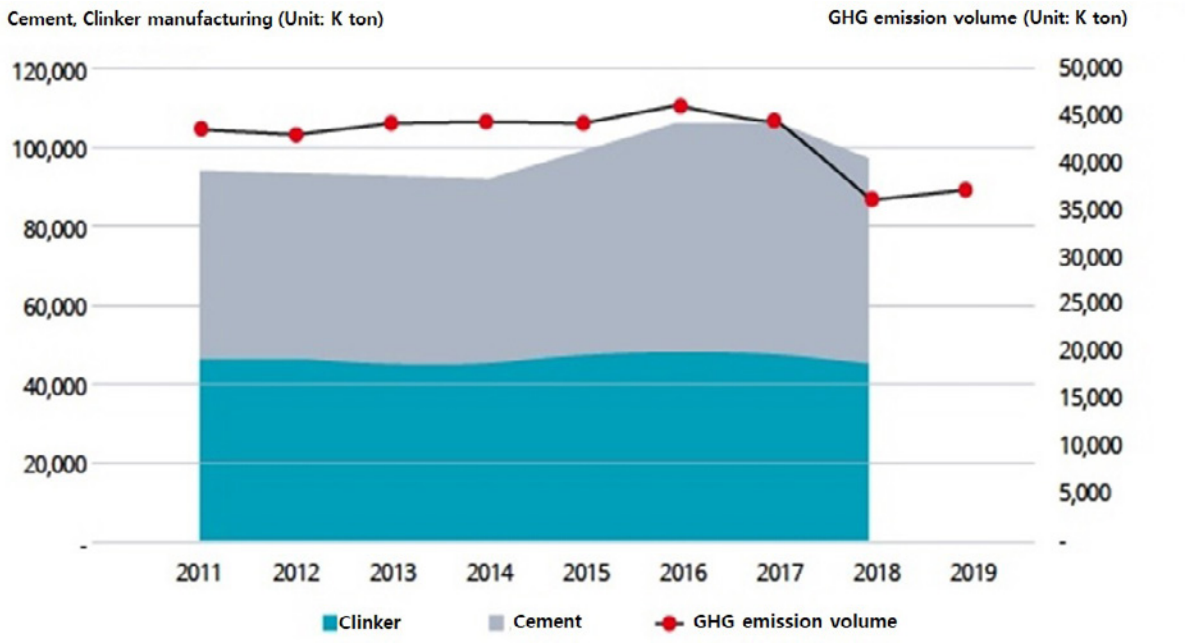
Source : Steel & Iron production (Korea Iron& Steel Association), GHG Emission (NGMS)[29]

28) Major Steel & Iron company (POSCO Hyundai Metal), Petrochemical (LG Chemicals, Lotte Chemical, Hanwha Total, Yeochun NCC, SK Global, and Kumho Petrochemical), and cement makers (Ssangyong ENC Samphy Cement, Ssangyong CNE, Sampyo Cement, Sungshin Cement, Halla Cement, Hanil Cement, Hanil HD Cement, Asia Cement) represent 23% of national GHG emission.

29) Statement emission statistics was used for the GHG emission. (Sum of company-level emission for 2019). GHG emission includes all types of GHG emitted by the Steel & Iron business subject to K-ETS. In other words, Steel& Iron production and GHG emission on the graph does not have 100% correlation.

- Cement/Clinker production and GHG emission also did not have much difference over the past 8 years (2011-2018) (Figure 3-13). However, Cement/Clinker production and GHG emission showed proportionate relation. In 2018, GHG Emission reduction rate (18.7%) was nearly double the Cement /Clinker production reduction rate (9.2%).

<Figure 3-13> Domestic cement clinker production and GHG emission (2011-2018)

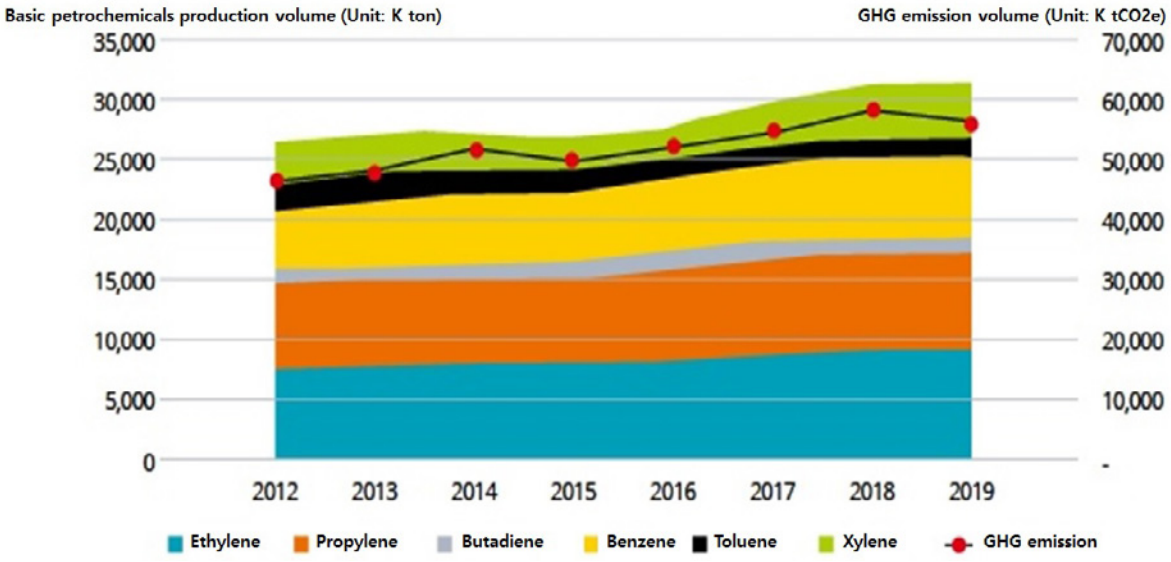


Source : Cement ·Clinker production (Korea Cement Association), GHG Emission (NGMS)[30]

- Basic petrochemicals production trend (2012-2019) shows difference per oil, but overall production continuously increased (18.5% increased). GHG emission also continuously rose, illustrating similar trend with the basic petrochemicals production (20.4% increased) (Figure 3-14).

30) Statement emission statistics was used for the GHG emission. (Sum of company-level emission for 2019). GHG emission includes all types of GHG emitted by the Cement business subject to K-ETS. In other words, Cement / Clinker production and GHG emission does not have 100% correlation. Cement/Clinker production data is not updated by Korea Cement Association for 2019.

<Figure 3-14> Domestic basic petrochemicals production and GHG emission (2012-2019)



Source : Basic Petrochemicals production (Korea Petrochemical Association), GHG Emission (NGMS)[31]

- In achieving net zero GHG emission in 2050, GHG reduction in these three businesses may play a critical role. Innovative projects to be considered by each of the Steel & Iron, Petrochemical and Cement businesses can be summarized as [Table 3-10]. 2050 Net Zero scenario for Industry Sector can be developed by calculating reduction potential for each business, and legislative improvement and additional R&D are required to achieve 2050 net zero goal.

4) Need to establish stronger target than the 2050 LEDS reduction goal

- As discussed in Chapter 3.2, 2050 LEDS industry sector reduction scenario ranges from maximum of 65.5% (Plan 1) to minimum of 18.5% (Plan 5) (Transition sector not included).
- 2050 LEDS suggests the Industry Sector GHG Reduction scenario including the external electricity and heat purchase, with 3 levels of reduction goals (High scenario 57%, Medium scenario 45.6%, and Low scenario 25.8%) (Figure 3-15). The 2050 GHG reduction goal can be raised by strengthening 8 tools[32] suggested for reduction and by introducing additional methodologies.

31) Statement emission statistics was used for the GHG emission. (Sum of company-level emission for 2019). GHG emission includes all types of GHG emitted by the Petrochemical business subject to K-ETS. In other words, Basic petrochemical production and GHG emission does not have 100% correlation.

32) Hydrogenation technology, reuse of material, new material transition and high value-added products, equipment efficiency improvement, smart plant and industrial complex, CCS, low-carbon fuel and material use, emission reduction during industrial process, hydrogenation and CCUS energy increase.

[Table 3-10] Steel & iron, cement, and petrochemical business level innovation

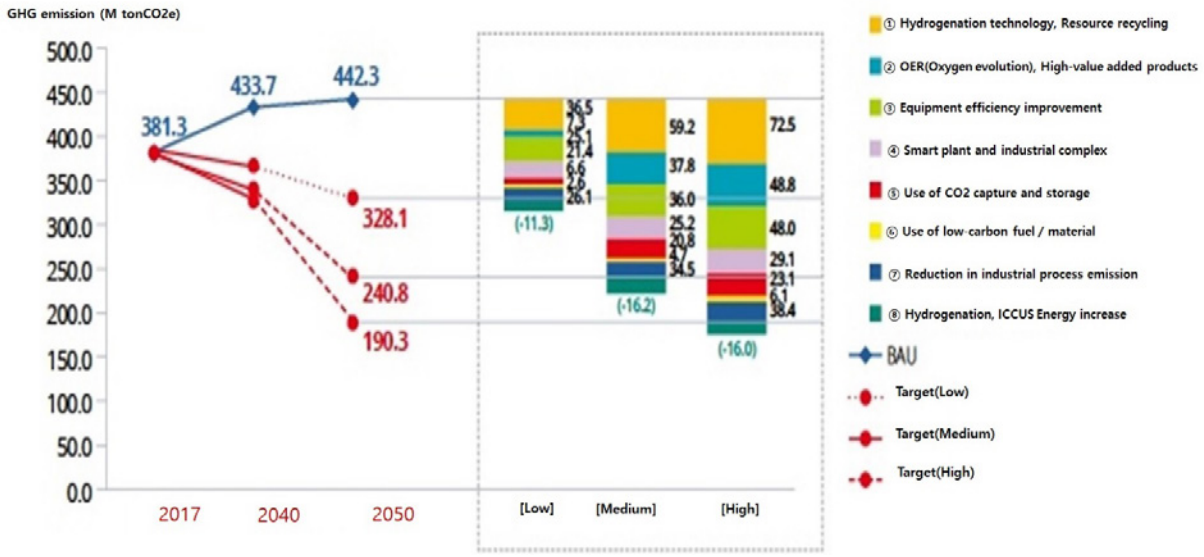
Business	Technology innovation projects	Policy innovation projects	Company innovation projects
Steel & Iron	• Combine Hydrogen direct reduction iron and electricity furnace (DR H2 + EAF) • Develop Blast furnace/ pure oxygen converting furnace carbon capture technology • Develop refinement methodology for higher hyper-pure, high value Steel & Iron reuse/recycle • Replace natural gas to synthetic methane gas	• Continued decrease of total emission allocation under K-ETS • Introduce/enhance regulation on Steel & Iron with carbon intensity higher than BM • Introduce policies inducing the use of low-carbon steel & iron and materials in green remodeling and new construction of public infrastructure and buildings[33]	• Expand R&D for development and increased reuse/recycling of Hydrogen direct reduction iron • Participate actively in Green Steel & Iron standardization efforts • Purchase/procure Green Steel & Iron (automobile, ship building companies) • Establish and participate in RE 100 goal
Cement	• Hydrogen + electricity sintering process development • Green construction material such as low-carbon cement/ concrete • Develop process of emitting diluted CO_2 or of lowering CO_2 capturing cost	• Continued decrease of total emission allocation under K-ETS • Introduce/enhance regulation on Cement with carbon intensity higher than BM • Introduce policies inducing the use of low-carbon cement / concrete in public infrastructure and buildings	• Replace sintering fuel to hydrogen or renewable electricity, R&D investment in Carbon capture technology, run pilot projects • Enhance construction material efficiency and resolve challenges in recycle rate increase • Establish and participate in RE100 goal

33) 2050 Net zero GHG emission requires clear standard on green industry or products. Technical Expert Group (TEG) within EU is preparing Green classification structure screening criteria and introduced 3 principles in setting 2030 and 2050 transition pathway for large emitters without carbon solution or with insufficient solution. First, much lower GHG emission level compared to the industry average emission. Second, no hindrance in development and deployment of low-carbon alternatives. Third, no contribution to lock-in of carbon intensive asset from whole lifecycle perspective. Activities are classified into the following 3 groups; 1st, if the activity is already low-carbon, capital is required to develop and spread the activities. Technology classification for these activities is likely to be long-term and stable, and these activities are called 'Green' activity. Second, activities that may contribute to 2050 Net Zero transition, but currently not on the pathway must enhance the performance significantly compared to industry average. Technology classification for these activities requires regular review / correction against the emission net zero pathway, and they are called 'Greening of' activity. Third group is about the activities that enables low-carbon performance or that will enable significant amount of emission reduction and were called 'Greening by' activities, but now they are called 'enabling' activities (EU Technical Expert Group on Sustainable Finance, Taxonomy: Final report of the Technical Expert Group on Sustainable Finance, 2020, p. 20).

Petrochemical	• Develop/advance high quality & large-scale mechanical recycling and chemical recycling • Develop sustainable bio-fuel (to replace Naphtha, natural gas) • Replace Green hydrogen and low-carbon electricity for the process	• Strengthen low-carbon criteria for packages, household appliances, etc. • Introduce new policy on product recyclability, strengthen manufacturer liability • Impose carbon tax for burning plastic at least equivalent to the landfill	• Strengthen cooperation in overall value chain to enhance the circularity (from product design to processing) • Enhance R&D on recyclability of plastic goods and recyclable material • Capture opportunity and enter into new market for recycling

Source : Mission Possible: Reaching Net-zero Carbon Emissions from Harder-to-abate Sectors by Mid- Century, by Energy Transitions Commission (2018), developed by author based on page 40-42

<Figure 3-15> 2050 LEDS industry sector GHG reduction scenario (external electricity and heat purchase included)



Source : 2050 Low Carbon Society Vision Forum (2020), 2050 LEDS, page 70.

- For example, if transition to renewable energy in power generation sector significantly lowers the power emission factor, the emission level can be significantly reduced by purchasing external electricity. As in Plan 1 of Low Carbon Society Vision Forum, if renewable energy electricity reaches 60.8% then we can purchase external electricity with 60% lower GHG emission. In other words, the industry sector can additionally reduce 50million ton of emission

by purchasing external electricity (Based on the condition that current assumption of 83 million ton GHG emission from the external electricity purchase remains).

- If the steel & iron business replaces soft coal with green hydrogen for coking fuel, then significant amount of emission reduction would be realized. For example, currently the integrated steel mill process emission by POSCO and Hyundai Steel represents 42% of overall industry sector process emission. But if these 2 companies use green hydrogen for reducing agent instead of soft coal, then GHG emission would be reduced by at least 76 million ton per year.[34] On top of that, if the revolving furnace in the integrated steel mill is replaced with the electric furnace, using the renewable energy based electricity, then over 10million ton of GHG emission can be reduced per year.[35]

- According to the ETC analysis, Steel & Iron, Petrochem, and Cement business could reduce GHG emission by 38%, 56%, and 34%, respectively. It indicates that by redesigning the economy from a linear to a circular format covering the mining of raw material and product design to processing and disposal, at least 30% or more GHG emission can be reduced from the 3 biggest emitting businesses. Korea highly depends on material imports and must deal with the waste processing urgently. Considering the situation, establishing circular economy system would create bigger socioeconomic impact than in other advanced countries. Hence, the research on socioeconomic benefit from the circular economic system development and on transition to circular economy are urgent. Interdisciplinary / integrated research seems to be more effective than a study by a certain institution or researcher with specific expertise.

34) As of 2018, POSCO consumes 18million ton of raw coal, 1.2 million ton of hard coal, and 6 million ton of pulverized coal for reducing agent. When all these coals are replaced to green hydrogen, about 76million ton equivalent emission can be saved (CO2 power emission coefficient 2.91, 2.88, 2.99 are used).

35) POSCO consumed 17.76 TWh of electricity in 2018. When electricity emission coefficient is assumed 0.459/MWh, over 8million ton of GHG emission can be reduced per year.

Appendix 1. GHG Emission and energy consumption by businesses eligible for K-ETS allocation in 2017 (in order of GHG emission volume)

Order	Business	Number of companies for allocation	GHG Emission (T CO_2-eq)	Energy Consumption (TJ)
		444	**317,159,654**	**3,604,551**
1	Steel & Iron	40	102,564,787	677,621
2	Petrochem	92	54,616,368	1,013,216
3	Cement	24	44,881,525	241,519
4	Refinery	5	28,897,278	350,484
5	Industrial Complex	13	14,318,823	178,688
6	Semi-conductor	23	14,174,822	227,267
7	Display	4	11,418,223	145,443
8	Non-ferrous metal	28	8,429,108	125,083
9	Paper manufacturing	41	6,924,379	112,228
10	Textile	16	4,713,146	85,614
11	Automobile	31	4,336,800	86,846
12	EV	25	4,296,167	69,553
13	Glass	21	3,917,961	62,973
14	Telecommunication	7	3,426,007	70,336
15	F&B	25	3,107,041	63,413
16	Ceramics	6	2,438,553	16,223
17	Shipbuilding	11	2,083,421	36,304
18	Mechanical	20	1,432,268	27,731
19	Mining	5	789,131	2,250
20	Timber	7	393,846	11,759

Source : NGMS, key information on 2017 Statement Emission (https://ngms.gir.go.kr)

Appendix 2. 4-year average GHG emission by companies in industry sector

(unit: ton CO_2-eq.)

Order	Name of company	Business	Average (2015-2018)
1	POSCO	Steel & Iron	72,133,736
2	Hyundai Steel	Steel & Iron	20,675,992
3	Ssang Yong CNE	Cement	11,670,175
4	Samsung Electronics	Semi-conductor	8,240,037
5	GS caltex	Refinery	8,207,042
6	S-Oil	Refinery	7,892,583
7	LG Chemistry	Petrochem	7,709,340
8	SK Energy	Refinery	7,587,989
9	Sampyo Cement (former, Dongyang cement)	Cement	6,947,746
10	LG Display	Display	6,613,106
11	Lotte Chemical	Petrochem	5,787,430
12	Sungshin Cement	Cement	5,759,987
13	Hyundai OilBank	Refinery	5,440,901
14	Halla Cement	Cement	5,220,753
15	Hanil Cement	Cement	5,096,764
16	Samsung Display	Display	4,943,259
17	Hanwha Total	Petrochem	4,360,738
18	Hanwha Energy	Industrial complex	4,298,749
19	Hanil HD Cement	Cement	3,834,406
20	Yeochun NCC	Petrochem	3,629,342
21	Korea Zinc	Nonferrous Metal	3,428,555
22	SK Global Chemical	Petrochem	3,237,902
23	SK Hynix	Semi-conductor	3,189,655
24	Kumho Petrochemical	Petrochem	3,030,406
25	Asia Cement	Cement	2,883,210
26	GunJang Energy	Industrial complex	2,578,106
27	OCI	Petrochem	2,401,268
28	GS E&R	Industrial complex	2,317,190
29	POSCO Chemical	Ceramics	2,309,532
30	Dongkuk Steel Mill	Steel & Iron	1,936,845
31	SK Incheon Petrochem	Petrochem	1,690,870
32	KCC	Glass	1,617,678
33	SNNC	Nonferrous Metal	1,547,553
34	HyunDai Motors	Automobile	1,533,406
35	Hyosung	Petrochem	1,495,725
Total			241,247,973

Source : NGMS Statement Emission statistics, https://ngms.gir.go.kr/main.do

Reference

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Research on Strategy and Policy by Sector for Korea 2050 Carbon Neutrality

4

Building Sector

4.1 Energy Consumption and GHG Emissions of the Building Sector

4.1.1. Energy consumption status [36)]

1) Energy consumption status

- As of 2018, the building sector (residential, commercial, public) used 46,910,000 TOE of energy, accounting for approximately 20% of Korea's total energy consumption.
    - When broken down by the purpose of the buildings, residential buildings (50.0%) represented half of the total energy consumption by the building sector, followed by commercial (38.1%) and public (11.9%) buildings.

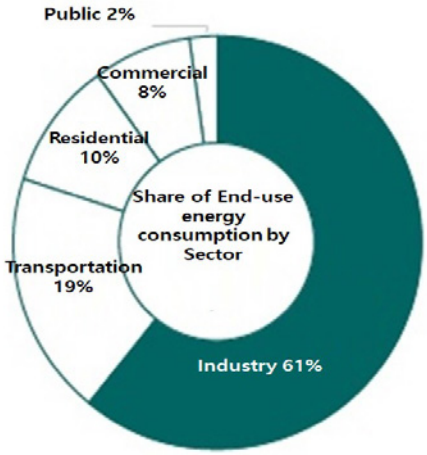
[Table 4-1] Final energy consumption of building sector by source (2018) (Unit: 1,000 TOE)

	Coal	Petroleum	City gas	Electricity	Thermal energy	New renewable	Total	Share (%)
Residential	432	3,366	10,901	6,079	2,289	393	23,460	50.0
Commercial	-	1,959	3,713	11,732	332	147	17,883	38.1
Public	-	1,429	99	2,784	61	1,195	5,567	11.9
Total	432	6,754	14,713	20,595	2,682	1,735	46,910	100.0

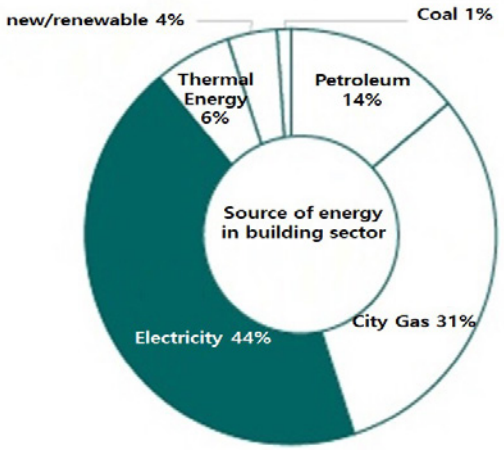
Source : 2019 Energy Statistical Year Book, Korea Energy Economics Institute.

- Broken down by the source of energy, the most frequently used source of energy was electricity (44%), followed by city gas (31%), petroleum (14%), thermal energy (6%), new/renewable energy (4%) and coal (1%). City gas also represented a significant portion. (Figures 4-1 and 4-2)

<Figure 4-1> Share of end-use energy consumption by sector



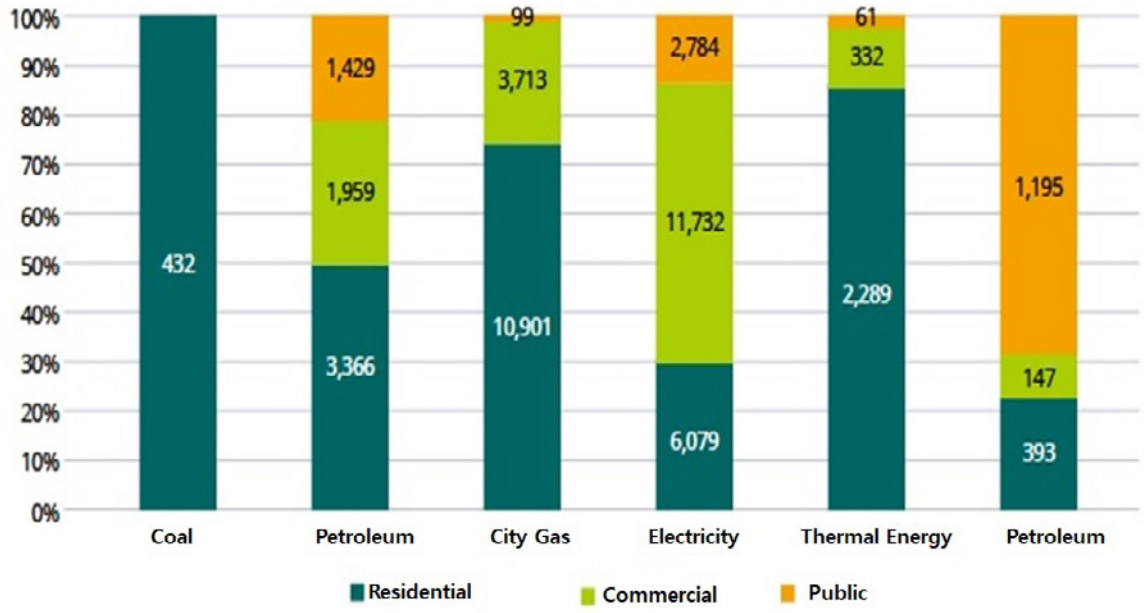
<Figure 4-2> Source of energy in building sector



Source : Developed by the author based on 2019 Yearbook on Energy Statistics.

- When looking at the purpose of the buildings and the source of energy, coal is used only in residential buildings and the use of petroleum by residential buildings exceed that of commercial buildings. Residential use of city gas and thermal energy is higher than public, but the commercial use of electricity is higher than the residential and public combined. Public buildings' use of new and renewable energy is about twice as high as residential and commercial combined. (Figure 4-3)

<Figure 4-3> Energy consumption and share of building sector by purpose of building and source of energy (2018)

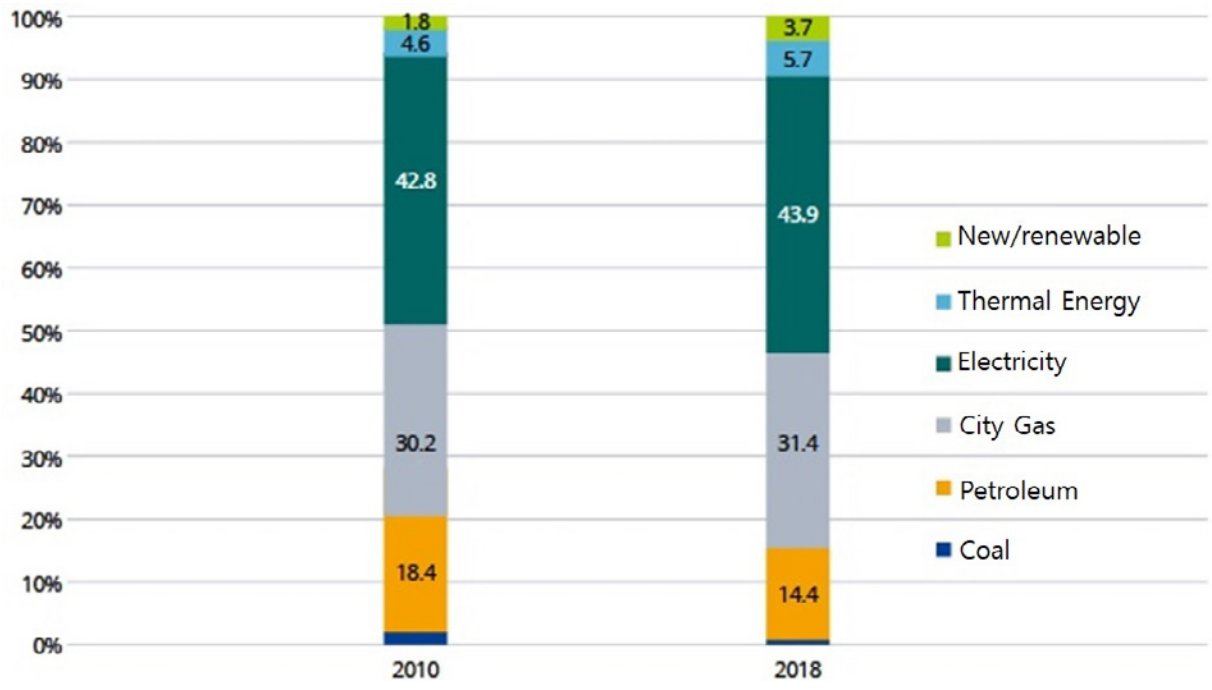


Source : Developed by the author based on 2019 Yearbook on Energy Statistics.

2) Trend of energy consumption

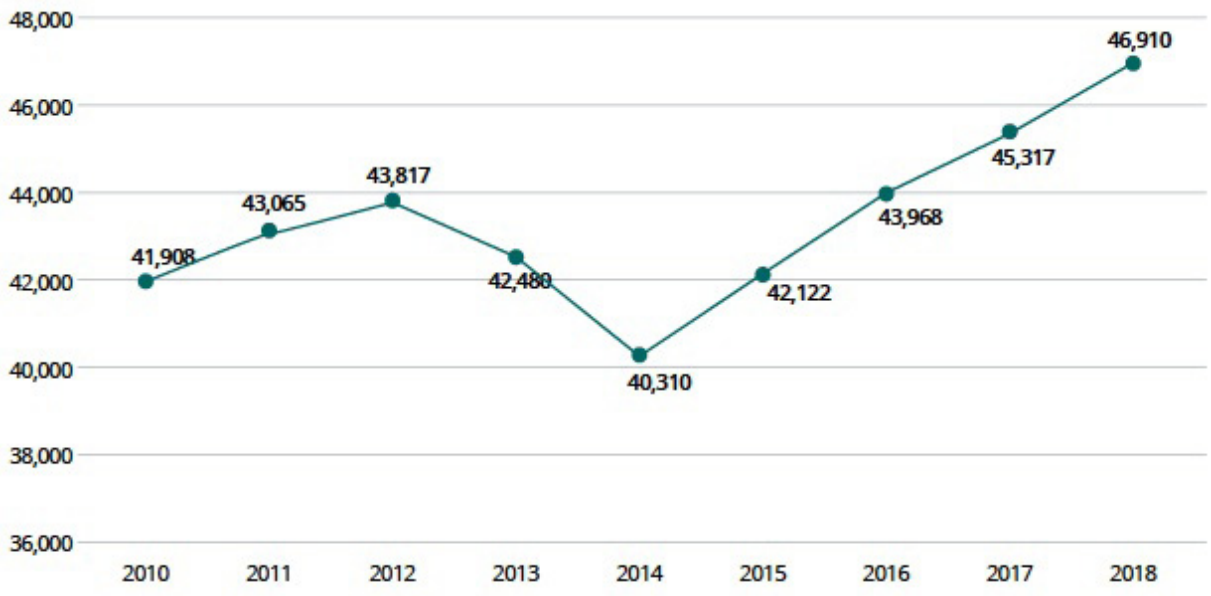
- Total energy consumption gradually increased after recording 41,909,000 TOE in 2010, and then recovered the pre-2010 level during 2012~2014. Energy consumption has been climbing up since 2014.
    - Petroleum took up 18.4% in 2010 but decreased to 14.4% in 2018; city gas increased from 30.2% in 2010 to 31.4% in 2018; electricity rose from 42.8% in 2010 to 43.9% in 2018. New and renewable energy approximately doubled from 1.8% in 2010 to 3.7% in 2018. (Figures 4-4, 4-5).

<Figure 4-4> Shift of shares of energy consumption in building sector by energy source (%)



Source : Developed by the author based on 2019 Yearbook on Energy Statistics.

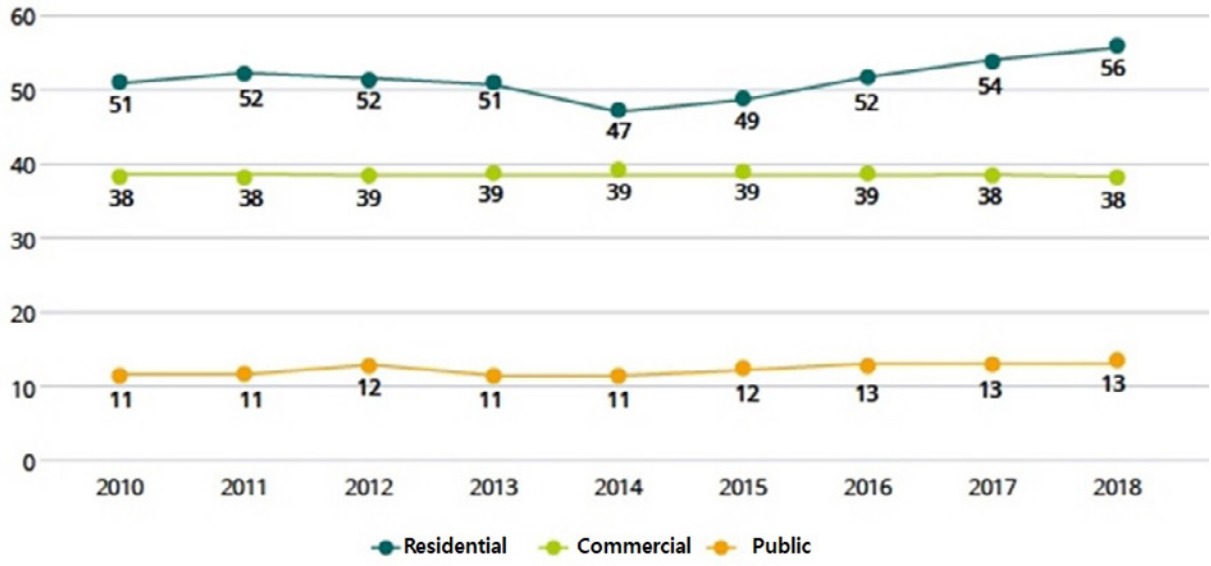
<Figure 4-5> Trend of total energy consumption in building sector (Unit: 1,000TOE)



Source : Jung, Young-Sun, Kim, Tae-Hyung (2018).

- Energy consumption was the greatest by residential buildings (51%) in 2010, followed by commercial (38%) and public (11%); while the commercial buildings are maintaining the 38% level, residential consumption increased to 56% and public to 13% in 2018, indicating that the share of energy consumption by residential buildings is getting bigger.

<Figure 4-6> Trend of share of energy consumption by purpose of building (%)



Source : Developed by the author based on 2019 Yearbook on Energy Statistics.

- Table 2 compares the energy consumption of 2010 and 2018, broken down by the purpose of the buildings and the source of energy. The use of coal and petroleum by residential buildings declined; petroleum consumption and city gas consumption by commercial and public buildings decreased, respectively. The use of electricity, thermal energy and new/renewable energy increased in all types of buildings.

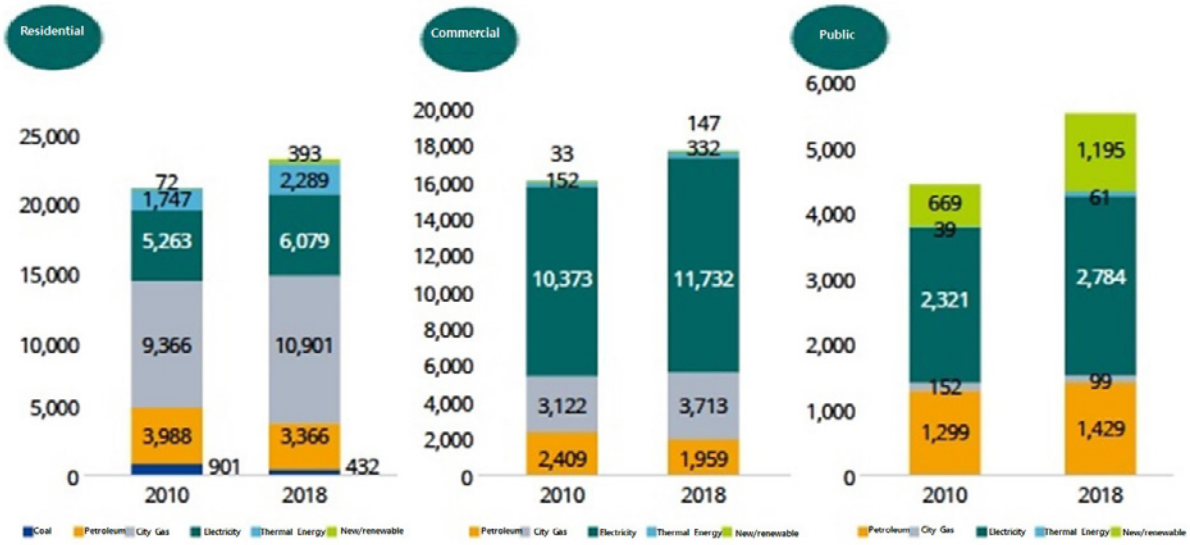
[Table 4-2] Comparison of 2010 and 2018 energy consumption by purpose of building and source of energy

	Residential	Commercial	Public
Coal	Decreased	-	-
Petroleum	Decreased	Decreased	Increased
City gas	Increased	Increased	Decreased
Electricity	Increased	Increased	Increased
Thermal energy	Increased	Increased	Increased
New/renewable	Increased	Increased	Increased

Source : Developed by the author based on 2019 Yearbook on Energy Statistics.

- While residential buildings are heavily dependent on city gas, commercial and public buildings used more electricity. The use of new and renewable energy increased in all types of buildings, but the commercial use was far less than residential and public use. On the other hand, public buildings became more reliant on petroleum in 2018 than in 2010. The increase of consumption by public buildings was most evident in new and renewable energy and also in petroleum, which is essentially fossil fuel.

<Figure 4-7> Comparison of energy consumption
by purpose of building and source of energy (2010 vs 2018)



Source : Developed by the author based on 2019 Yearbook on Energy Statistics.

4.1.2 Status and characteristics of GHG emissions by building sector

1) GHG emissions status[36)]

- Total GHG emitted (CO_2e) by the building sector in Korea (residential, commercial, public) was 175.0 million tCO_2e in 2017, accounting for around 24.7% of the country total GHG emissions of 709.1 million tCO_2e.
    - Considering that the final energy consumption by the building sector represents approximately 20% of the country's total energy consumption as of 2017, the level of GHG emissions is somewhat high. It is because around 40% of the energy consumed by the building sector was electricity, which has higher GHG emission factor than other sources of energy.

36) For the GHG emissions status, total emissions was taken from the data of Ministry of Environment; "Estimation and Characteristics of Greenhouse Gas by the Building Sector based on National Energy Statistics (Youngsun Jung, Taehyung Kim (2019))" was referred to for GHG emissions by source of energy and purpose of buildings, due to the limitation of public data. Korea Institute of Civil Engineering and Building Technology received the figures by energy source from the Korea Real Estate Board and estimated the emissions, but it only covers residential and commercial buildings and does not include public buildings. As for the GHG emissions status analysis for the building sector, it should be noted that the total GHG emission by the public buildings had been excluded from the detailed GHG emissions status analysis due to the discrepancy of statistics collection standard by departments and institutions, and the limitation of the disclosed public data.

[Table 4-3] GHG emissions by building sector (residential, commercial) by source of energy

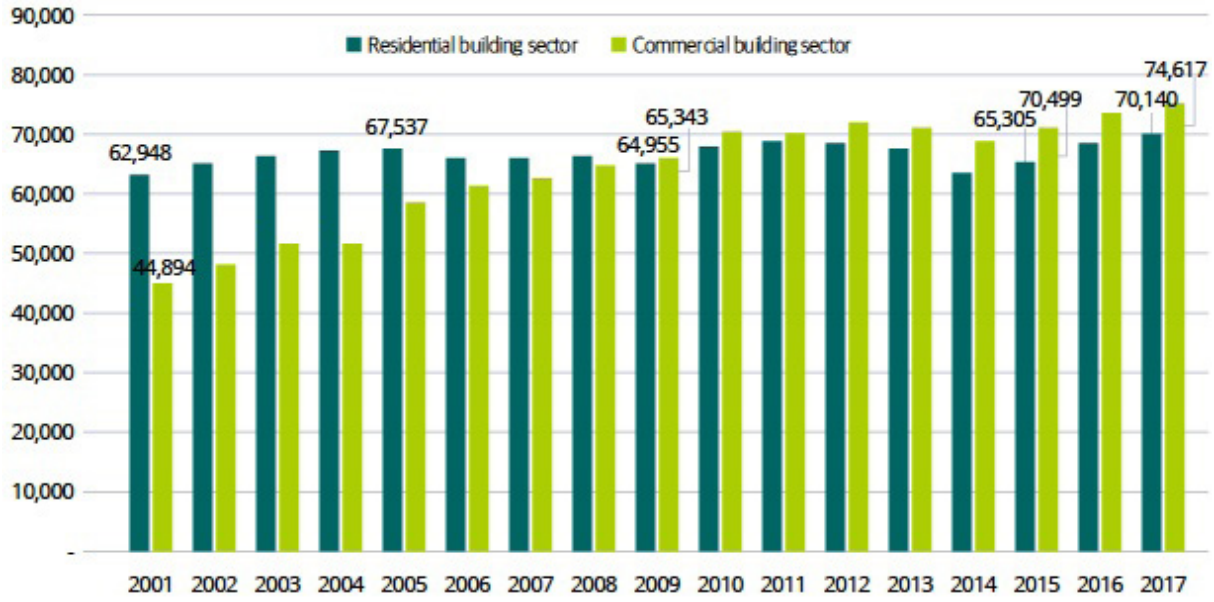
(2017) (Unit: 1,000 tCO_2e)

	Coal	Petroleum	City gas	Electricity	Thermal energy	Total
Emission	2,446	15,440	29,438	91,797	5,637	144,758
Share (%)	1.7	10.7	20.3	63.4	3.9	100.0

Source : Jung, Youn-sun, Kim, Tae-hyung (2019).

- In 2017, 70.1 million tCO_2e of GHG was emitted from residential buildings and 74.6 million tCO_2e from commercial buildings.[37] (public buildings excluded)

<Figure 4-8> GHG emissions by buildings sector (residential, commercial) (1,000 tCO_2e)

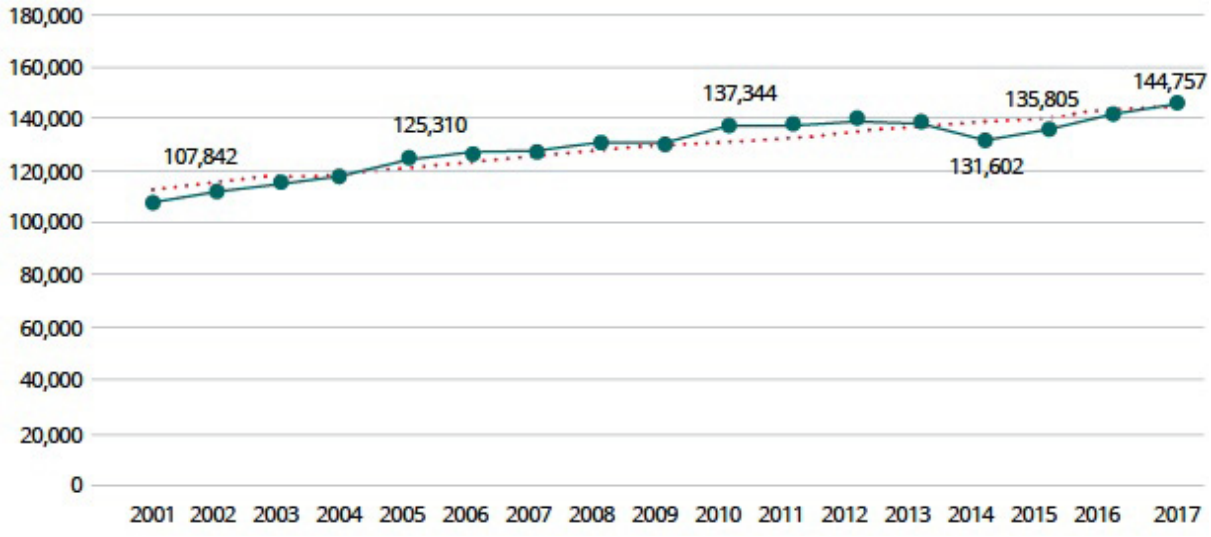


Source : Jung, Youn-Sun, Kim, Tae-Hyung (2019)

- When analyzing the trend of the GHG emissions by the building sector, the graph continued to move up from 2001 and made a downward turn in 2014. The reduction was caused by the decreased energy consumption by the building sector, and the GHG emissions have been rising continuously since 2015.

37) The statistics concerning the GHG emission by the public buildings are presented in the National Inventory Report which is published every year by the Greenhouse Gas Inventory and Research Center, but it cannot be regarded to be realistic as electricity and thermal energy, indirect emissions, are excluded in this Report. Hence, the detailed GHG emissions figures are limited to residential and commercial buildings.

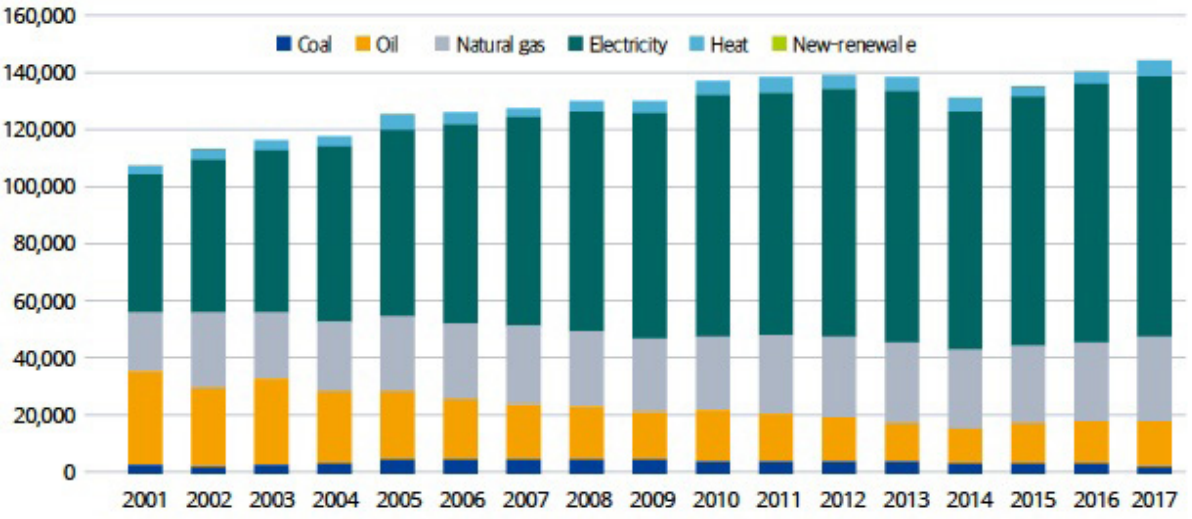
<Figure 4-9> Trend of GHG emission by building sector (residential, commercial) (1,000 tCO_2e)



Source : Jung, Young-Sun, Kim, Tae-Hyung (2019)

- The trend of the GHG emissions broken down by energy source shows that the GHG emitted from electricity is rapidly increasing. The emission from petroleum is declining, but incremental GHG is emitted from coal. The reason seems to be the growing consumption of coal energy by the public sector.

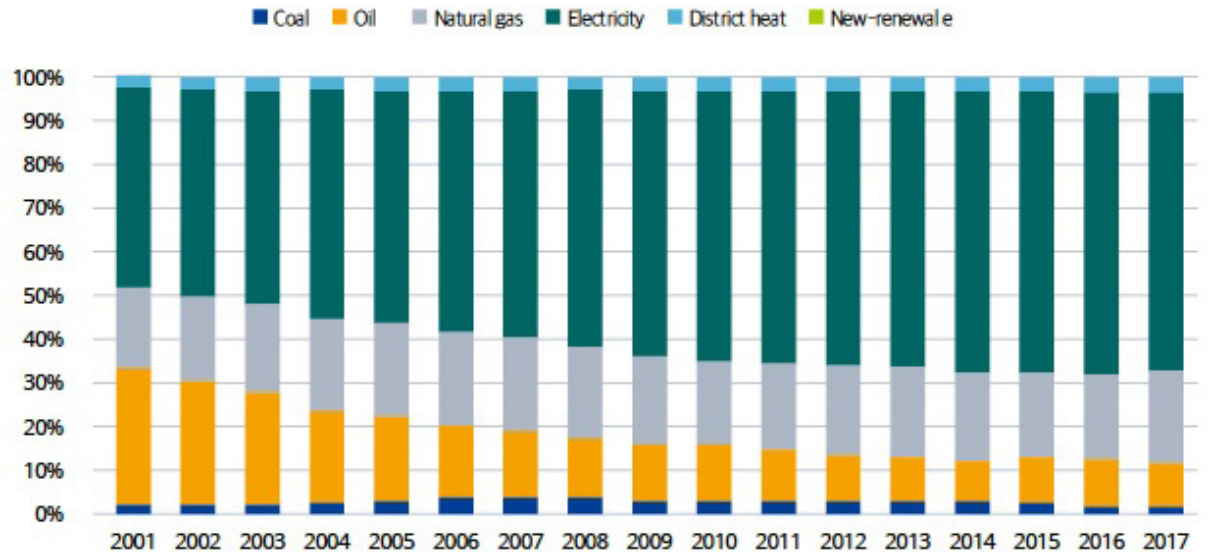
<Figure 4-10> Trend of GHG emissions by building sector (residential, commercial) by source of energy (1,000 tCO_2e)



Source : Jung, Young-Sun, Kim, Tae-Hyung (2019)

  - In 2001, GHG emission from electricity represented 45.3%, but has risen to 63.4% in 2017. The share of GHG emission from coal increased from 18.5% to 26.3%.

<Figure 4-11> Share of GHG emission by building sector (residential, commercial) by source of energy (%)



Source : Jung, Young-Sun, Kim, Tae-Hyung (2019)

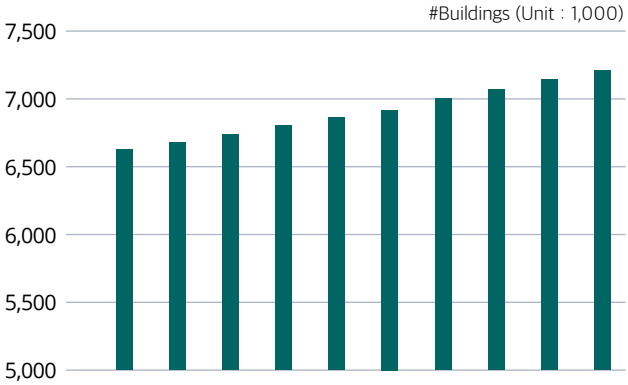
2) Characteristics of energy consumption and GHG emissions

- A key characteristic of energy consumption by the building sector is that it is strongly dependent on network-based energy (electricity, thermal energy, city gas), and the consumption of the network-based energy is prominently rising.
  - Comparing 2015 with 1997, electricity, city gas and thermal energy consumption increased by 163%, 97% and 70%, respectively.

- Compared to the residential buildings, GHG emission by the commercial buildings displayed a significant jump. This is not because the GHG emission by the residential buildings shrunk, but because the emission by the commercial buildings have actually increased substantially, seemingly due to the increased use of electricity that has high GHG emissions factor.

- Each year, the number of buildings is increasing by average 1%, and accordingly, the energy consumption by the buildings is also rising. As the number of old buildings naturally increase, buildings that are 15 years or older accounted for 67.2% of all buildings in 2018. Enhancing the energy efficiency of old buildings should be taken into consideration when developing policies for 2050 Long-term Low Greenhouse Gas Emission Development Strategy governing the energy consumption and GHG emissions of the building sector.

<Figure 4-12> Number of Buildings and Total Floor Area



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
#Buildings	6,618	6,677	6,732	6,796	6,852	6,911	6,987	7,055	7,127	7,192
Fluctuation (%)	-	0.88	0.83	0.96	0.82	0.87	1.09	0.97	1.02	0.92

Number of Buildings by Year and Yearly Fluctuation (as of 2018)

Category	Share in #Buildings		Share in Total Floor Area	
Total	7,191,912	100.0%	3,754,127,599	100.00%
~ 9 years	1,247,428	17.3%	961,332,470	25.6%
10~14 years	573,539	8.0%	509,738,903	13.6%
15~19 years	649,523	9.0%	542,677,394	14.5%
20~24 years	771,150	10.7%	592,810,670	15.8%
25~29 years	744,498	10.4%	509,351,958	13.6%
30~34 years	497,285	6.9%	216,152,624	5.8%
35 and above	2,169,438	30.2%	336,637,531	9.0%
Others	539,051	7.5%	85,426,049	2.3%

Distribution by Age of Buildings (as of 2018)

Source : Park, Duk-Joon, 2020, 'Challenges to Achieve Net-zero in Energy Consumption by Buildings"

- The number of buildings and their electricity consumption are expected to more than double by 2050; hence the total GHG emission is anticipated to rise further. In order for 2050 LEDS to succeed or to achieve net-zero, the policy measures for the building sector need to be more innovative and bolder.

4.2 Review of Long-term LEDS Scenario and Reduction Measures for Building Sector in Korea and Other Countries

4.2.1 Korea's scenario and reduction measures

1) 2050 Long-term Low Greenhouse Gas Emission Development Strategy (proposal)

● **Key Assumptions**

- (Population and Households) The population is assumed to grow by average 0.1% per annum between 2017 and 2040, then decrease by average 0.5% per annum between 2040 and 2050; the number of households is assumed to increase by average 0.6% per annum between 2017 and 2040 due to the increase of one-person households, then decrease by average 0.03% per annum between 2040 and 2050.

[Table 4-4] Korean Population and Number of Households Forecast

[Unit: million]	2017	2030	2040	2050	2017~2040	2040~2050
Population	51.4	52.9	52.2	49.4	0.1%	-0.5%
#Households	19.5	21.6	22.3	22.2	0.6%	-0.03%

* Actual figures up to 2015; 2016 Outlook by Statistics Korea

Source : 2050 Low Carbon Society Vision Forum (2020), 2050 LEDS

- (GDP) During the period of the forecast, GDP is expected to grow by average 2.0% per annum between 2017 and 2040, and then by 1.0% between 2040 and 2050.

[Table 4-5] GDP growth forecast of Korea

[Unit: million persons]	2017	2030	2040	2050	2017~2040	2040~2050
GDP Growth rate	3.1%	1.7%	1.2%	0.9%	2.0%	1.0%

Source : 2050 Low Carbon Society Vision Forum (2020), 2050 LEDS.

● Forecasting methods

- The energy forecast up to 2040 as provided by the 3rd Energy Master Plan has been referred to as much as plausible, and the Extended Energy Master Plan was also utilized considering the relevance with target demand.
- Energy: GHG emission was calculated by collating the BAU figures across the sectors, and then applying the electricity energy emission factor and the latest inventory calculation method (2017).

● For the purpose of developing the GHG emission scenario for the building sector, it is proposed that the emission be reduced by 17.5% at minimum to 22.5% at maximum by 2050, compared to 2017; average 0.1% reduction per annum and average 0.5% reduction per annum had been deduced for up to 2040 and from 2040 onward, respectively.

[Table 4-6] 2050 Emission forecast for building sector (Unit: M ton CO_2e, %)

Year	2017	2040	2050	Average annual increase / decrease (%)	
				2017~2040	2040~2050
Emission	175.0	172.1	173.9	-0.1%	-0.5%

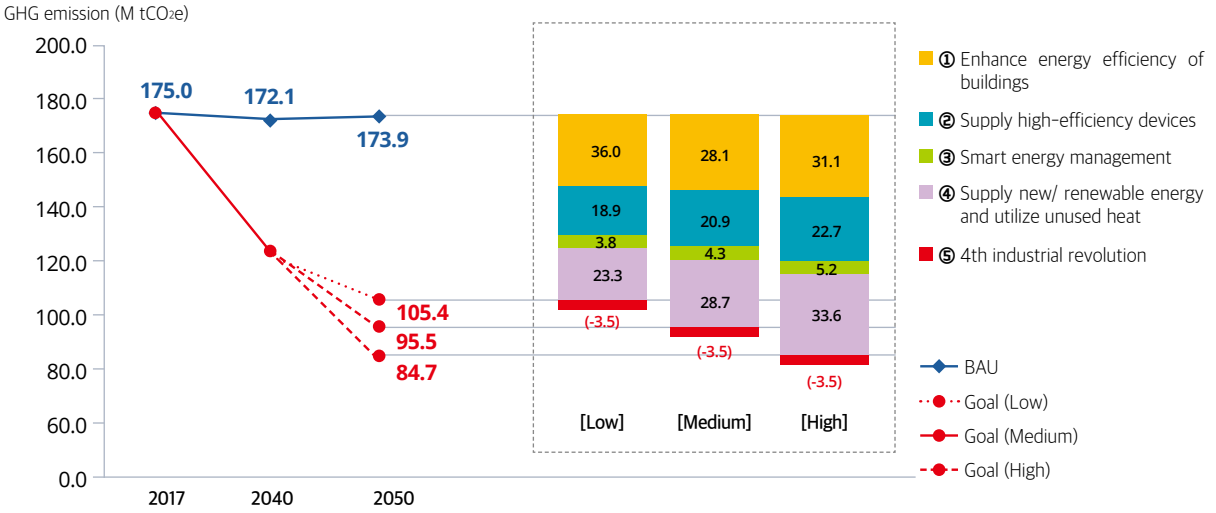
Source : 2050 Low Carbon Society Vision Forum (2020), 2050 LEDS.

[Table 4-7] 2050 Emissions scenario for building sector (Unit : M ton CO_2e, %)

Category		2050 Target as per Review on the Low Carbon Society Vision Forum (vs. 2017)				
		Option 1	Option 2	Option 3	Option 4	Option 5
Building Sector	Emission	175	188	203	214	225
	Reduction Quantity	35.3	34.0	32.5	31.4	30.3
	%Reduction	66.8%	64.4%	61.6%	59.5%	57.3%
	Key social aspects	Green buildings become common; maximize new / renewable energy, e.g. unused heat etc	Green buildings become common; stronger supply of new / renewable energy	Green buildings become popular; stronger supply of new / renewable energy	Green buildings become popular; seek supply of new / renewable energy	Stronger management of green buildings; seek supply of new / renewable energy

Source : 2050 Low Carbon Society Vision Forum (2020), 2050 LEDS.

<Figure 4-13> 2050 LEDS GHG emission reduction scenario for building sector



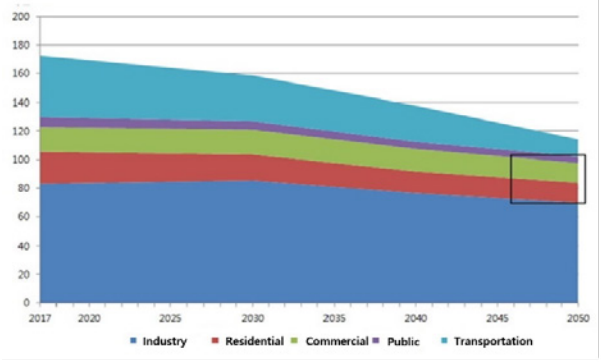
Source : 2050 Low Carbon Society Vision Forum (2020), 2050 LEDS.

2) Decarbonization and energy transition scenario by KEI

● Key Assumptions

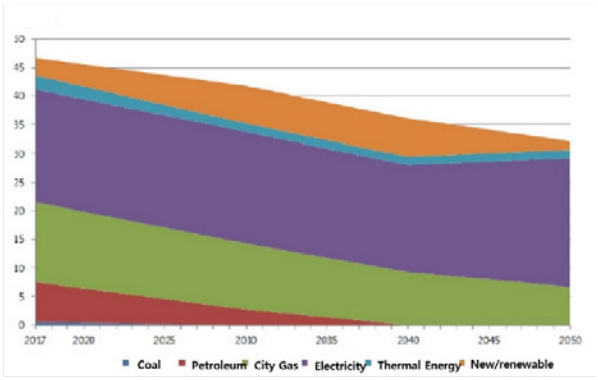
- National Research Council for Economics, Humanities and Social Sciences (NRC) commissioned the research on "Sustainable Development and Transition of Energy and Industry" to Korea Environment Institute (KEI) as a joint research project in 2019, and Dr. Lee, Chang-Hun et al, proposed the In-depth Scenario on Energy Transition to Limit Global Warning below 1.5℃ by 2050.
- Through dramatic improvement of energy efficiency, increased use of electricity which has high potential of decarbonization, and drastic expansion of use of renewable energy, the scenario suggests that the CO_2 emission by Korea can be cut by 91.5%, from 592 million tons of CO_2 equivalent in 2017 to 50 million tons of CO_2 equivalent in 2050, and that net-zero can be achieved with the support of developing countries in reducing GHG emission.
- Assuming that energy efficiency would be improved by 3.0% every year starting from 2018, final energy consumption can be reduced by 33.7%, from 172.6 million TOE in 2017 to 114.4 million TOE in 2050.
- The final energy consumption by the building sector was 46.7 million TOE in 2017, representing 27.1% of total final energy consumption, and is forecasted to decrease by 32.4%+ by 2050, reaching 31.6 million TOE. The use of electricity is expected to escalate rapidly from 2040, assuming that electrification will gain full speed from this period. The share of electricity in energy consumption is expected to increase from 42.0% in 2017 to 56.1% by 2050.

<Figure 4-14> Final energy consumption by sector



Source : Lee, Chang-Hun et al. (2019)

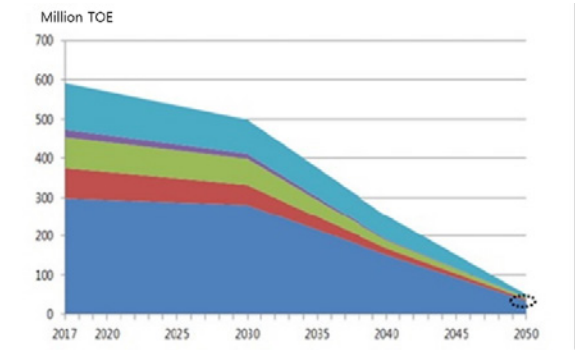
<Figure 4-15> Energy consumption by source by building sector



Source : Lee, Chang-Hun et al. (2019)

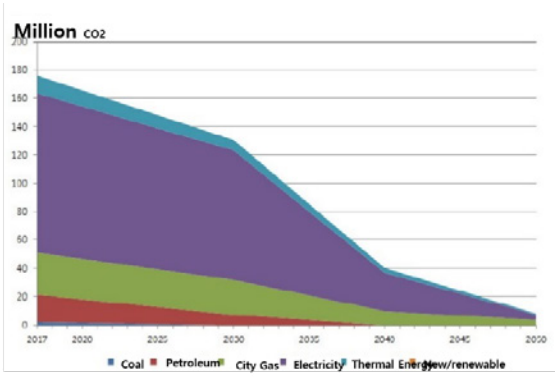
- CO_2 emission by the whole building sector will be reduced by 95.3%, from 176.2 million tons in 2017 (29.7% of total emission) to 8.2 million tons in 2050, to account for 16.2% of total emissions.
- In particular, CO_2 emission from electricity will decrease sharply, contributing to a large reduction of emissions between 2030 and 2040; this assumes that renewable energy will replace the reduced use of electricity.

<Figure 4-16> CO_2 emission pathway by sector



Source : Lee, Chang-Hun et al. (2019)

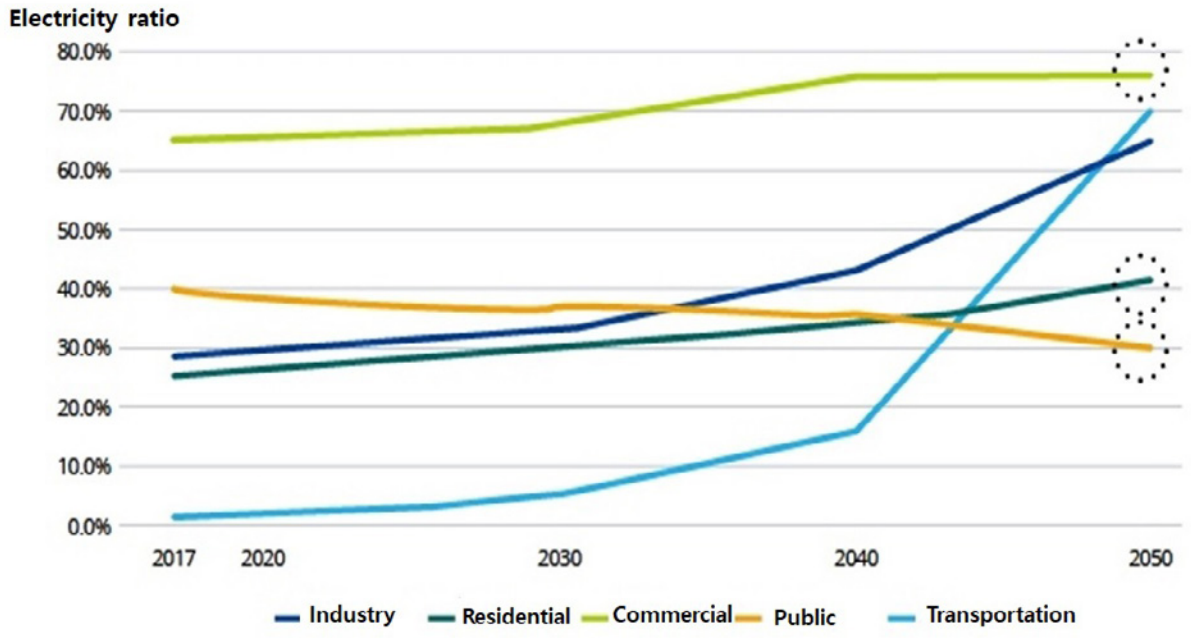
<Figure 4-17> CO_2 Emission pathway of building sector



Source : Lee, Chang-Hun et al. (2019)

- Electrification is foreseen to trend upward in the residential and commercial buildings, but to move downward in the public buildings.

<Figure 4-18> Electrification ratio by sector



Source : Lee, Chang-Hun et al. (2019)

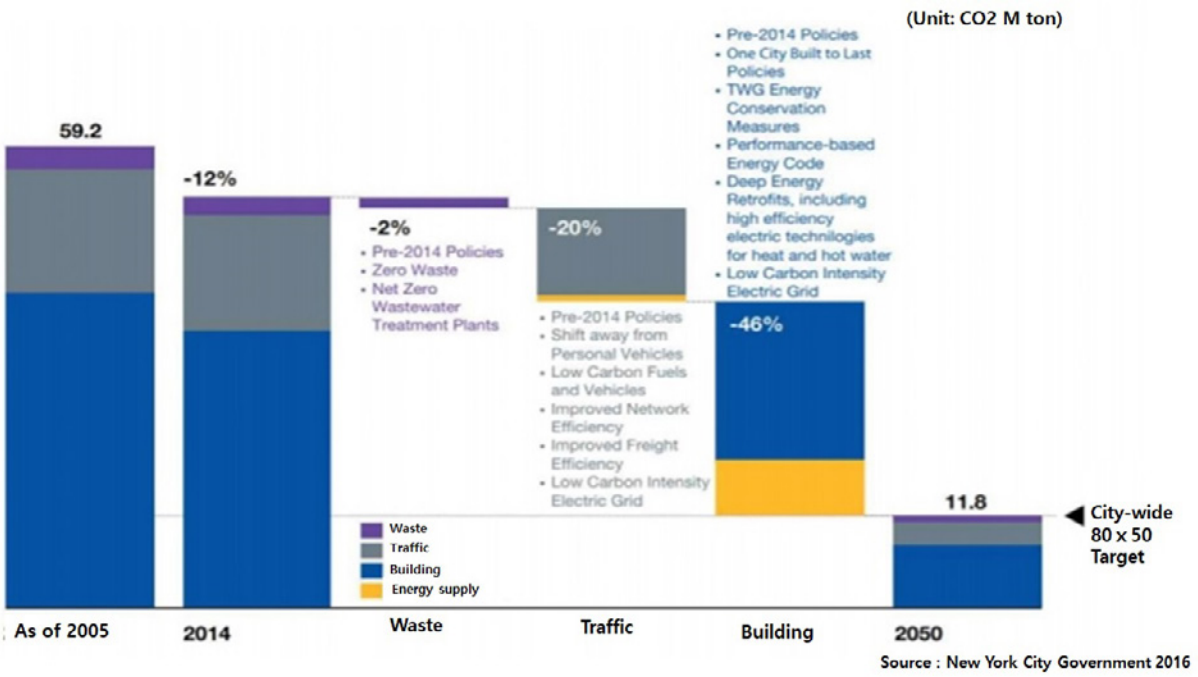
4.2.2 Scenario and reduction plan of other countries

1) 2050 Roadmap of New York City[38)]

- By publishing New York City's Roadmap to 80X50 in September 2016, New York City declared its long-term strategy to reduce GHG emission with a view to achieving the Local Law66; in the Roadmap, the role of the building sector is emphasized to be critical in order for the City to reduce GHG emission by 80% by 2050.
    - The building sector and the transportation sector are anticipated to contribute to achieving the targeted 80% GHG emissions cut by, respectively, 46% and 20%; the Roadmap underscores the importance of enhancing energy efficiency of the building sector.

38) This section had been extracted from the Report on NCY's Green New Deal Policy and its Implications published by Korea Research Institute for Human Settlements (Lee, Jung-chan, 2019).

<Figure 4-19> Pathway to cut 80% of GHG emission by 2050 as per NYC Roadmap to 80X50



Source : New York City Government 2016

- NYC particularly emphasizes the need for the strategy to reduce GHG emission from medium-sized and large buildings. To this end, the Climate Mobilization Act was passed, aiming for the medium-sized and large buildings to reduce GHG emission by 40% until 2030 and by 80% until 2050.

- The Climate Mobilization Act is a package of ten legislations, consisting of eight Introductions and two Resolutions. The contents are as below:

[Table 4-8] Summary of NYC's Climate Mobilization Act

<table>
<tr><th>Category</th><th>Summary</th></tr>
<tr><td>Building Retrofits</td><td>
● Core of the 10 legislations contained in the Climate Mobilization Act
● To obligate medium-sized and large buildings, whose total ground area is 25,000 ft2 (2,300m2) or above, to reduce GHG emission by 40% by 2030 and by 80% by 2050, compared to 2005 level
- A more aggressive goal of 40% by 2025 and 50% by 2030 has been imposed on the NYC government buildings
● To form the Office Building Energy and Emission Performance in NYC to be the organization responsible for restricting GHG emission by buildings already in NYC
- To create a government-led protocol to assess the annual energy consumption volume of the buildings
- To monitor energy consumption and GHG emission by the buildings, and supplement the emissions assessment methodology, emissions restriction/goal-setting/planning in order to reduce GHG emission by 40% compared to 2005 by 2030
- To develop an online website where building owners can assess and submit their emission quantity, to serve as the basis to evaluate and prove the respective building's GHG emission every year
● This legislation is to be applied to medium and large sized buildings from 2024 with the purpose of assessing and restricting GHG emissions
- The buildings are being coded and graded currently to be assigned with emissions cap for 2024~2029 and 2030~2034
- From 2050, the same emissions cap (0.0014tCO_2e/ft2/year; 1.4kg/ft2/year) will be applied to all buildings without differentiation
</td></tr>
<tr><td>PACE Financing</td><td>
● To implement the Sustainable Energy Loan Program so as to provide funding to building owners to assist their installation of renewable energy systems and improvement of energy efficiency
- This refers to PACE (Property Assessed Clean Energy) financing; the objective is to provide the funds required to improve the buildings' energy efficiency
- The government provides the building owners with the funds necessary to install renewable energy systems or improve energy efficiency; building owners will gain profit by saving energy costs and generating energy in small quantities; building owners will be repaying the government loan over a long-term through property tax etc (e.g.: 20 years)
</td></tr>
<tr><td>Building Efficiency Grade</td><td>
● To adjust the criteria for grading the energy efficiency of buildings
- While grade B (out of A~D) was assigned if a building exceeded 50%, all grade ranges have been adjusted so that the cutoff for grade B is now 70%
<table>
<tr><th>Category</th><th>Grade A</th><th>Grade B</th><th>Grade C</th><th>Grade D</th></tr>
<tr><td>Before</td><td>90-100%</td><td>50-89%</td><td>20-49%</td><td>1-19%</td></tr>
<tr><td>After</td><td>85-100%</td><td>70-84%</td><td>50-69%</td><td>1-54%</td></tr>
</table>
</td></tr>
</table>

Large Wind Turbines	● NYC Department of Buildings (DOB) must include wind energy generation in its toolbox of renewable energy technologies ● DOB has obligation to develop and support with the standards, technology and authorization for installation of large wind turbines in appropriate locations - (Definition) Large wind turbines with 200m2 or wider swept area defined in the building code - (Speed) Resistance up to 130 mph (58.1 m/s) - (Disposal) Turbines to be disposed of if the manufacturer judges that the turbine's life cycle is over or if the turbine had not been generating energy for over 12 months - (Others) To provide the standards for appearance (color), design, suspension and lock, shadow and signal interference
Green Roofs for New Construction	● To add sustainable roofing zone as a new building code in NYC - (Definition) To obligate sustainable roofing zone for new construction or major renovation- a roof structure that has either the solar photovoltaic power generation system or the green roof system or the combination of the two systems - If the roof area is 200f t2 (18.5m^2) or below, minimum 4kw solar photovoltaic power generation system needs to be installed - If the roof inclination is 2/12 or less (4km or less), the building should at least have the green roof system
Green Roofs on Smaller Buildings	● To expand the target for application of sustainable roofing zone as defined in the Green Roofs for New Construction legislation - (Before) If the roof area is 200f t2 (18.5m^2) or below, minimum 4kw solar photovoltaic power generation system needs to be installed - (Added) If the purpose of the building is Group R (residential) and the building has 5 or less floors, 4+kw solar photovoltaic power generation system needs to be installed for the roof area of 100 or less ft2 (9.2m^2) ● The NYC Housing Preservation and Development (HPD) should analyze the potential impact of 1032-A (sustainable roofing zone) on the affordability of certain buildings within four years - To consider such aspects as tax exemption, loan, subsidy, HPD operation, among others
Green Roof Tax Abatement	● NY State legislature to pass the legislation on increasing real estate tax cut for installing Green Roofs to 15 dollars per 1 ft2, and for the governor to sign it - While it costs, in average, 25 dollars/ft2 to install the Green Roof, the government's subsidy is only 4.5~5.23 dollars/ft2 (20%); to promote Green Roofs, NYC Council is prompting the NY State legislature to increase the subsidy to around 60% (15 dollars/ft2)

Source : Lee, Jung-chan (2019), The Official Website of the City of New York (2019)

2) IEA Scenario[39)]

- The Energy Technology Perspectives 2017 issued by the International Energy Agency (IEA) analyzed the three GHG emissions reduction scenarios ("RTS", "2DS", "B2DS") of the building sector.

[Table 4-9] IEA Climate Change Scenarios

Scenario	Key Assumptions
RTS (Reference Technology Scenario)	Application of NDC
2DS (2°C Scenario)	50% probability of global warming by less than 2°C
B2DS (Beyond 2°C Scenario)	50% probability of global warming by less than 1.75°C Reduction measures for the respective sectors are more rigid, assuming minimum CDR (e.g. BECCS), compared to IPCC's SR15, so it is good reference to the 1.5°C policies

Source : IEA (2017), Energy Transition Forum

- The breakdown of final energy consumption by the building sector by source of energy according to the analysis of IEA provides the grounds to expect an increase of supply of electric, thermal and renewable energy.

[Final 4-10] Final energy consumption by building sector by source of energy

Final Energy Consumption (PJ[40)])					Difference vs. RTS (NDC)				
	2014	2030				2014	2030		
		RTS	2DS	B2DS			RTS	2DS	B2DS
Coal	5,733	4,440	4,233	4,201	Coal	1,291	1,000	0.953	0.946
Petroleum	13,201	12,860	12,286	11,479	Petroleum	1,027	1,000	0.955	0.893
Natural gas	25,830	26,813	25,457	24,432	Natural gas	0,963	1,000	0.949	0.911
Electricity	38,228	43,129	41,835	41,724	Electricity	0,886	1,000	0.970	0.967
Thermal	6,393	7,008	6,935	6,956	Thermal	0,912	1,000	0.990	0.993
Renewable energy	3,857	4,978	5,163	5,245	Renewable energy	0,775	1,000	1.037	1.054
Traditional biomass	29,802	30,190	30,082	30,082	Traditional biomass	0,987	1,000	0.996	0.996
Total	123,044	129,419	125,991	124,119	Total	0,951	1,000	0.974	0.959
Final energy consumption per capita (MWh)	4,712	4,600	4,207	3,898	Final energy consumption per capita (MWh)	1,024	1,000	0.914	0.847

Source : IEA (2017), Energy Transition Forum

39) This section had been extracted from the Study on Policy Measures for Management of Demand for Building Energy for the Development of the Basic Plan for Climate Change conducted by the Energy Transition Forum (2018).

40) PJ (petajoule) = 1015 J ≈ 23885 toe

- According to the RTS (NDC) scenario, heating has a great potential for saving energy regardless of which scenario, and the saving potential of cooling is greater under the B2DS scenario than the 2DS. (Table 4)
  - The B2DS scenario requires greater reduction of final energy consumption and states that there is more potential to save energy due to increase of demand for cooling following global warming. The scenario foresees that air-source heat pumps (ASHP) will play a bigger role in cooling.
  - Although less significant than cooling and heating in terms of absolute quantity, the potential to reduce energy consumption of hot water and lighting is expected to grow as the goal to mitigate climate change gets tougher.

[Table 4-11] Reduction of final energy consumption in building sector compared to RTS (NDC)

Reduction of Final Energy Consumption				
2DS	2014	2020	2025	2030
Heating	0	-3877	-18628	-44675
Cooling	0	-615	-3343	-9240
Hot water	0	-1025	-3932	-8005
Lighting	0	-717	-3273	-7234
Cooking	0	-145	-981	-2832
Home appliances	0	-810	-1963	-5644
Others	0	-1433	-5421	-11330
B2DS	2014	2020	2025	2030
Heating	0	-5814	-27251	-66044
Cooling	0	-1649	-8738	-21522
Hot water	0	-1186	-6168	-16436
Lighting	0	-1520	-7740	-18298
Cooking	0	-817	-2286	-6853
Home appliances	0	-584	-3633	-103106
Others	0	-1433	-5642	-12085

Contribution by Sources of Demand				
2DS	2014	2020	2025	2030
Heating	0	47.7%	49.6%	50.2%
Cooling	0	7.6%	8.9%	10.4%
Hot water	0	12.6%	10.5%	9.0%
Lighting	0	8.8%	8.7%	8.1%
Cooking	0	1.8%	2.6%	3.2%
Home appliances	0	3.8%	5.2%	6.3%
Others	0	17.6%	14.4%	12.7%
B2DS	2014	2020	2025	2030
Heating	0	46.5%	44.3%	43.6%
Cooling	0	13.2%	14.2%	14.2%
Hot water	0	9.5%	10.0%	10.8%
Lighting	0	12.2%	12.6%	12.1%
Cooking	0	2.5%	3.7%	4.5%
Home appliances	0	4.7%	5.9%	6.8%
Others	0	11.5%	9.2%	8.0%

Source : IEA (2017), Energy Transition Forum

- The B2DS scenario analyzes the contribution of the respective means of saving energy applicable to the building sector to mitigate climate change (compared to RTS).
  - As time passes, the impact of “technology replacement” will increase; prudent yet bold policies are required since replacing technologies is difficult for buildings once they are built and district heating is related with city planning.

- "Efficiency improvement of devices/equipment" and "enhancing building envelope" could also contribute considerably in reducing the final energy consumption.

[Table 4-12] Contribution by different means of reducing energy consumption under B2DS Scenario (vs. RTS)

Reduction of Final Energy Consumption (PJ)					%Reduction by Different Means under B2DS vs. RTS				
2DS	2014	2020	2025	2030	2DS	2014	2020	2025	2030
Building envelope improvement	0	-3377	-6542	-9912	Building envelope improvement	0	24.2%	23.1%	23.7%
Device/equipment efficiency improvement	0	-4949	-8893	-12133	Device/equipment efficiency improvement	0	35.5%	31.4%	29.0%
Technology replacement	0	-4054	-9433	-14887	Technology replacement	0	29.0%	33.3%	35.5%
Others	0	-1576	-3480	-4960	Others	0	11.3%	12.3%	11.8%

Source : IEA (2017), Energy Transition Forum

- According to the analysis on the contribution by the respective means to reduce CO_2 emission in the building sector to mitigate climate change as per the B2DS scenario, B2DS requires a far more drastic cut of GHG emission, largely CO_2 emission, than the RTS.

  - In terms of the potential to reduce CO_2 emission of the end-use energy, the source of electricity is expected to have a growing impact; accordingly, IEA predicts that low carbon emission or decarbonization of Electricity will be the essence of the policies pertaining to GHG emissions reduction in the building sector.

[Table 4-13] Contribution by different means to reduce CO_2 emission under B2DS Scenario

(vs. RTS)

CO_2 emission (GT CO_2)				
2DS	Peak(2013)	2020	2025	2030
RTS	9,534	9,042	9,153	9,279
B2OS		8,137	6,855	5,050
Direct reduction		528	1,387	2,442
Improving building envelope		135	324	548
Efficiency improvement of devices/equipment		168	414	684
Technology and fuel replacement		225	649	1,230
Indirect reduction (generation)		378	910	1,787
%Reduction vs. peak		14.6%	28.1%	**47.0%**
%Total reduction vs. RTS		10.0%	25.1%	**45.6%**
%Direct reduction vs. RTS		5.8%	15.2%	26.3%

%Reduction by Reduction Means under B2DS vs. RTS and Peak Emission

2DS		2014	2020	2025	2030
Direct Reduction	Building envelope improvement	0	14.9%	14.1%	13.0%
	Efficiency improvement of devices / equipments	0	18.5%	18.0%	15.7%
	Technology and fuel replacement	0	24.9%	28.3%	29.1%
Indirect reduction (Generation)		0	41.6%	39.6%	42.3%

Source : IEA (2017), Energy Transition Forum

● **Need for electrification of buildings** (Deason et al., 2018)

- As the volume of indirect reduction has greater potential than direct reduction, the US National Renewable Energy Laboratory is working on the technologies and scenarios which enable the building sector to operate mostly on Electricity as the end-use energy.
- The air-source heat pump space heating/cooling (ASHP) supplies 2~4 times more heat than the electric energy input required to operate (i.e., COP[41] = 2~4); despite variations subject to the air temperature of the heat source, ASHP has better energy efficiency than electric heaters. Also, ASHP is more appropriate for electrification owing to its cost-effectiveness as it can provide heating and cooling simultaneously.
- Electric water heaters combined with demand response (DR) are capable of reacting flexibly to the request for demand reduction by the governing body of the Electricity market (e.g. Korea

41) COP (coefficient of performance): [Output cooling/heating energy] / [Input electric energy]

Power Exchange) by shifting, reducing or turning on the load. The capacity to react to the request for demand reduction could serve as another income source for the building owner (other types of water heaters cannot be used). Broader implementation of policies that support the combination of demand response and electric water heaters is likely to expedite efforts for electrification.

- The characteristics of net-zero energy buildings make them favorable to electrification; according to the grading criteria, full electrification could be an easier option for net-zero energy buildings than mixing city gas and Electricity . Also, due to other advantages such as cost, efficiency and intensity of GHG emission (when supplying low emission Electricity), building more net-zero energy buildings could be an effective driver of electrification.

4.3 Policy Recommendation for Building Sector

4.3.1 Difficulties in promoting GHG emissions reduction in building sector

- Korea's policies to enhance energy efficiency and reduce GHG emissions in the building sector have been rather fragmented as they are developed by the Ministry of Land, Infrastructure and Transport (MOLIT), Ministry of Environment (MOE) and Ministry of Trade, Industry and Energy (MOTIE). Enforcement and authorization/certification are conducted by professional institutions under the ministries such as Korea Land and Housing Corporation (LH), Korea Environment Corporation (KEC), Korea Environmental Industry & Technology Institute (KEITI) and Korea Energy Agency (KEA).
- The statistics on energy consumption is announced by the Korea Energy Economics Institute (KEEI), Korea Real Estate Board (REB), Greenhouse Gas Inventory and Research Center (GIR) and the Korea Energy Agency (KEA) using different collection methods and criteria; GIR and KEA are responsible for greenhouse gas related statistics, but the scope of disclosure is limited.

[Table 4-14] Energy statistics collection in building sector

Owner		Enforcement by		Data provision by	Disclosed information				
					By building / By purpose	By registered address	Total volume, residential/ commercial/ public	Electricity/ city gas/ thermal energy Consumption volume	Petroleum/ coal consumption volume
MOLIT	Commission → Report ←	REB	Data collection ←	KEPCO Korea Gas Corporation (KGC)	x / x	○	○	○	x
MOE	Commission → Report ←	GIR	Data collection ←	REB KEEI	x / x	x	Total GHG	x	x
MOTIE	Commission → Report	KEA	Data collection ←	KEPCO Excess energy consuming companies	x / x	x	x	Total energy consumption	
KEEI		KEEI	Data collection ←	KEPCO KGC Korea National Oil Corporation Korea Coal Corporation	x / x	x	○	○	○

Source : developed by the author

- Many building energy related laws, regulations, systems and authorization/certifications are in place, governed by multiple institutions; however, nobody is evaluating how much GHG emission has actually been reduced affected by such systems and projects.
    - Either, the standards for evaluating the energy efficiency and the effect of GHG reduction and

the standards for technology options are not clearly defined, or are not shared sufficiently with the building owners.

- In the case of green remodeling, the standards for improving energy efficiency have been developed for insulation, windows and doors; As a result, most of the green remodeling projects that receive government funding tend to focus on insulation, windows and doors.

[Table 4-15] Laws, regulations, systems and authorization for building sector in Korea

Category	Higher level law	Laws, regulations, systems and certification
Increase of green buildings	Green Building Construction Support Act	Standards for designing energy saving buildings; Total energy consumption cap for buildings; Certification of energy efficiency rating for buildings; Certification of net-zero energy buildings; Certification for green construction and related incentives; Energy saving plan for buildings; Green remodeling projects;
Management of GHG emissions in buildings sector	Basic Act on Low Carbon Green Growth	GHG energy target management system for buildings; External emission trading businesses for building sector;
Rationalization of energy use	Energy Use Rationalization Act	Carbon point scheme; Policy to monitor efficiency of energy consuming equipment; Rationalization of energy use by public institutions; ESCO business; Supply of Building Energy Management System (BEMS);
Promotion of use of new and renewable energy	New and Renewable Energy Development, Use, and Distribution Promotion Act	Support for supplying new and renewable energy-Building support business; System obligating public institutions to use new/renewable energy;

Source : developed by the author

- Until recently, the envelope of buildings and cooling and heating technologies were considered as the only levers to manage energy efficiency/reduction and GHG emission reduction in the building sector, and the policies and R&D support were concentrated solely on those areas. A variety of policies were enforced sporadically without differentiating the types or sizes or the reduction pathways of the buildings.

4.3.2 Policy direction

1) Challenges

- The most significant challenges for the Korean building sector in reducing the GHG emissions to achieve carbon neutrality are increasing number of buildings, augmenting share of old buildings and incremental Electricity consumption.
- Residential buildings and public buildings must, respectively, refrain from using city gas, and petroleum and coal, and ultimately completely abandon these energy sources. Furthermore, commercial buildings must increase their use of renewable energy.
- To control GHG emissions, the amount of GHG emitted by using Electricity must be drastically cut; the source of electric energy should be shifted to renewable energy so that Electricity can be generated with zero emission.
- As more buildings will age going forward, the enhancement of energy efficiency of old buildings and commercial buildings is urgent. However, there are insufficient practical tax benefits or support policies to encourage the investment by building owners.
- Energy consumption by non-residential buildings, especially by commercial buildings, is rapidly increasing; energy consumption by commercial buildings needs to be more effectively managed. More comprehensive and innovative technologies should be applied to the building sector, such as increased use and storage of electricity generated from renewable energy sources, electrification and comprehensive design of environmentally friendly buildings, in order to achieve carbon neutrality.
- As the data on energy consumption by buildings and its disclosure are not extensive enough, it is necessary to obligate the installation of smart meters and establish the Data Dam on buildings' energy consumption, for the purpose of creating a comprehensive system for managing energy consumption and GHG emissions.
- It is currently difficult to control the increase of electric energy consumption because the electricity cost is not differentiated by the specific purposes of the commercial buildings.

2) Policy recommendation

- With a view to reducing the GHG emissions by the building sector, the 2nd Basic Plan for Climate Change Response proposes: ▲ increase of green buildings (improved energy performance of existing buildings and stronger energy performance standards applied for authorization of new constructions); ▲ enhancement of energy efficiency (stronger standards on energy consumption efficiency for home appliances, office devices and lighting); and ▲ supplementation of infrastructure (establishment of energy data infrastructure for buildings, enhanced self-sufficiency of energy at city level).

- To reduce the GHG emissions by the building sector, the 2050 LEDS suggests: ▲ enhancement of energy efficiency of buildings; ▲ supply of high-efficiency devices; ▲ smart energy management; and ▲ supply of new and renewable energy and utilization of unused heat.

- For the purpose of this report, it is proposed that all buildings achieve net-zero (some buildings to become micro power plants) and become intelligent buildings, and that the (electric, gas, thermal) energy trading system and the GHG cap system are introduced in the building sector so that the Korean building sector can become carbon neutral.

    - To support this idea, the report will propose policy directions specifically for the respective purpose of the buildings, by distinguishing old and new buildings, for the short and long-term, and for the innovation of systems, technologies and the society.

[Table 4-16] Strategy for building sector to achieve carbon neutrality by 2050

Purpose **Residential** / Target **Systems Innovation**

Existing Buildings	New Buildings
Short-term (~2022) and mid-term (~2030) Preparation for systems innovation for drastic GHG emissions reduction from 2030	Short-term (~2022) and mid-term (~2030) Preparation for systems innovation to achieve net-zero buildings and net-zero cities
• To support green remodeling with public fund only where it is directly related to energy efficiency and GHG reduction • To develop regulation on emissions directly related to the quantity of reduction • To adopt GHG emissions cap by purpose of buildings • To adopt inter-building GHG emission trading system • Full scope re-designing of zero energy buildings (to adjust from current 5-grades to 3-grades to achieve net-zero practically; prompt installation and utilization of renewable energy)	• To obligate inclusion of renewable energy inside buildings when planning new cities and new buildings (e.g. wind and solar energy) • To obligate installation of smart meters and HEMS for new constructions • Comprehensive environmentally friendly design of buildings • To develop energy consumption and GHG emissions monitoring system at local government level
To develop energy consumption and GHG emissions monitoring system at local government level	Long-term (2030~) Inter-building energy trading system
• Regulation on existing buildings' energy efficiency - Installation and use of renewable energy, replacement with high-efficiency devices, adoption of building energy management system • To apply cap on total energy consumption by buildings, cap on total GHG emission by buildings • To develop and pilot inter-building (electric, thermal, gas) energy trading system • To implement energy and GHG emission trading system by purpose of buildings • To facilitate inter-building energy trading market from 2040 • To obligate ESS or fuel battery installation when building renewable energy facility	• To implement energy and GHG emission trading system by purpose of buildings • To implement inter-building (electric, thermal, gas) energy trading system • To facilitate inter-building energy trading market from 2040 • To adopt net-zero certification for all buildings • To adopt intelligent building certification for all buildings • To consider quantity of solar radiation, condition, speed and direction of wind when designing and building new cities; to minimize the movement of vehicles to minimize energy consumption and GHG emissions. To adopt a certification system for the above.

Purpose **Residential** / Improvement **Technology Innovation**

Existing Buildings	New Buildings
Short-term (~2022) and mid-term (~2030)	Short-term (~2022) and mid-term (~2030)
• Among the new technologies applicable to residential buildings such as insulation, building envelope, and heating, ventilation and air conditioning system (HVAC), select those that can be applied in the short-term for public rental houses to spread the effect of controlling energy consumption and GHG reduction • To develop and pilot urban small-size wind power technology optimized for residential buildings • To develop and install HEMS optimized for residential size areas • To analyze building energy data by supplying smart meters • To develop air-source heat pumps optimized for residential size buildings	• To install urban small-size wind turbines, built-in and roof-type solar photovoltaic power generators • To install electric water heaters combined with demand response • To install air-source heat pumps • To develop next generation bio-technologies applicable to buildings (e.g. microalgae) • To turn some buildings into micro power plants by using renewable energy and unused heat and storing energy
Long-term (2030~)	Long-term (2030~) Electrification; some buildings functioning as power plants (2040~)
• To install renewable energy facilities (e.g. roof-top, close range, roof, wall) • To use electricity instead of gas for cooling and heating (by purpose) • To install air-source heat pump optimized for residential size buildings and install water heaters combined with demand response	• To consider optimization of energy efficiency when constructing physical (electric, gas, thermal) energy network infrastructure • To use electricity instead of gas for cooling, heating and cooking (by purpose) • To obligate installation of electric water heater combined with demand response (by purpose) • To obligate air-source heat pumps (by purpose)

Purpose **Residential** / Improvement **Technology Innovation**

Existing Buildings	New Buildings
Short-term (~2022) and mid-term (~2030)	Short-term (~2022) and mid-term (~2030)

- Unlike power generation or transportation, buildings are fixed to certain cities or districts; local governments can assume ownership regarding energy consumption and GHG emissions, and set reduction targets and directions.
- Each local government can set the direction toward carbon neutrality and induce residents' consensus.
- It is important for the individuals to change their behaviors and understand that energy consumption may increase to a certain extent following the use of electric devices and electrification, but that it is actually a way of saving energy; it is also important to reach a social consensus, to change the social convention and culture to internalize the habit of saving energy.
- Nationwide energy saving campaign can be implemented : e.g. social campaigns, public advertisements, campaigns within business circles or community service centers of the respective local governments, educational campaigns at primary and secondary schools, online and SNS campaigns.

Long-term (2030~)	Long-term (2030~)

- The society needs to believe that saving energy is actually an act of accumulating asset and that it could become a source of income generation.
- The society needs to perceive that saving energy is a social etiquette and the habit of cultured and intellectual people.

Purpose **Residential** / Improvement **Technology Innovation**

Existing Buildings	New Buildings
Short-term (~2022) and mid-term (~2030)	Short-term (~2022) and mid-term (~2030)
• To provide tax benefits when non-residential commercial buildings adopt and apply technologies to enhance energy efficiency and reduce GHG emissions * Legislation to create realistic tax benefits, which are differentiated by purpose and size of buildings, is required to attract investment by building owners • To support green remodeling with public fund only where it is directly related to energy efficiency and GHG reduction • To develop regulation on emissions directly related to the quantity of reduction • To adopt GHG emissions cap by purpose of buildings • To adopt inter- building GHG emission trading system • Full scope re-designing of zero energy buildings (to adjust from current 5-grades to 3-grades to achieve net-zero practically; prompt installation and utilization of renewable energy) • To obligate ESS or fuel battery installation when building renewable energy facility	• To obligate inclusion of renewable energy inside buildings when planning new cities and new buildings (e.g. wind and solar energy) • To obligate installation of smart meters and HEMS for new constructions • To develop energy consumption and GHG emissions monitoring system at local government level
Long-term (2030~)	Long-term (2030~)
• Regulation on existing buildings' energy efficiency - Installation and use of renewable energy, replacement with high-efficiency devices, adoption of building energy management system etc • To apply cap on total energy consumption by buildings, cap on total GHG emission by buildings • To develop and pilot inter-building (electric, thermal, gas) energy trading system • To implement energy and GHG emission trading system by purpose of buildings • To facilitate inter-building energy trading market from 2040	• To implement energy and GHG emission trading system by purpose of buildings • To implement inter-building (electric, thermal, gas) energy trading system • To facilitate inter-building energy trading market from 2040 • To adopt net-zero certification for all buildings • To adopt intelligent building certification for all buildings • To consider quantity of solar radiation, condition, speed and direction of wind, distance between buildings and height of buildings when designing and building new cities; to minimize the movement of vehicles to minimize energy consumption and GHG emissions. To adopt a certification system for the above.

Purpose **Residential** / Improvement **Technology Innovation**

Existing Buildings	New Buildings
Short-term (~2022) and mid-term (~2030)	Short-term (~2022) and mid-term (~2030)
• To develop and pilot urban small-size and large-size wind power technology optimized for commercial buildings • To obligate BEMS in all buildings • To analyze building energy data by supplying smart meters • To design buildings that minimize movement of people and goods and minimize use of energy, and to develop and pilot relevant digital technologies (starting from public buildings; to provide tax benefit for private companies) • To develop technologies conducive to energy efficiency and GHG reduction which can be applied to old, large commercial buildings	• To install urban small-size wind turbines, built-in and roof-type solar photovoltaic power generators • To develop next generation bio-technologies applicable to buildings (e.g. microalgae)
Long-term (2030~)	Long-term (2030~)
• To install renewable energy facilities (e.g. roof-top, close range, roof, wall) • To use electricity instead of gas for cooling and heating (by purpose) • To replace with high-efficiency devices • To apply new technologies conducive to energy efficiency and GHG reduction which can be applied to old buildings	• To consider optimization of energy efficiency when constructing physical (electric, gas, thermal) energy network infrastructure • To use electricity instead of gas for cooling, heating and cooking (by purpose) • To turn some buildings into micro power plants by using renewable energy and unused heat and storing energy • To transform all buildings to intelligent buildings (optimize energy consumption via AI monitoring)

Purpose **Residential** / Improvement **Technology Innovation**

Existing Buildings	New Buildings
Short-term (~2022) and mid-term (~2030)	Short-term (~2022) and mid-term (~2030)

- Unlike power generation or transportation, buildings are fixed to certain cities or districts; local governments can assume ownership regarding energy consumption and GHG emissions and set reduction targets and directions.
- Each local government can set the direction toward carbon neutrality and induce residents' consensus.
- It is important for the individuals to change their behaviors and understand that energy consumption may increase to a certain extent following the use of electric devices and electrification, but that it is actually a way of saving energy; it is also important to reach a social consensus, to change the social convention and culture to internalize the habit of saving energy.
- Nationwide energy saving campaign can be implemented : e.g. social campaigns, public advertisements, campaigns within business circles or community service centers of the respective local governments, educational campaigns at primary and secondary schools, online and SNS campaigns.

Long-term (2030~)	Long-term (2030~)

- When designing or purchasing a building, building owners believe that energy efficiency and GHG emission are the most critical factors.
- The society needs to believe that saving energy is actually an act of accumulating asset and that it could become a source of income generation.
- The society needs to perceive that saving energy is a social etiquette and the habit of cultured and intellectual people.

Source : developed by the author

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Research on Strategy and Policy by Sector for Korea 2050 Carbon Neutrality

5

Transportation Sector

5.1 Status and Characteristics of Energy Consumption and GHG Emission in Transportation Sector

5.1.1 Energy consumption in the transportation Sector

1) Energy Consumption in Korea

- Energy consumption in Korea tripled between 1990 and 2016, from 75.106 million TOE to 222.681 million TOE, and the industry sector accounted for 61.4% of the total energy consumption in 2016.
  - Total energy consumption increased by average 4.3% per annum since 1990, and 18.9% was consumed by the transport and transportation sector in 2016.

[Table 5-1] Energy consumption in Korea (Unit: 1,000TOE)

Sector	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016
Industry	36,150	62,946	83,912	94,366	117,046	127,005	128,451	130,379	135,331	135,713	138,469
	48.1%	51.6%	56.0%	55.2%	59.8%	61.7%	61.7%	62.0%	63.3%	62.2%	61.4%
Domestic Commercial	21,971	29,451	32,370	36,861	37,256	37,542	37,884	37,408	35,539	36,603	38261
	29.3%	24.1%	21.6%	21.6%	19.0%	18.2%	18.2%	17.8%	16.6%	16.8%	17.0%
Trans portation	14,173	27,148	30,945	35,559	36,938	36,875	37,143	37,330	37,636	40,292	42,714
	18.9%	22.3%	20.7%	20.8%	18.9%	17.9%	17.8%	17.8%	17.6%	18.5%	18.9%
Public Others	2,812	2,416	2,625	4,068	4,483	4,560	4,769	5,178	5,336	5,753	6,237
	3.7%	2.0%	1.8%	2.4%	2.3%	2.2%	2.3%	2.5%	2.5%	2.6%	2.8%
Total	75,106	121,961	149,852	170,854	195,723	205,982	208,247	210,295	213,842	218,361	225,681
%Increase	-	62.39%	22.87%	14.02%	14.56%	5.24%	1.10%	0.98%	1.69%	2.11%	3.35%

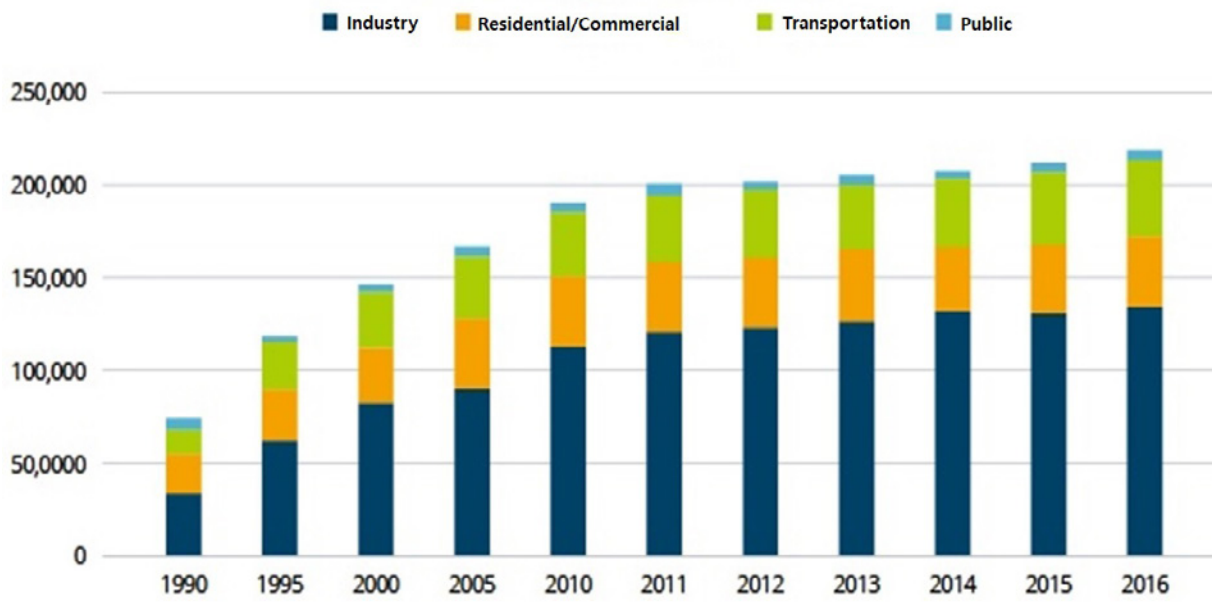
Source : Energy Statistical Year Book 2017, KEEI

2) Energy consumption of transportation sector

- In 2016, the transportation sector consumed 42.714 million TOE, which represented 18.9% of the total national energy consumption of 225.681 million TOE; 80.5% of that figure was used on the roads.
  - Average annual growth rate in transportation sector
    -1990~2000: 7.2%; 2000~2010: 2.7%; 2010~2016: 2.4%

• Energy consumption soared from late 2015 due to the low oil price worldwide. As of 2016, roads accounted for the highest share of 80.5%, followed by air transport (10.9%), marine (7.8%) and rail (0.8%).

<Figure 5-1> Energy consumption in Korea



Source : Energy Statistical Year Book 2017, KEEI

[Table 5-2] Energy consumption in transportation sector (Unit: 1,000TOE)

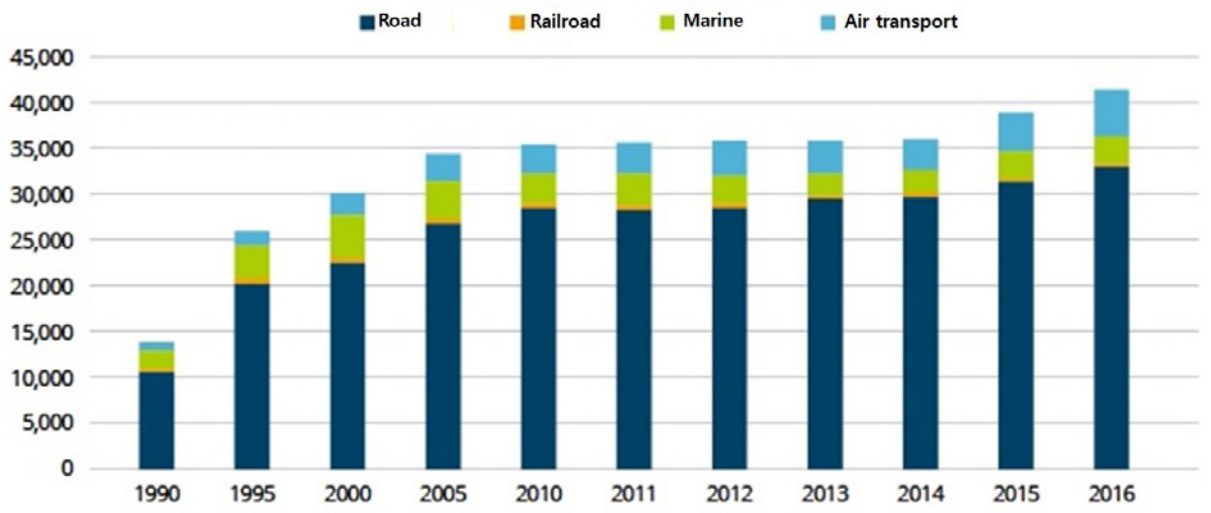
Category	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016
Road	11,205	21,218	23,554	28,144	29,820	29,672	29,886	30,813	31,045	32,768	34,369
(share)	79.1%	78.2%	76.1%	79.1%	80.7%	80.5%	80.5%	82.5%	82.5%	81.3%	80.5%
Rail	392	464	513	505	383	371	370	342	302	309	335
(share)	2.8%	1.7%	1.7%	1.4%	1.0%	1.0%	1.0%	0.9%	0.8%	0.8%	0.8%
Marine	1,669	3,618	4,705	4,092	3,282	3,366	3,154	2,433	2,319	2,946	3,351
(share)	11.8%	13.3%	15.2%	11.5%	8.9%	9.1%	8.5%	6.5%	6.2%	7.3%	7.8%
Air transport	908	1,849	2,174	2,819	3,453	3,467	3,733	3,742	3,971	4,269	4,659
(share)	6.4%	6.8%	7.0%	7.9%	9.3%	9.4%	10.1%	10.0%	10.6%	10.6%	10.9%
Total	14,174	27,148	30,945	35,559	36,938	36,875	37,143	37,330	37,636	40,292	42,714
%Increase	-	91.5%	14.0%	14.9%	3.9%	-0.2%	0.7%	0.5%	0.8%	7.1%	6.0%

Source : Energy Statistical Year Book 2017, KEEI

5.1.2 GHG emission in transportation sector

1) GHG Emission in transportation sector

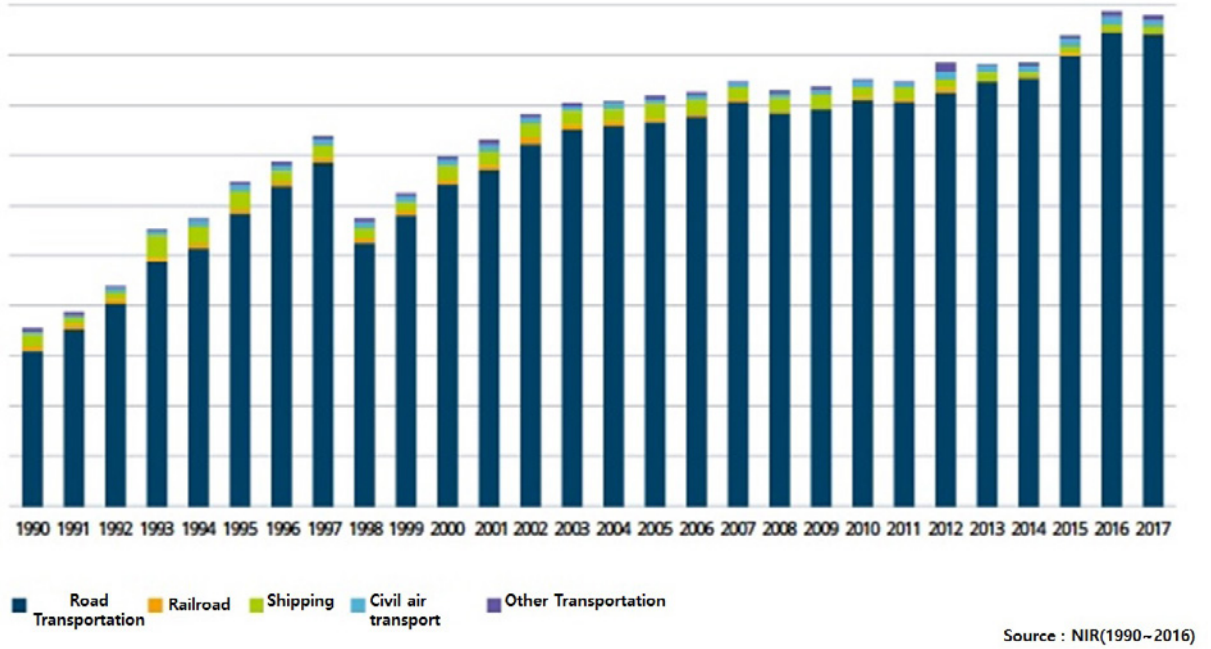
<Figure 5-2> Energy consumption in transportation sector



Source : Energy Statistical Year Book 2017, KEEI

- The trend is continuously on the rise excluding the times of the Korean financial crisis in 1998 and the global financial crisis in 2008.
- Recently, the growth rate has slowed down compared to before 2000.

<Figure 5-3> Trend of GHG emission in transportation sector (Unit: 1,000 ton CO_2 eq.)



Source : NIR(1990~2016)

- Compared to 1990, the GHG emission by the transportation sector increased by 62.8 million tons in 2017 (increased by 276.9%).
- Road transportation displayed an outstanding growth of 63.4 million tons (increased by 305.1%).
- The emission decreased in 2017 by 0.5 million tons compared to 2016 (0.3 million tons less in road transportation) → The decrease is thought to have been caused by reduced fuel consumption as the international oil price started to rise, not driven by policy.

[Table 5-3] Trend of GHG emission in transportation sector (Units: M tons CO_2 eq.)

Category	1990	1995	2000	2005	2010	2015	2016	2017
Transportation	35.5	64.7	69.9	81.8	85.4	94.2	98.8	98.3
Private Air Transport	0.8	1.3	1.4	1.0	1.1	1.5	1.7	1.7
Road	30.9	58.5	64.5	76.9	81.1	90.1	94.6	94.3
Rail	0.9	0.9	1.0	0.8	0.6	0.3	0.3	0.3
Marine	2.4	3.6	2.8	2.8	2.3	1.6	1.4	1.3
Others	0.4	0.3	0.3	0.3	0.4	0.6	0.8	0.8

Source : National Greenhouse Gas Inventory Report of Korea (1990~2017)

5.1.3 Characteristics of GHG emission in transportation Sector

- Road transportation takes up 94.3% of total emission. Road transportation emitted 63.4 million more tons of GHG compared to 1990 (305.1% increase) and is leading the growth of Korea's GHG emission.
- Purchase of diesel cars rapidly increased after implementation of the clean diesel policy and such, but the fuel economy of the vehicles is constantly deteriorating due to the consumers' unreasonable inclination toward larger cars.
- There is still much room for developing the green transport including public transportation and bicycles due to lack of policies to manage the demand for transportation and the traffic related policies being centered on cars.

[Table 5-4] Fuel economy and average GHG emission targets of new Korean cars

	Category	2015	2016	2017	2018	2019	2020
Average Fuel Economy of New Cars	Average Fuel Economy (km/L)	17	18.6	19.2	19.6	21.4	24.3
	GHG Emission (g/km)	140	127	123	120	110	97

Source : Ministry of Environment

[Table 5-5] Car sales in Korea (Unit: #Cars, %)

Category		2012	2013	2014	2015	2016
Subcompact		202,844 (17.3%)	182,021 (16.0%)	186,702 (15.4%)	173,418 (13.1%)	173,008 (12.9%)
Compact		247,632 (21.1%)	237,512 (20.9%)	255,055 (21.0%)	298,160 (22.5%)	331,167 (24.7%)
	SUV	6,661	11,998	32,932	86,233	110,621
	CDV	-	-	-	2,956	6,087
Intermediate		500,914 (42.6%)	497,135 (43.7%)	506,653 (41.7%)	539,073 (40.6%)	479,135 (35.7%)
	SUV	219,515	246,988	264,537	302,086	266,508
	CDV	21,854	35,419	32,860	24,323	10,039
Full-size		182,667 (15.5%)	186,308 (16.4%)	211,482 (17.4%)	259,478 (19.6%)	269,502 (20.1%)
	SUV	30,674	34,509	40,285	63,881	77,540
	CDV	30,448	30,442	41,629	68,266	65,992
Executive		41,834 (3.6%)	34,051 (3.0%)	54,051 (4.5%)	56,647 (4.3%)	90,567 (6.7%)
	SUV	73	11	1		-
	CDV	269	144	14	1,030	5,245
Total		1,175,891 (100.0%)	1,137,027 (100.0%)	1,213,943 (100.0%)	1,326,776 (100.0%)	1,343,379 (100.0%)

Source : Korea Automobile Manufacturers Association (KAMA)

※ Note) SUV (Sports Utility Vehicle), CDV (Car Derived Van)

- Despite the broadening sales of diesel cars, average empty vehicle weight and average GHG emission are on an upward trend because a lot of the cars sold are large vehicles.
- The government is promoting energy transition by applying stricter average fuel economy thresholds to cars and supplying eco-friendly vehicles, but unreasonable car consumption is continuing and becoming a permanent trend.

[Table 5-6] Trend of (new) car registration in major car manufacturing countries (%)

Category	France	Italy	Japan	Korea
SMALL	52.2	62.2	37.1	12.9
LOWER MEDIUM	27.7	19.0	25.0	24.7
UPPER MEDIUM	13.1	12.3	21.9	35.7
EXECUTIVE	6.9	6.5	15.9	26.8
Total	100.0	100.0	100.0	100.0

Source : Association Auxiliaire de l'Automobile (AAA), JAMA (Japan Automobile Manufacturers Association), KAMA

※ Note) Number of newly registered cars in 2016 for France and Italy;
Cumulative number of registered cars in 2015 for Japan; Cumulative number of registered cars in 2016 for Korea
Categorization in Japan: Small (below 660cc), Lower medium (660~ below 1,500cc),
Upper medium (1,500~ below 2,000cc), Executive (2,000cc and above)
Categorization in Korea: Small (below 1,000cc), Lower medium (1,000~ below 1,600cc),
Upper medium (1,600~below 2,000cc), Executive (2,000cc and above)

[Table 5-7] Cumulative number of registered cars in Korea (Unit: #Cars, %)

Category	Subcompact	Small	Medium	Large	Total
2014	1,608,004 (10.2%)	3,446,486 (21.9%)	6,582,922 (41.8%)	4,108,048 (26.1%)	15,747,162 (100.0%)
2015	1,711,674 (10.3%)	3,544,547 (21.4%)	6,883,857 (41.6%)	4,417,823 (26.7%)	16,561,665 (100.0%)
2016	1,798,962 (10.4%)	3,671,554 (21.2%)	7,154,802 (41.3%)	4,707,737 (27.2%)	17,338,151 (100.0%)

Source : KAMA

- Even if the importance of the car industry in Korea is placed into consideration, the behavioral pattern of the Korean consumers is clearly different from those of other major car manufacturing countries.

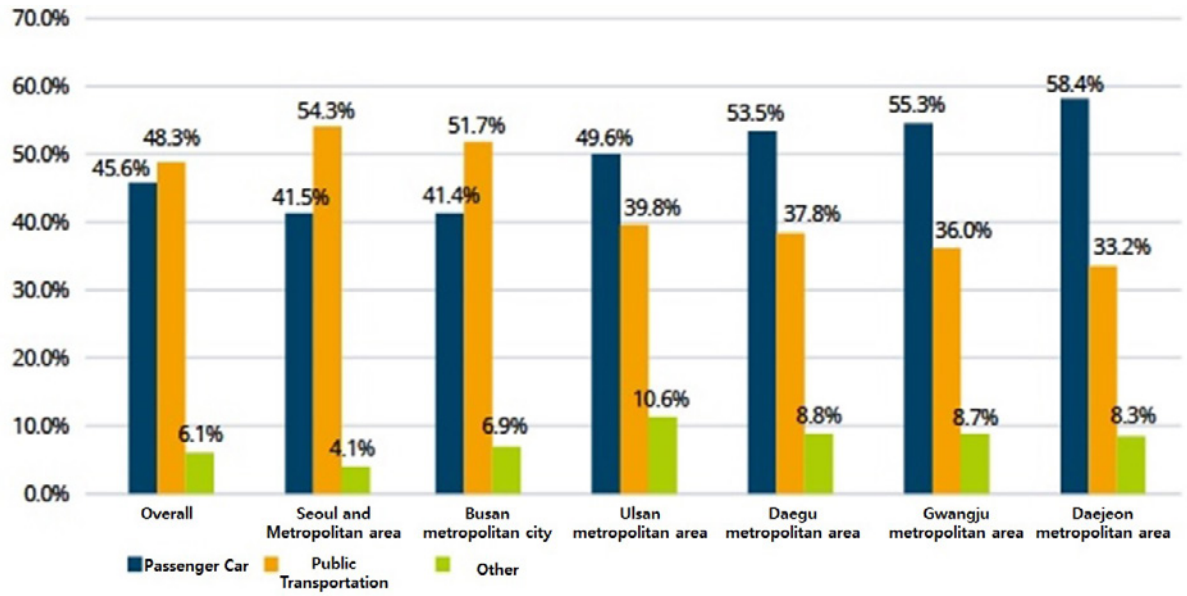
[Table 5-8] Trend of average GHG emission by new Korean cars (Unit: g/km)

Category	2013		2014		2015		2016		2017	
	City	Mixed	City	Mixed	City	Mixed	City	Mixed	City	Mixed
All Cars	164.9	140.8	165.1	141.5	166.8	143.4	166.3	143.7	165.8	143.9
(General)	160.6	136.6	160.7	137.1	161.4	137.7	162.8	139.1	162.9	140.2
(Multi-purpose)	177.0	153.8	174.6	151.3	175.4	153.0	173.1	152.2	177.4	155.8
(Other types)	-	-	206.8	179.4	194.9	169.5	171.4	151.0	170.1	150.4
Van	221.9	191.5	232.0	200.4	230.4	199.9	225.0	196.3	231.5	201.6
Truck	212.8	197.3	224.9	206.0	220.4	203.2	222.6	205.9	224.5	207.6
Total	172.7	149.4	173.3	150.0	173.9	150.9	173.1	150.9	172.0	151.4

Source : Korea Energy Agency (KEA)

- Since 2015, average GHG emission has been continuously increasing and it is uncertain whether the target of 97 g/Km (for passenger cars) can be attained in 2020.
- It is imperative that average emission targets and monitoring policies are provided for medium and large vans and trucks.
    - In other countries, fuel efficiencies are regulated not only for passenger cars but also for medium and large vehicles (vans and trucks).
    - There is virtually no regulation on fuel economy for medium and large vehicles in Korea.

<Figure 5-4> Share of public transport in metropolitan areas, nationwide



Source : Ministry of Land, Infrastructure and Transport (2010)

- Apart from Seoul and Busan Metropolitan, use of passenger cars prevails notably over public transportation.
  - The situation cannot be improved unless the public transport infrastructure is developed and the use of cars is controlled.

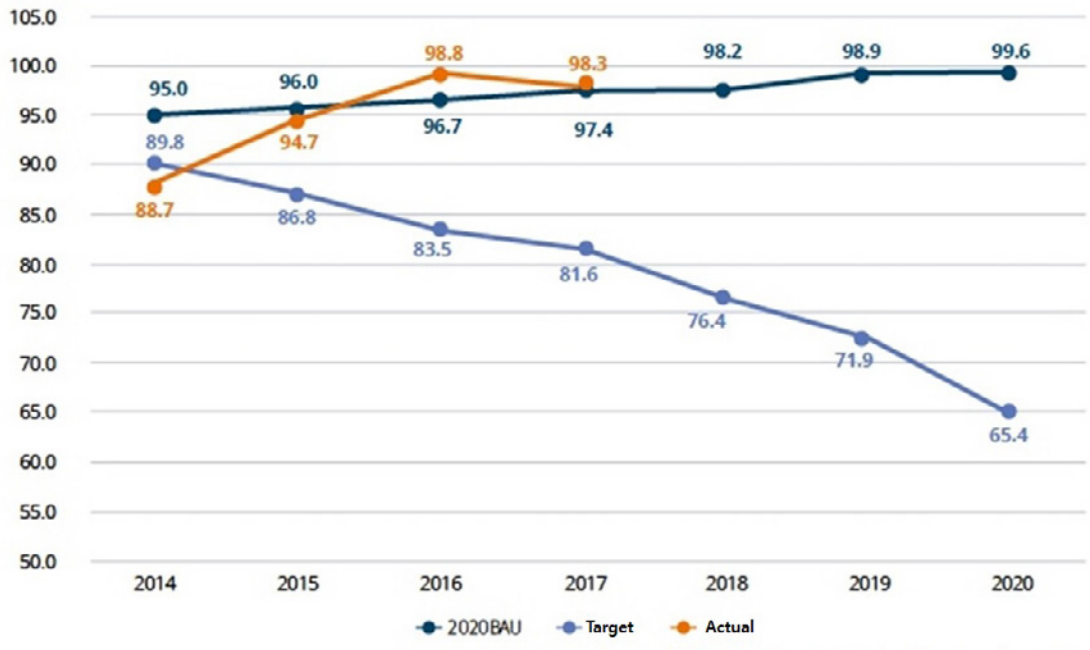
5.2 Outlook and Performance of GHG Emission in Transportation Sector

5.2.1 Comparison of actual GHG emission against 2020 GHG mitigation Roadmap

- While the 2014 actual was below the BAU outlook or the target, GHG emission exceeded the target and approached the BAU outlook closely in 2015.
  - The BAU outlook in 2014 may have been set too high, but the sharp rise of actual emission in comparison with the yearly outlook is still clearly visible.

<Figure 5-5> Comparison of 2020 GHG Reduction Roadmap and actual emission

(Unit: M tons CO_2 eq.)

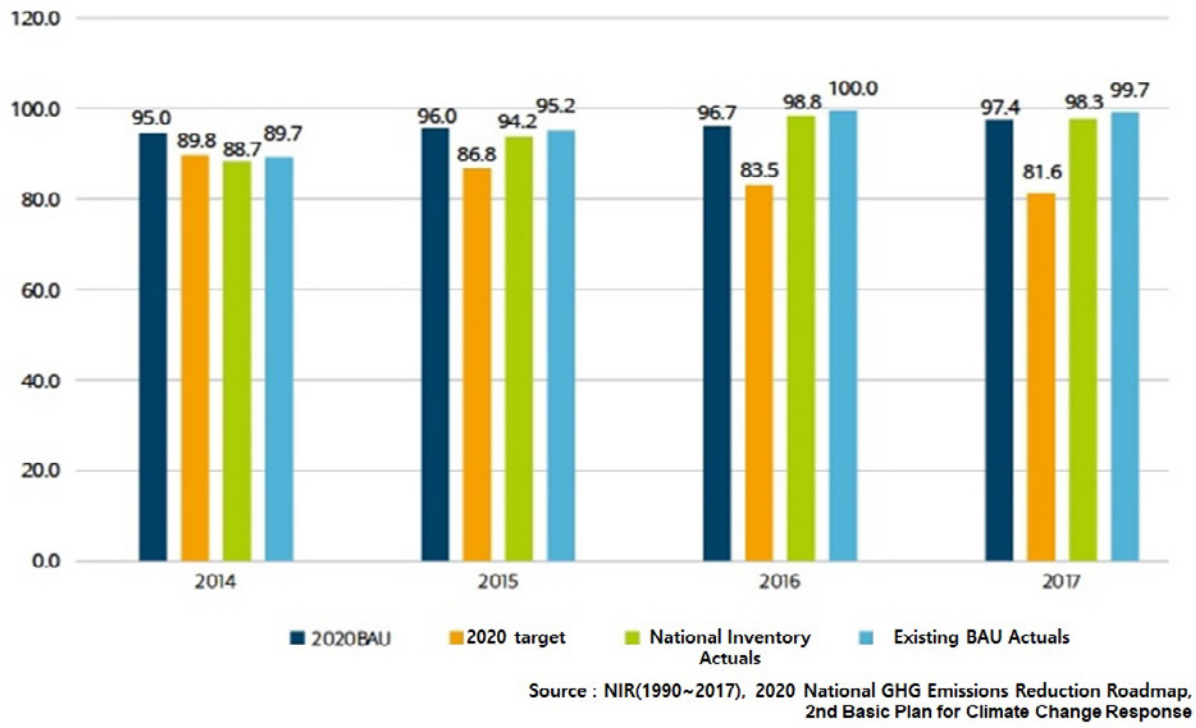


Source : NIR(1990~2017), 2020 National GHG Emissions Reduction Roadmap

- The actual figures exceeded the BAU outlook in 2016 and 2017, widening the gap with the targets (15.3 million tons →16.7 million tons).
  - It is effectively unfeasible to meet the GHG emission target in 2020.

<Figure 5-6> Comparison of 2020 GHG Reduction Roadmap and actual emission

(Unit: M tons CO_2 eq.)



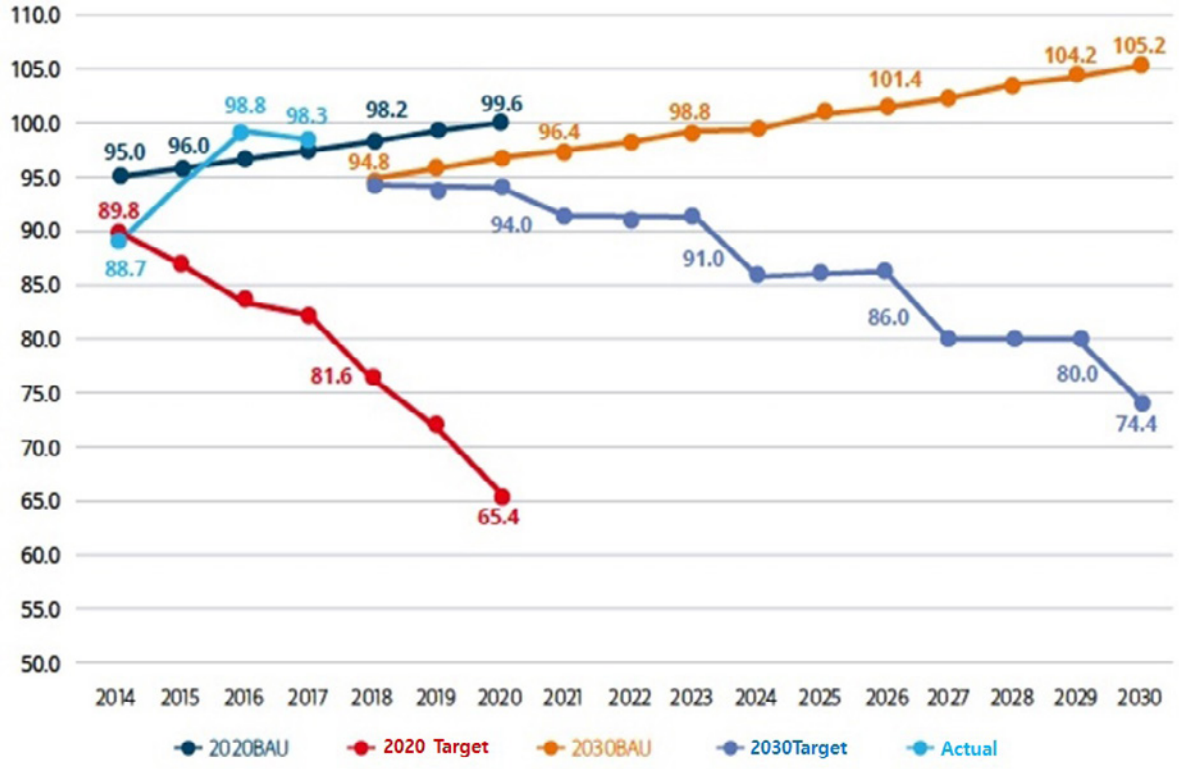
Source : NIR(1990~2017), 2020 National GHG Emissions Reduction Roadmap, 2nd Basic Plan for Climate Change Response

- It is questionable whether all possible policy and technical measures are taken to reduce greenhouse gas emissions.
  - If the mitigation measures as proposed in the 2020 GHG Emissions Reduction Roadmap were implemented, the actual emission should have at least decreased, even if it failed to meet the target, but the actual emission is still on an upward trend.
  - It is, however, noteworthy that the GHG emission in 2017 was less than in 2016.
  - It is yet unclear whether the aforementioned reduction was the consequence of policy implementation or whether such was influenced by the upturn of the oil price; validation should be conducted after deriving the 2018 GHG emission inventory, in order to confirm if the GHG reduction policies had any effect.

- In order to achieve the 2020 GHG emission reduction target (to become close enough to the 2020 target), 32.9 million tons need to be reduced from the 2017 level over the period of three years.

<Figure 5-7> Comparison between GHG Emissions Reduction Roadmaps (2020 VS 2030)

(Unit: M tons CO_2 eq.)



Source : NIR (1990~2017), 2020 National Greenhouse Gas Emissions Reduction Roadmap, 2nd Basic Plan for Climate Change Response.

- The 2017 actual emission is approximately 4 million tons higher than the 2018 BAU outlook; 2018 is the starting year of the 2030 GHG Emissions Reduction Roadmap.
- Policy goals should be established and implemented in the short-term, so as to approach nearer to the 2020 outlook as per the 2030 Roadmap.
- In the long run, for the purpose of achieving the 2030 Reduction Roadmap, GHG mitigation measures introduced in the 2020 Roadmap need to be assessed and relevant policies should be revised.

5.3 LEDS Scenario for Transportation Sector in Korea and Other Countries

5.3.1 LEDS Scenario of Korea

[Table 5-9] 2050 LEDS reduction target for transportation sector (proposal)

Category		2017 Status	2050 Target as per Forum Review				
			Option 1	Option 2	Option 3	Option 4	Option 5
Country	Emission	709.1	178.9	222.0	279.5	355.9	425.9
	Reduction Quantity	-	530.2	487.1	429.6	353.2	283.2
	%Reduction	-	75%	69%	61%	50%	40%
Transportation	Emission	98.3 (13.9%)	26.3 (14.7%)	28.8 (13.0%)	33.8 (12.0%)	36.0 (10.1%)	40.0 (9.4%)
	Reduction Quantity	-	72.0 (13.6%)	69.5 (14.2%)	64.6 (15.0%)	62.3 (17.6%)	58.4 (20.6%)
	%Reduction	-	73.3%	70.7%	65.7%	63.4%	59.4%

Source : Ministry of Environment, Review on the Low Carbon Society Vision Forum (2020)

* 2050 reduction and reduction rate are in comparison with 2017
* The percentage in ( ) is the sector share against nationwide (country) GHG emission and reduction
* Unit: M tons CO_2 eq.

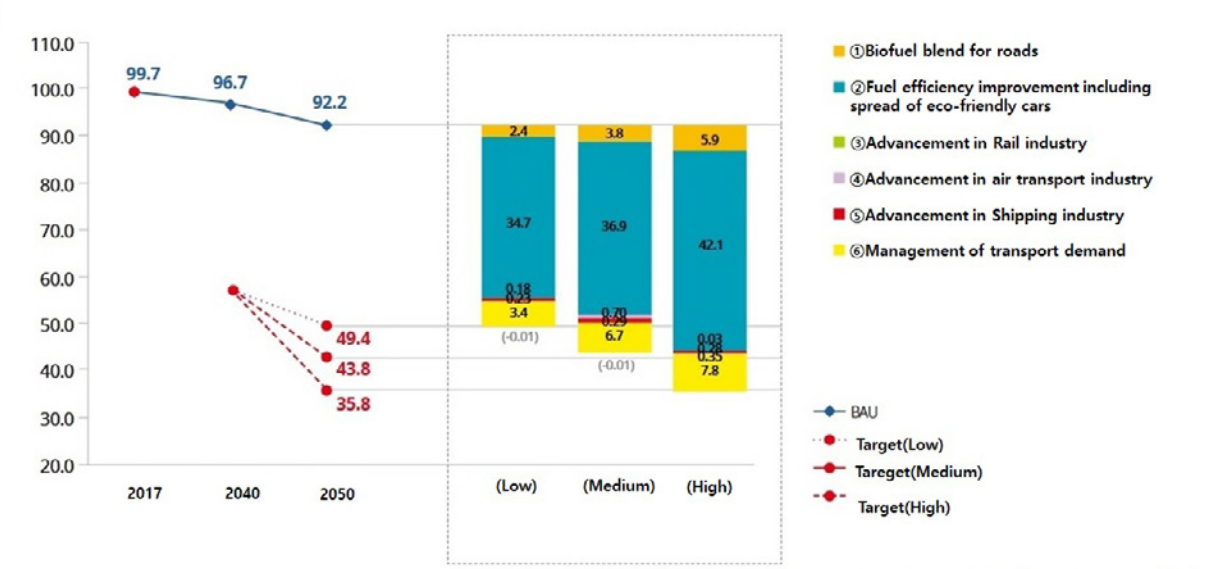
- Low-, medium- and high-intensity scenarios were developed for the analysis and five options were proposed as the means to attain the 2050 GHG emission reduction target (Option 1 being the mildest and Option 5 being the most drastic option).
- Lower intensity of the options requires the transport and transportation sector to emit lesser GHG and reduce more emissions compared to the whole country emission, implying that the transport and transportation sector has a large room for improvement.

1) Low-intensity scenario - a low-cost option that is highly likely to be accepted by the public; government's official relevant plans will be maintained until 2050.
※ (Ex) Wider use of bio-diesel blend and eco-friendly cars; improvement of average fuel economy; streamlining marine and air transport industries.

2) Medium-intensity scenario- higher cost than low-intensity option; including more challenging reduction measures.
※ (Ex) Low-intensity scenario (intensified version) + use of bioethanol blend + railway power · hydriding

3) High-intensity scenario- higher cost than medium-intensity option; including ambitious reduction measures based on future innovative technology.
※ (Ex) Medium-intensity scenario (intensified version) + other future technology (means proposed as innovative technology domestically and abroad).

<Figure 5-8> Reduction of GHG emissions of transportation sector by 2050



Source : Ministry of Environment, Review on the Low Carbon Society Vision Forum plan (2020)

5.3.2 Key agenda and goal of LEDS of Korea

(Basic Direction) To construct a low carbon society by establishing environmentally friendly transportation system

(Key Agenda) Broader use of environmentally friendly vehicles; Enhancement of ICEV efficiency and reinforcement of low carbon requirements; Promotion of low carbon development in rail, aviation, and marine industries; Establishment of low carbon logistics system; and Advancement of demand management;

1) Broader use of environmentally friendly vehicles

- **Increase supply of environmentally friendly vehicles by securing market competitiveness**
  - Accelerate purchase of eco-friendly vehicles by maintaining the subsidy for buying eco-friendly cars and extending tax benefits for such as individual consumption tax and acquisition tax, considering the market situation.
  - Induce reduction of hydrogen price considering how and where green hydrogen is produced and ensure competitiveness of hydrogen cars by providing financial support and drastically increasing the number of hydrogen stations.
  - Secure safety of driving eco-friendly cars throughout the process of production, storage, transportation and consumption to ensure the trust of the public.

- **Expand electric and hydrogen car charging infrastructure**
  - (Electric car) Increase the supply of fast chargers in multi-user facilities such as apartments (mandatory equipment of chargers), markets, gas stations and service areas to ensure convenience of using electric cars.
  - (Hydrogen car) Convert existing LPG·CNG charging stations to multi-fuel stations that have hydrogen chargers, and expand charging infrastructure in major city hubs by easing regulations on station establishment.

- **Secure technical competitiveness of industries related to eco-friendly cars and strengthen support**
  - Create a hydrogen industry ecosystem to enable production of green hydrogen that entails no GHG emission and to expand technology research and development so that the key parts for hydrogen cars and charging stations can be produced domestically.
  - Discover and develop industries deriving from the increased use of electric vehicles (EV), including EV battery manufacturing technology, EV based transportation market and recycling of old batteries.
  - Continuously discover and expand the demand for eco-friendly cars such as hydrogen cars and EV, focusing on those drivers who own buses, taxis and trucks for business purpose.

2) Enhancement of ICEV efficiency and reinforcement of low carbon requirements

● Expedite GHG reduction by improving the efficiency of vehicles, e.g. fuel economy

- Apply tougher average fuel economy (GHG emissions) standards for vehicles (passenger cars, vans and small trucks) considering the national GHG emissions reduction target and the possibility of reaching the industry standard , and ensure successful implementation of average fuel economy standards for medium and large trucks (to be implemented in 2022).

  ※ **Implementation of Average Fuel Economy and GHG Management System for Cars (2012~, Ministry of Trade, Industry and Energy and Ministry of Environment)**

- Continuously develop technologies required to enhance fuel economy, e.g. lighter engines and parts, and measures to improve the efficiency of hybrid conversion (electrification).
- Increase support to lay the foundation for stable supply of car parts, e.g. development of core parts (electric propulsion, autonomous vehicles), and to develop the ecosystem for commercial vehicles.

● Reinforce the requirement on blending renewable fuel into transportation fuel

- Set a long-term implementation goal by such as increasing the level of biodiesel blend as required by the Renewable Fuel Standard and including bioethanol in the list of mandatory ingredients for blending.

  * **(RFS, Renewable fuel standard) A program that mandates the oil refinery or the oil exporter/ importer to blend a certain percentage of biodiesel into the original diesel. (implemented in July 2015)**

- Seek stable supply and demand through diversification of biofuel suppliers, majority of which currently tends to be from overseas, by producing and supplying biofuel made by recycling local waste resources (e.g. waste cooking oil).

3) Promotion of low carbon development in rail, air transport and marine industries

● Continue transition to low carbon and zero emission fuels such as electric and hydrogen

- Rail : Replace diesel railway vehicles that reach the end of lifespan with electric vehicles; conduct R&D for and supply commercial use of hybrid locomotives using hydrogen batteries.

  ※ **Establish the systematic background for the purpose of developing hydrogen charging infrastructure for railway vehicles and filling the quota for locomotives in possession as prescribed in the national plan with hydrogen fuel cell based railway vehicles.**

- Air Transport, Marine : Introduce electric aircrafts; further develop and supply eco-friendly means of transportation including hydrogen, electric and LNG ships.

● **Increase fuel economy and introduction of biofuels**

- Take into consideration the characteristic of different transportation means and the trend of global technology development and enhance the efficiency of aircrafts* and ships**.

  * **(Aircrafts) Increase the use of Aircraft-Ground Power Supply (AC-GPS) and restrain the use of auxiliary power unit; minimize airtime of aircrafts; adopt new high-efficiency aircrafts and replace old models; pursue cost-efficient flying**

  ** **(Ships) Improve technologies, for example, to make lighter vessels, reduce road friction and use highly efficient propellers; optimize sea route and define low vessel speed zones**

- Seek ways to regulate and monitor the quota for bio-air transport fuel or biodiesel fuel to be blended into original fuels, including expanding the scope of application of RFS.

4) Establishment of low carbon logistics system and advancement of demand management

● **Enforce environmentally friendly logistics system centering on rail and marine transportation**

- Accelerate modal shift from road to rail and marine transportation.
- Modify relevant systems to, for example, incentivize applicable parties following the transition to an eco-friendly logistics system with reference to the relevant laws on railroads and coast shipping.

● **Promote enhanced demand management through advancement and increased application of C-ITS technology**

- Develop and operate a real-time monitoring system for major main roads including expressways and national highways, based on the prediction of traffic demand, to provide information on traffic and bypasses.
- Lay legal and systemic grounds to introduce C-ITS*, which is already utilized in passenger transport, in freight transport.

  * **(Cooperative-Intelligent Transport Systems) Next-generation traffic intelligence system which informs the drivers of nearby traffic situation and driving hazards such as sudden stops and road debris.**

● **Promotion of low carbon transportation means**

- Improve the environment for pedestrians and bicycle users by ameliorating the pedestrian

environment, implementing bicycle policies customized to the respective regions and creating a safe environment for bicycles.

- Supplement the public transportation network to enhance user convenience by expanding metropolitan bus routes and building metropolitan transit centers.

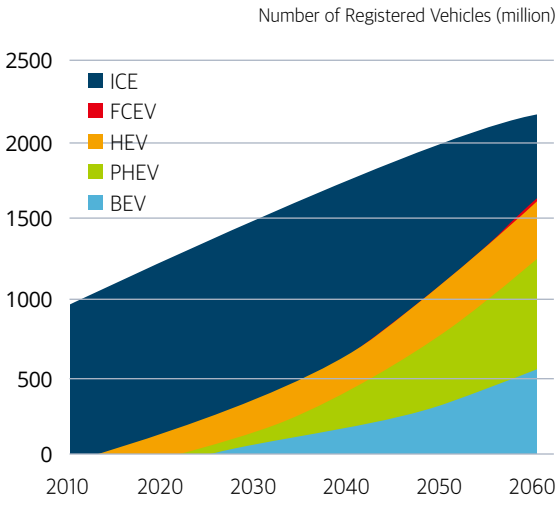
5.3.3 LEDS Scenario of major countries

1) International trend of long-term Low Emission Development Strategies (LEDS)

- Global IEA Goal: According to 2DS (2℃ Scenario), over 50% of all the passenger cars to be sold worldwide will be electric vehicles (EV, including plug-in hybrid models) by 2050.

<Figure 5-9> Cumulative Number of Registered Vehicles by Type according to IEA 2DS

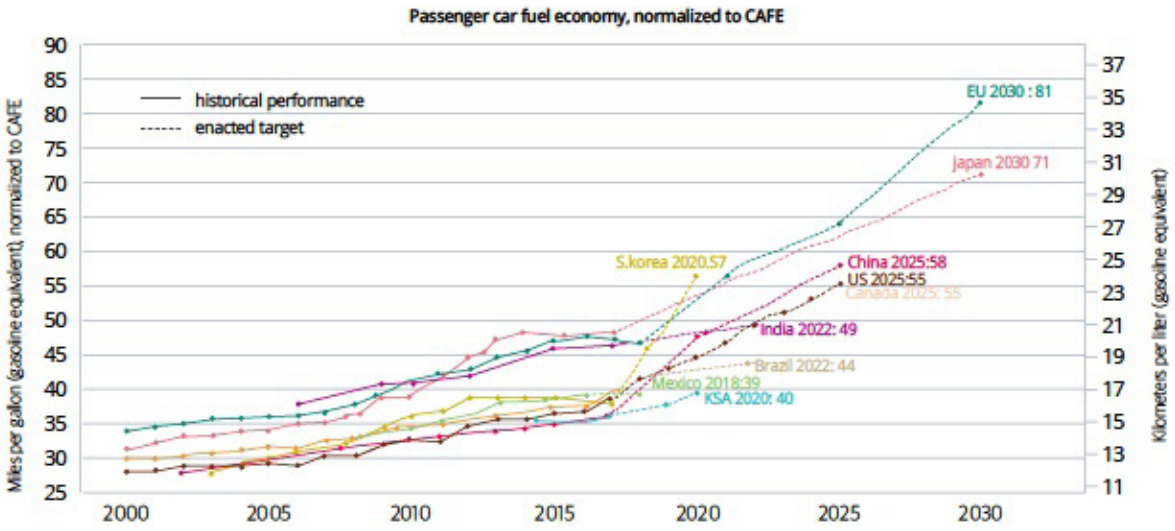
#Cumulative vehicles (million)	2040	2050
EV (including PHEV)	404(23%)	796(40%)
FCEV	12(0.7%)	24(1.2%)
HEV	224(13%)	307(15%)
ICE	1,140(64%)	871(44%)
Total	1,780(100%)	1,998(100%)



Source : Energy Technology Perspectives (ETP) 2017

- Global : The United States adopted Phase 2 (2018-2027) regulations following Phase 1 (2014-2017), and Europe decided to implement the GHG Emission Reporting System in 2019.
- Global : 37.5% improvement is expected in 2030, compared to 2021, in the passenger cars in Europe (around 35 km/L in 2030).

<Figure 5-10> Passenger car fuel economy



Source : International Council on Clean Transportation, ICCT ('19)

<Figure 5-11> Key agenda for the transportation sector for Global Energy System Transition

Source : IRENA (2019)

- IRENA : Tasks have been assigned to the respective sectors to facilitate the transition to the global energy system. The key agenda for the transportation sector are: improvement of energy efficiency, faster electrification of means of transportation, and promotion of biofuels in the air transport and marine industries.

2) LEDS Scenario of Germany

- **Status and Goal**
  - The energy efficiency of transportation is continuously improving, but the effect of reduced GHG emission is mitigated by the constant increase of passenger and freight demand.
  - As of 2014, in comparison with 1960, energy consumption by the transportation sector tripled, accounting for 30% of the total energy consumed countrywide, of which 90% was consumed by road transportation.
  - However, it is notable that the GHG emission is on a downward trend, decreasing from 163 million tons of CO_2 equivalent in 1990 to 160 million tons of CO_2 equivalent in 2014 (18% of country total emission).
  - Germany's goal is to reduce GHG emission by the transportation sector by 80~95% by 2050, with 1990 as the baseline, for which it targets to reduce GHG emission by 95~98 million tons of CO_2 equivalent (40~42% reduction) by 2030.

[Table 5-10] 2030 GHG emission reduction goal of Germany by sector

Category	1990	2014	2030	2030
	Emission (M tons CO_2eq)	Emission (M tons CO_2eq)	Emission (M tons CO_2eq)	Emission (M tons CO_2eq)
Energy	466	358	175-183	62-61%
Building	209	119	70-72	67-66%
Transport	163	160	95-98	42-40%
Industry	283	181	140-143	51-49%
Agriculture	88	72	58-61	34-31%
Sub-total	1,209	890	538-557	56-54%
Others	39	12	5	87%
Total	1,248	902	543-562	56-55%

Source : Climate Action Plan 2050, German federal government.

● **Key Strategy**

- Funding for electric transportation methods: to provide financial support until technologies required to supply electric means of transportation are developed and applied to a certain level.
- Tax benefits to broaden the application of electrification technologies: to provide tax benefits to those transportation methods that use electricity, particularly, generated from renewable energy.
- Policy enforcement to expedite transition of transportation: to leverage on the strongest policy measure to move away from the traditional road transportation to railway and inland water transportation.
- Increased use of railway: to expand policies and infrastructure to promote the use of metropolitan and urban railway for better linkage with and replacement of individual transportation means.
- Update on the strategy to encourage walking and riding bicycles: to extend the implementation of the National Cycle Paths Plan (NRVP) beyond 2020, expand the legal and systemic support to support the private sector in promoting the use of bicycles and monitoring the performance, and to ultimately connect such efforts with programs aiming to encourage walking.
- Promotion of alternative fuels in air transport and marine industries: to develop programs to expedite electrification in air transport and marine industries and to continuously promote the use of existing biofuels.
- Promotion of digitalization and development of cross-sectoral cooperation system: to expand the collaboration with the relevant technology areas to accelerate digitalization of the transportation sector and to promote mutual cooperation.

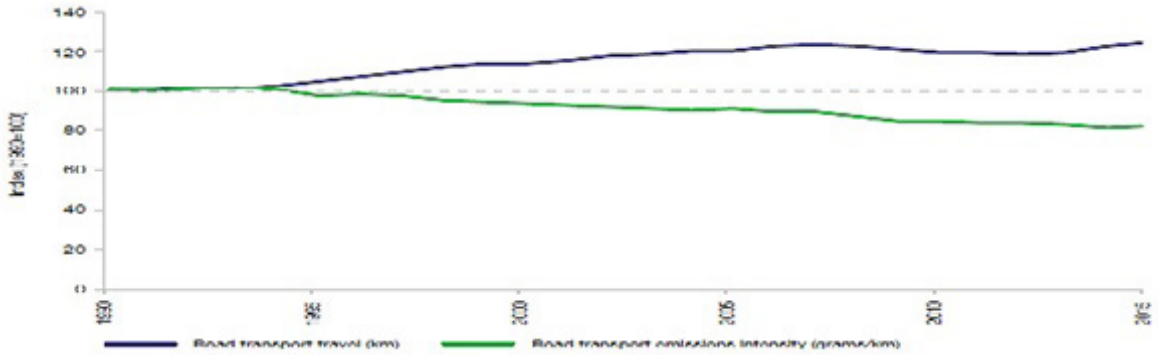
3) LEDS Scenario of the United Kingdom

● **Status and Goal**

- The UK reduced its nationwide GHG emission by 42% in 2015 compared to 1990, and the transportation sector accounts for approximately 24% of the total country emission.

<Figure 5-12> GHG Emission by Road Transportation between 1990-2015

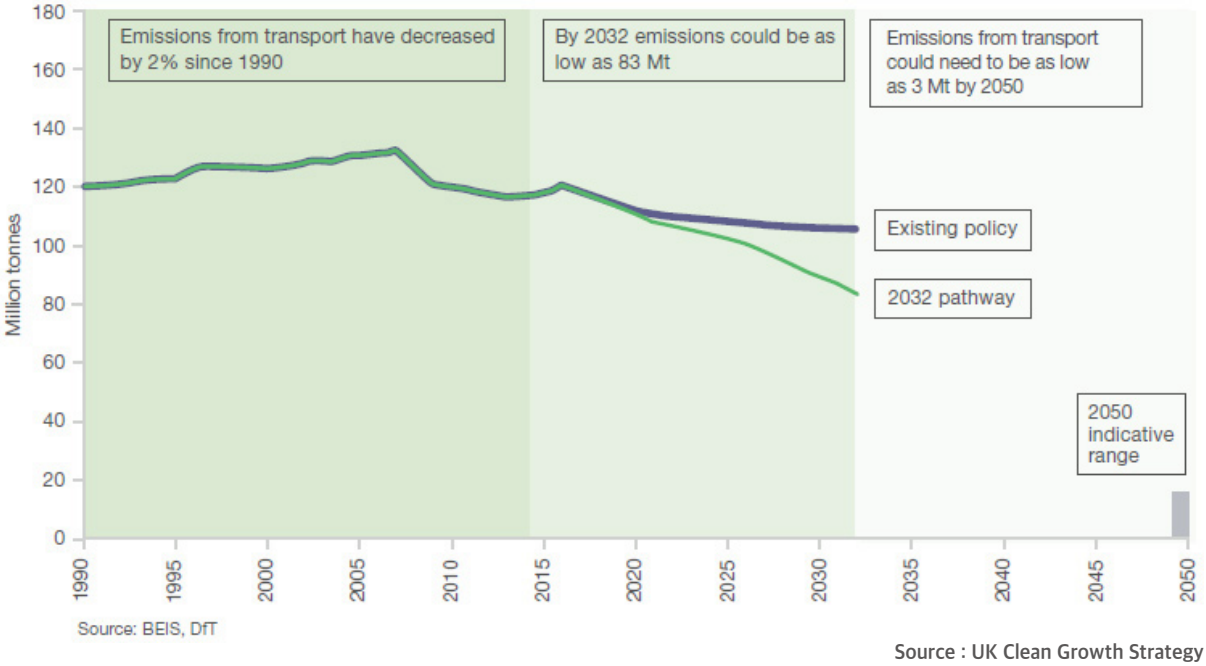
(passenger cars, vans, trucks)



Source : UK Clean Growth Strategy

- Transportation demand increased by 9% in 2015, compared to 1990, but the GHG emission declined by 2% and the energy efficiency was improved by 16% compared to 2000.
- As of 2015, more than 115,000 ULEV (Ultra Low Emission Vehicle) are in use; around 3% of the fuels used by the transportation sector are biofuels, of which 50% has been recycled from wastes.
- GHG emission has decreased by 2% in 2015, in comparison with 1990. The goal is to reduce the emission to below 86 million tons of CO_2 equivalent by 2032 and below 3 million tons of CO_2 equivalent by 2050.

<Figure 5-13> GHG Emission by the UK Transportation Sector and expected emission under Clean Growth Pathway



Source : UK Clean Growth Strategy

Key Strategy

- Prohibition of sales of ICEV: to ban the selling of passenger cars and vans that use gasoline and diesel from 2040.
- Financial support for eco-friendly cars: to provide financial support of GBP 1 billion to ULEV vehicles including electric cars.
- Establishment of global top notch electric car charging network: to invest an additional GBP 80 million to expand the fast-charging network and consumer-friendly charging network.
- Support for eco-friendly buses and taxis: to inject GBP 50 million to support plug-in taxis, construct 10 plus regional charging stations, and replace current buses with eco-friendly buses.
- Support for people hired in the eco-friendly vehicle industries: to seek support to encourage more employment in the eco-friendly transportation industries.
- Announcement of policy to increase eco-friendly vehicles in the public sector: to increase the use of eco-friendly vehicles in the public sector to lead the consumption of eco-friendly vehicles.
- Promotion of short-distance commute in an environmentally friendly manner: to invest GBP 1.2 billion to facilitate eco-friendly commute for short distances, such as walking and riding bicycles.
- Support measures to replace urban road freight transportation with rail transportation: to develop cost-effective means to replace road freight transportation with rail freight transportation in the urban areas.
- Promotion of research projects on transition to eco-friendly transportation: to invest GBP 25 million to promote investment and R&D in connection with the industry to accelerate the development of Battery Electric Vehicles (BEV).
- Innovation of investment in eco-friendly logistics: to create innovation in investment through such as the Faraday Challenge, with a view to plan for and realize an eco-friendly logistics system.

4) LEDS Scenario of France

● Status and Goal

- After reducing the per capita GHG emission by 11% in 2013, compared to 1990, France has been maintaining such level since.
- The national GHG reduction goal after 2020 is: 40% cut by 2030 and 75% cut by 2050, compared to 1990.
- To this end, France strived to decrease the GHG emissions by average 8 million tons of CO_2 equivalent per annum from 2005 to 2013, and is targeting to reduce average 9~10 million tons of CO_2 equivalent per annum during the following 35 years until 2050.
- Currently, the transportation sector represents 28% of total GHG emissions. The goal is to reduce the 2013 level by up to 29% by 2028 and to 2/3 (60%) by 2050.

● Key Strategy

- Revolutionary improvement of the fuel economy of the vehicles: to achieve 2L/100km (50km/L by the Korean standard) and to increase the number of charging stations by 2030.
- Acceleration of enhancement of energy efficiency: to promote low carbon emission of the public transportation including buses and to expand the charging facilities for electric cars (e.g. charging terminal) in order to reduce the emission of GHG.
- Management of transportation demand: to control the demand for transportation through city planning, remote working and carpooling.
- Replacement of personal cars with other transportation means: to provide tax benefits for using bicycles and to promote the use of public transportation.
- Acceleration of transition of transportation means: to transport freight by trains and ships.

5.4 Policy Recommendation for Transportation Sector

5.4.1 Comparison of internal and external LEDS Scenarios and Implications

1) Comparison of internal and external LEDS Scenarios

[Table 5-11] LEDS reduction goals and measures of internal and external transportation sectors

Category	Reduction Goal, Transportation Sector	Technology related Measures	Policy Measures
Korea	73.3% cut vs. 2017	- Public use of eco-friendly cars - Enhancing efficiency of ICEV - Low carbon emission by rail, air transport and marine industries	- Establishment of low carbon logistics system - Advanced demand management
Germany	80~95% cut vs. 1990	- Acceleration of transportation sector electrification - Broader use of alternative fuels in air transport and marine industries - Promotion of digitalization	- Facilitation of transition of transportation means - Promotion of use of railway - Promotion of walking and cycling - Establishment of cross-sectoral cooperative system
UK	Over 95% cut vs. 1990	- Increased supply of eco-friendly vehicles - Eco-friendly buses and taxis - Expansion of charging network for eco-friendly cars	- Prohibition of sales of ICEV - Financial investment to supply eco-friendly cars - Support for eco-friendly vehicle industries and employees - Promotion of walking and cycling - Transition of road transportation to rail transportation in urban areas - Innovation of investment in eco-friendly logistics
France	Over 60% cut vs. 1990	- Revolutionary improvement of car fuel economy - Expansion of charging network for eco-friendly cars - Improvement of energy efficiency in transportation sector	- Transportation demand management - Promotion of transportation means to replace passenger cars - Acceleration of transition to rail and ship transportation

Source : Green Transport

- When comparing the LEDS scenarios of Korea and other countries, five options are proposed for Korea to achieve the goal, with 2017 as the base year for setting the reduction goal. For the purpose of this study, the strongest option was used for comparison.
- Among the countries that officially submitted the LEDS report, Germany, the UK and France, the major OECD member countries, were analyzed. The three countries aim to cut GHG emissions by 60~95%, with 1990 level as the baseline, by 2050. The reduction goals vary, reflecting the circumstances of the respective countries, but the ideas to achieve the goals are not so much different from Korea.
- Plans to reduce GHG emission mostly involve improvement of vehicle fuel economy and increasing the use of environmentally friendly vehicles; in parallel, there are also efforts to build the charging infrastructure for eco-friendly cars.
- Also, in order to improve the energy efficiency of various transportation means, the countries commonly propose to increase the use of alternative fuels such as biofuels and gas.
- In addition to the technology related measures, one country proposed such strong policy measure as prohibiting the sales of ICEV; but common measures chosen by most countries include transition of transportation means and management of transportation demand, promoting walking and riding bicycles, and establishing environmentally friendly logistics systems.
- In some cases, like the UK, detailed financial investment and procurement plans were provided as part of the policies designed to achieve the GHG emissions reduction goals with a view to facilitate the GHG reduction policies, but most countries have not shared such specific financial plans.

2) Implications from the comparison of internal and external LEDS Scenarios

- The greatest difference between the LEDS scenarios of Korea and other major countries is that countries like Germany, the UK and France have set an interim goal in the year 2030 in order to reach its ultimate GHG emission reduction goal by 2050; in 2030, they plan to evaluate the progress of various policies in place and propose to take additional actions to further reduce the emissions.
- In addition to the policies already in place such as to improve the car fuel economy, Germany, the UK and France are planning for more challenging missions such as increasing the supply and use of environmentally friendly vehicles. In the case of Europe, the sales of eco-friendly cars are recently increasing following the regulation on average GHG emission (95g/km in 2020) for new cars in the major countries.

- Also, most European countries already differentiate the vehicle taxes according to the amount of GHG emission as a means to reduce the emissions in the general transportation sector. The Bonus-Malus scheme of France is a key example, which either gives a generous allowance or imposes a strong tax according to how much GHG is emitted by the car being purchased.
- The most visible difference between Korea and the aforementioned three countries in terms of the policies governing traffic demand control and transition of transportation means is whether policies and systems are actually being enforced.
- In the case of Korea, the 2020 GHG Emissions Reduction Roadmap and the 2030 GHG Emissions Reduction Roadmap have already proposed the implementation of policies to control the demand for transportation and transition to more efficient transportation means; but no actual implementation has been identified since and the Roadmaps are merely making policy recommendations, so the outcome of the policies could not be assessed. On the other hand, other countries have already adopted the LEZ (Low-emission Zone; restricting access of polluting vehicles) universally. London's Congestion Charge is a well-known policy to control the traffic volume.
- There are considerable implications. For example, policies to facilitate the replacement of passenger cars with walking and cycling are already universally implemented in the mentioned three countries, but these countries are also planning to expand pedestrian-only zones and bicycle roads to further accelerate the existing efforts.

5.4.2 Comparison of internal and external LEDS Scenarios and implications

- With reference to Korea's LEDS scenario, further analysis was conducted to identify the issues to be addressed by the transportation sector to reach similar levels of GHG reduction and Net-Zero emissions as Germany, the UK and France.
- A detailed analysis of the scenario, including the strategy for future supply of vehicles and the estimation of number of registered cars by type, is required, for which a diverse and thorough study should be accompanied. However, the purpose of this paper has been limited to rough estimation and suggestion of direction.
- The paper could be meaningful in that the strategic agenda that needs to be addressed for Korea to

achieve Net-zero had been summed up, albeit the practical limitations; however, further specific analyses will be necessary.

- Before proposing the strategic agenda for the transportation sector, other measures to enable further reduction of GHG emissions were reviewed on top of the major reduction measures presented so far in the LEDS. Then, the reduction targets were derived by applying the reduction rates stated in the LEDS.

[Table 5-12] Estimated reduction rate by different measures based on reduction target

(Unit: Mtons CO_2 eq.)

Category		2017 Status	Comparison of Reduction Scenario		
			Original LEDS	85% Cut Option	95% Cut Option
Emission and Reduction Target	Emission	98.3	26.3	14.7	4.9
	Reduction	-	72.0	83.6	93.4
	%Reduction	-	73.3%	85%	95%
Reduction by Different Measures	Increase use of biofuel for road transportation		5.9	6.9	7.7
	Supply eco-friendly cars and improve fuel economy		42.1	48.9	54.6
	Develop rail transportation		0.03	0.03	0.04
	Develop air transportation		0.24	0.28	0.31
	Develop marine transportation		0.35	0.41	0.45
	Manage transportation demand/traffic		7.8	9.1	10.1

※ Note) The amount of reduction by different measures as proposed in the 85% and the 95% cut options is the amount derived by applying the same reduction rate proposed in the LEDS. For example, GHG emissions reduction through supply of eco-friendly cars and fuel economy improvement as per the LEDS accounts for 58.5%; 58.5% of the 85% cut option is 48.9 million tons, and 58.5% of the 95% cut option is 54.6 million tons.

Source : Green Transport

- In the case of the existing LEDS, the amount of reduction by different measures as suggested in the above table was measured through scenario analyses and simulations, so the figures are deemed to

be quite objective. However, the amount of further reduction was calculated, not with the level of technology development or the actual policy effect in consideration, but by simply applying the reduction rates presented in the LEDS, so they cannot be regarded as objective figures.

- How much more reduction would be required had been estimated for each measure according to the heightened reduction target. The numbers are subject to change based on the policies to be implemented afterwards.

- In the case of supply of eco-friendly cars and improvement of fuel economy, which account for the largest share of the reduction, the assumption as per the LEDS was that 93% of total cars will be electrified (electric and hydrogen cars); since the scenario already assumes a high level of electrification, there seems to be little room for further cut to be attained from electrification.

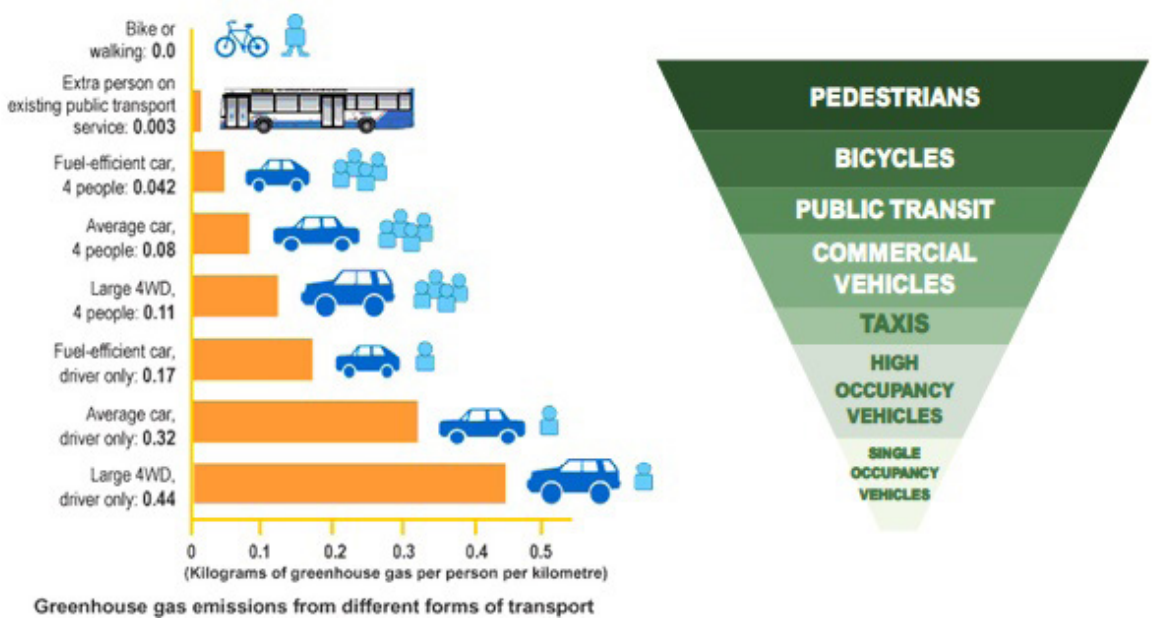
- As traffic (transportation demand) control is the area that has the greatest emissions cut potential, leveraging on the policies to control the demand for transportation seems to be a realistic option to achieve additional GHG emissions reduction. This does not simply mean raising the bar to supply more electric or hydrogen vehicles; the policies should aim to promote the use of existing public transportation means including subways and trams and of new public transportation means like electric buses, and to transition the transportation means to cycling and walking.

- Furthermore, in terms of promoting the use of electric and hydrogen vehicles, it would be more desirable not just to supply them for personal transportation but to drive the demand toward electric/hydrogen car sharing in parallel. To this end, adopting the LEZ to incentivize shared electric/hydrogen cars in the cities and introducing Tax Incentives on Sales of Eco-friendly Vehicles to differentiate the tax based on GHG emission could be important policy measures.

5.4.3 Policy recommendation for the transportation sector sectorSector

1) Shift of paradigm in traffic and transportation policies

<Figure 5-14> Comparison of GHG Emissions among transportation means and priority of traffic policies

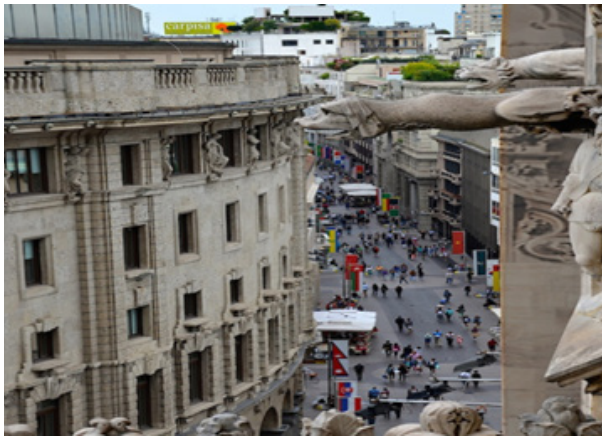


Source : WCTR, World Bank

- The shift of paradigm from valuing passenger cars, supplying facilities and higher speed to promoting walking and green transport.
- Pulling away from the fragmented policies respectively governing demand control, public transportation, pedestrians and bicycles , and shifting to more organic and comprehensive measures.

@ "Shared Space," a broad boulevard shared by pedestrians and vehicles in London

@ Change of New York Time Square



@ Pedestrian Street in Milan

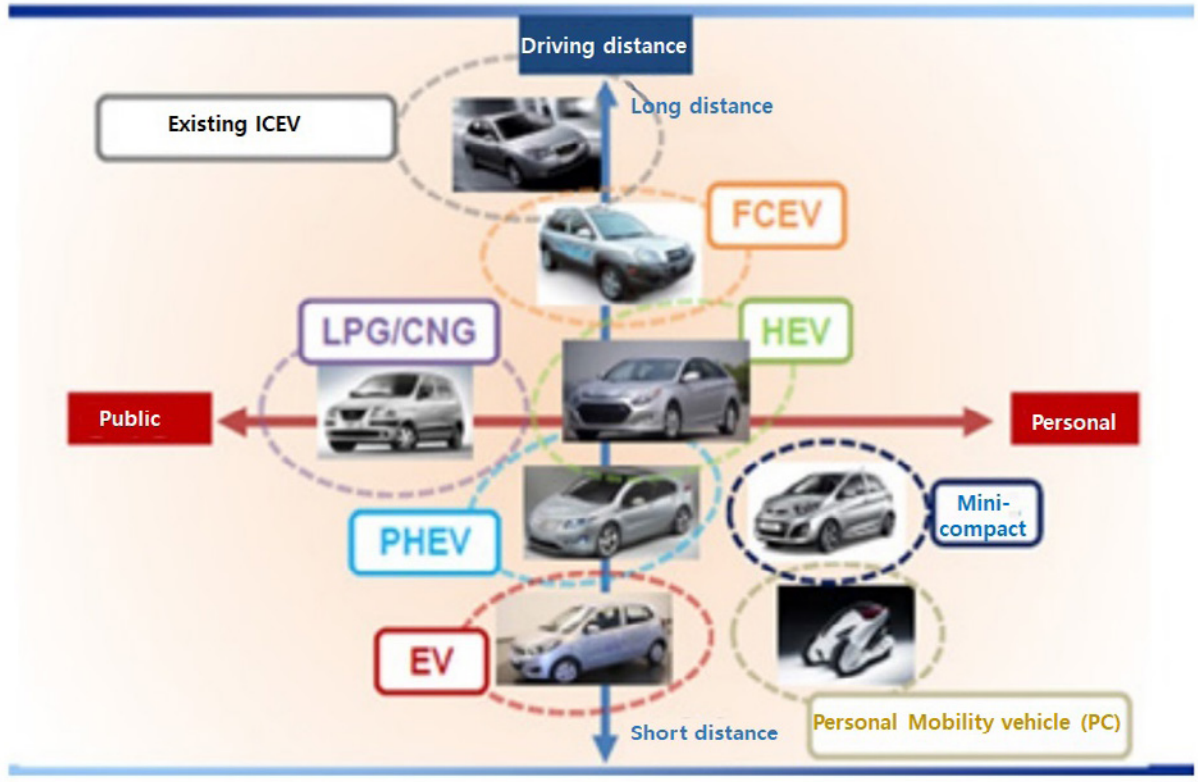
@ Public transportation only district in Zurich

2) Streamlining the transportation sector in line with GHG-micro dust policies

- Need for coordination between measures for micro dust and measures for GHG.
  - Following the regime change after the announcement of the 2030 GHG Emissions Reduction Roadmap, the focus shifted to micro dust.
- Clear limitation of pursuing incentive (subsidy) dependent policies, without regulation.
  - Restricting traffic volume and managing demand are necessary to deal with both micro dust and GHG.
- Eco-friendly vehicle measures and ICEV reduction roadmap that consider the future vehicle market structure.

- Long-term roadmap addressing the reduction of ICEV and considering the future vehicle market structure is required.
- Relying on highly efficient electric cars and hydrogen cars will meet limits.

Future Vehicle Market Structure



Source : Min, Kyoung-Doug (Seoul National University), Prediction of future vehicle market structure

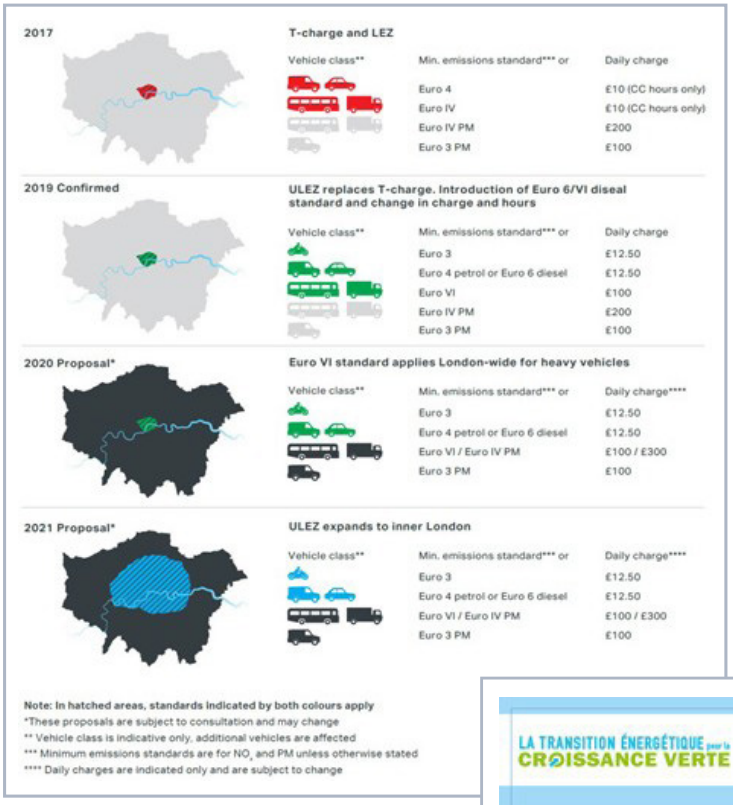
[Table 5-13] Key ICEV regulations and eco-friendly vehicle policies of other countries

Major Policies		Implementing Countries
ICEV Regulation	Suspended sales of ICEV	• (EU) Norway (in 2025) Denmark, Netherland, Sweden, Germany, UK (2035). Spain, France (2040) • (Others) India ('30), China (TBD), Taiwan ('40), Japan (100% electrification by '50)
	Restricted use of old diesel vehicles (LEZ)	• (EU) Restriction of old diesel cars in cities (e.g. London, Paris) • (China) Old vehicles that are Euro3 or below are restricted in the beltway surrounding Beijing
	Restricted issuance and registration of registration plates	• (China) Registration plates to be assigned to electric cars first in 8 major cities including Beijing and Shanghai • (Iceland) Registration to be restricted in 2030
	Stricter GHG emission approval standard	• (US) Same emissions standard applied to diesel and gasoline cars • (Japan) Prohibition of diesel cars used for over 7 years that do not meet the emissions standard; penalty upon violation • (EU) Considering adoption of Euro 7:Focus on real world emissions, on-board monitoring
	GHG emission grading system	• (Germany) 4-grade classification, used for vehicle restriction • (US) 10-grade classification, used for introducing eco-friendly cars and encouraging purchase
Eco-friendly Vehicles	Mandatory sales of eco-friendly vehicles	• (US) Introduction of mandatory nonpolluting car sales scheme in 13 states including California (since 2005) • (Others) Canada (2018), China (2019), Spain (2040, 100%; declaration only)
	Mandatory purchase of low-pollution vehicles	• (Japan) Low-pollution high-efficiency scheme implemented for businesses (2011~ ongoing) • Mandatory increase of low-pollution high-efficiency cars to 15% by 2021
	Tax Incentives on Sales of Eco-friendly Vehicles	• (EU) France (2008~), Belgium (2008~) Sweden (2018~) • (Others) Singapore (2013~)

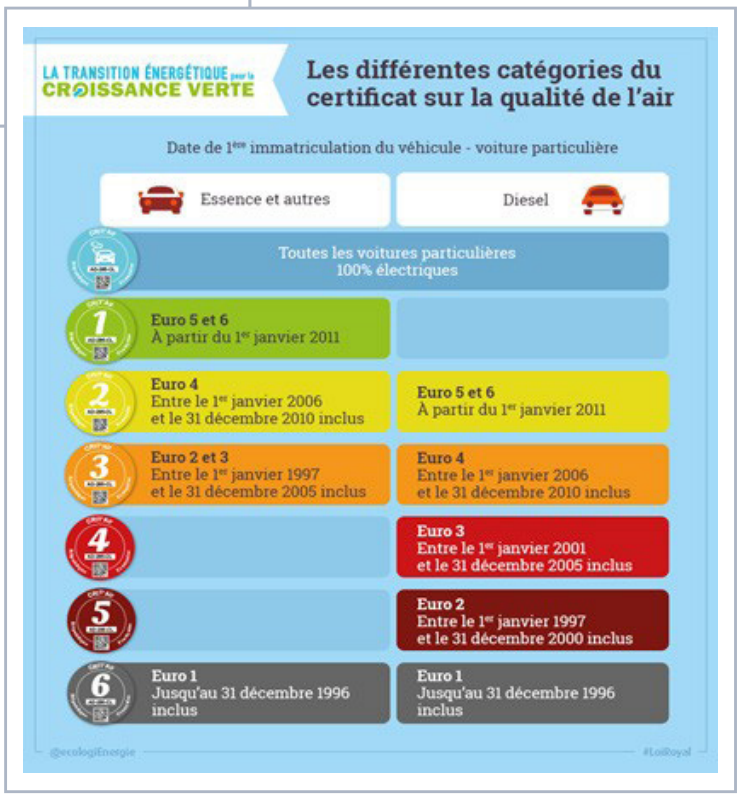
Source : National Council on Climate and Air Quality

- Measures against micro dust, such as restricting vehicles according to their environmental ratings, could also lead to GHG reduction.
  - At the moment, it will be easier to reach national consensus on the issue of micro dust than on GHG emission.
  - Micro dust policies and GHG policies should be coordinated going forward.

<Figure 5-15> Examples of implementing environmental rating in London and Paris



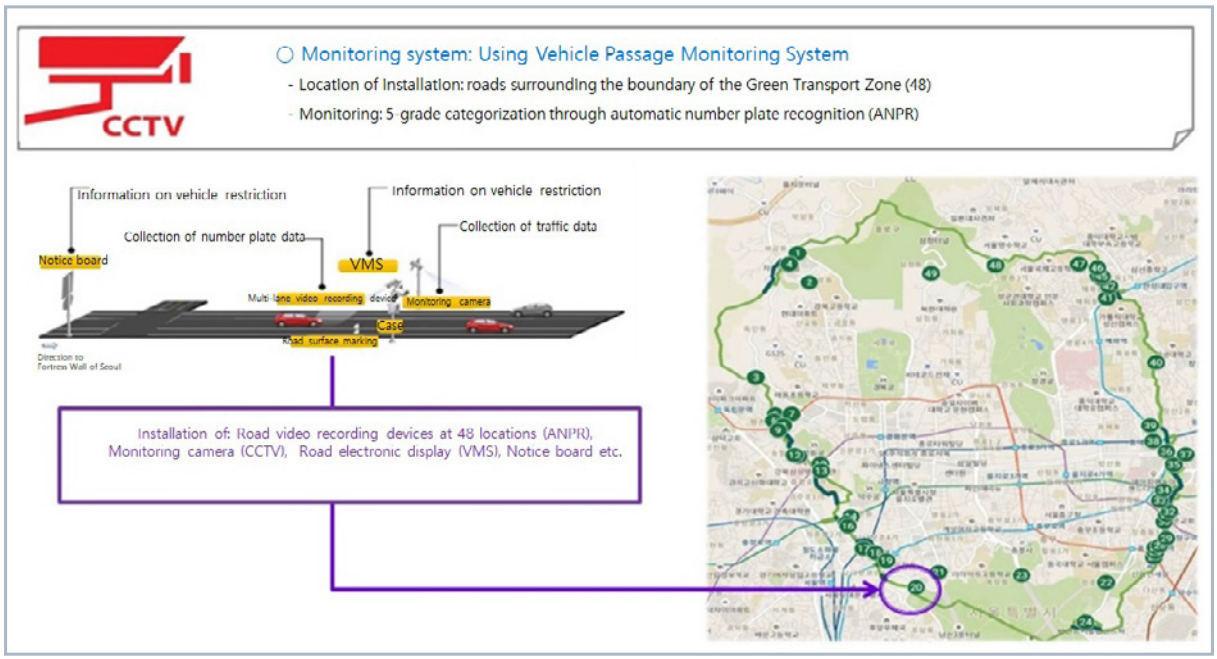
@ London ULEZ example



@ Environmental Rating for Cars in Paris

Source : Department for Transport London, Ministry of the Ecological Transition France

<Figure 5-16> Seoul City's Green Transportation Zone Operation Plan (December 2019~)



Source : Transportation Policy Department, Seoul Metropolitan City

3) Need for continuous efforts and consideration to induce citizens' participation

- Citizens' participation is critical for most GHG emissions and micro dust related measures to succeed in the traffic and transportation sector.
- It is necessary to devise regulations and incentives that could encourage citizens' participation.
  - Programs that enable communication with citizens, such as the Citizens' Policy Participation Group under the National Council on Climate and Air Quality, should be expanded.
- Policy improvement agenda where citizens can participate needs to be listed and utilized to increase relevant projects.
  - For instance, Seoul City's workshop to encourage walking and art contest on creating good walking environment (to trigger peoples' interest in the walking environment; to allow general citizens to take part in making changes).

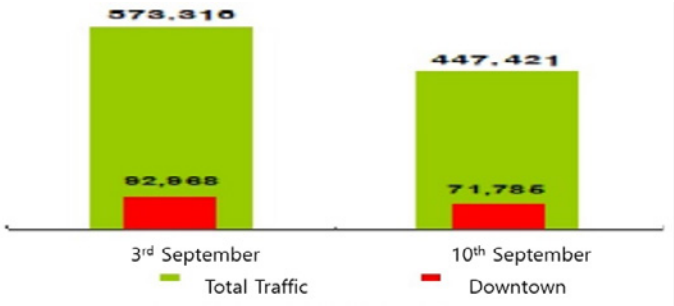
- Eco mileage for riding bicycles (e.g. incentive for cyclers; to measure how much GHG emission had been actually reduced by using the bicycle and provide mileage that could be used for public transportation).

- Car Free Day in Seoul (campaign designed to reduce car traffic through citizens' participation; to create the positive effect of decreased use of cars after experiencing streets without cars in the city).

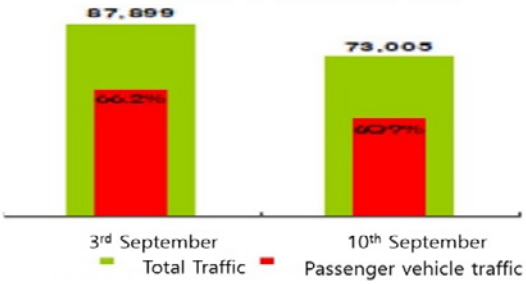
Ⓚ Overview of Car Free Day 2007

• **Car Free Street in Jongro**

Between 4am~6pm, September 10 (Mon); all vehicles restricted except buses from Gwanghwamun to Dongdaemun (2.84km); established temporary median bus roads



<Traffics in Seoul 7am-9am>



<Traffic during 7am-9am at 13 sites>

@ Reduced CO2 emission by 8~10%

- CO2 emission reduced by 452,767 tons annually
- Daily emission reduced by 1,240 tons; corresponding to 452,767 tons per annum
- 8~10% of CO2 emitted by passenger cars

@ Reduced fuel consumption by around KRW 270 billion

- Reduction of gasoline 142,286kl/year, diesel 40,202kl/year
- Equivalent to KRW 270 billion when applying the oil price of August 2007

Reference

2020 National Greenhouse Gas Emissions Reduction Roadmap
(jointly with government; January 2014)
2030 Revised National Greenhouse Gas Emissions Reduction Roadmap
(jointly with government; September 2018)
Monitoring and Research on the Progress of Greenhouse Gas Emission Reduction by Transportation Sector, Korea Transport Institute, August 2018
Preliminary Study and Analysis of Transportation Sector for Development of Greenhouse Gas Emission Reduction Roadmap, Korea Transport Institute, (November 2013)
2018 Vehicle Fuel Economy and CO_2 Emissions : Data and Analyses,
Korea Energy Agency
2018 National Inventory Report, Greenhouse Gas Inventory and Research Center

Research on Strategy and Policy by Sector for Korea 2050 Carbon Neutrality

6

Policy Agenda for 2050 Carbon Neutrality

This study investigated the policy agenda for 2050 carbon neutrality in 4 sectors; Electricity , industry, building, and transportation. Policy agendas for each sector are recommended in the respective chapters, and now we will discuss a comprehensive, nation-wide technology / institution agenda required to realize the specific agenda for each sector.

Despite numerous shortcomings due to limited time and number of researchers, this study is meaningful in that a study about policy agenda for 2050 Carbon Neutrality was performed in Korea. We expect various practical research per policy agenda discussed for each sector to follow this study.

6.1 Policy Agenda to Reduce Fossil Fuel

A Full reconsideration on fossil fuel subsidy

- Ever expanding fossil fuel supply infrastructure projects (petroleum storage, pipeline, gas storage facilities) that has been only developing will at least not grow with the drastic decrease of coal, gas, and petroleum usage. Now is the time to fundamentally transform the existing business model and make the announcement to the transition of fossil fuel energy infrastructure investment to demand management.
- CCS technology development is required for Bioenergy with carbon capture and storage (BECCS) but the use of gas field in the East Sea and post-combustion process at coal-fired power plant only for the purpose of increasing budget should be abstained. Detailed review on the annual performance of CCS (Emission vs captured, cost for installation and operation) installed at Boryeong and Hadong thermal power plants, amount of captured CO_2, and the use and storage of the captured CO_2 need to be performed.
- Green hydrogen production/usage technology needs to be developed, but the support of Renewable Portfolio Standards (RPS) on Fuel cell resulting in increase of LNG consumption must be reconsidered.
- Energy Master Plan, Master plans for Rationalization of Energy Use, Petroleum supply and demand plan, Gas supply plan, Coal plan, Overseas Resources Development plan, Electricity supply and demand plan, and renewable energy plan must be reviewed from comprehensive perspective.

B Cessation of coal financing and promotion of green finance

In achieving 2050 Carbon Neutrality, financial sector plays a critical role. Institutional foundation refraining from the Coal Financing while promoting Green Financing must be laid.

❶ System required to recover or suspend financial supports for the coal-fired thermal power plant.

- Old coal-based thermal power plant should be closed as soon as possible, and new coal-based thermal power plant project should be suspended.
- Information is required to induce early termination of old power generation projects and to lead to revocation or withdrawal of investment in new power generation project through analyzing the status of coal finance and assessment on risk exposure of domestic financial institutions.
  - Exhaustive study on financial support for coal-fired power generation project by domestic financial institutions.
  - Development of diverse legal systems leading to the voluntary withdrawal from financing the coal-fired power generation project.

    (※ lawmakers from Democratic party of Korea Kim Seonghwan, Woo Wonsik, Min Hyeongbae, and Lee Soyeong proposed '4 Acts prohibiting the overseas coal-fired power plant project', which is to ban the public financial institutions from financing the overseas coal-fired power plant project).

Note : Financing coal-fired thermal power plant by domestic financial institutions

Result of a study by Korea Sustainability Investment Forum (KoSIF), Office of lawmaker YangLee, Wonyoung, and Green Peace recently conducted over 162 public and private financial institutions in Korea invested about KRW 60 trillion in domestic and overseas coal-fired thermal power plant over the past 12 years in the form of PF, bond underwriting, or unsecured. KRW 45 trillion, or 75% of total coal financing was invested in the domestic coal-fired thermal plant, and most of them were financed by the domestic private financial institutions. National Pension, that has to invest in safe asset for long-term with the emphasis on the guarantee of life of the seniors and of people invested KRW 10 trillion, non-life/life insurance companies that have the obligation of compensating against the damage on life and health of people against safety accident (figure below).

<Figure> Coal finance by domestic financial institutions, home and abroad (2009-June 2020, accumulated)

Overseas coal financing ranking (Unit: KRW 100 Mn)

Ranking	Name of Institution	Amount
1	Korea Exim bank	48,585
2	Korea Trade Insurance Corporation	46,680
3	Samsung Life insurance	4,249
4	Korea Development Bank	2,696
5	Seoul Guarantee Insurance	1,832

Domestic coal financing ranking (Unit: KRW 100 Mn)

Ranking	Name of Institution	Amount
1	National Pension Service	98,339
2	Samsung Fire insurance	77,073
3	Samsung Life insurance	67,116
4	KB insurance	54,723
5	Hyundai Marine & Fire Insurance	21,538

Source : KoSIF, Office of lawmaker YangLee, Wonyoung, and Green Peace. 2020 Whitepaper on Coal Financing in Korea, page 6

② Development of system to promote green finance

- A system inducing the investment in low-carbon industries including renewable energy, EV, energy efficiency, distributed Electricity grid development, and etc. is required.

  - Clear guideline that can stimulate and induce investment in green industry or product such as green finance categorization criteria, Green bond guideline needs to be developed.

    (※ currently under development by the Ministry of Environment, and will be issued by the end of the year)

  - A system that requires companies and financial institutions to disclose the quantified climate risk exposure and business performance in the financial statements as the EU's Non-financial Reporting Directive needs to be urgently introduced.

    (※ need to be driven by the Financial Services Commission and the Ministry of Environment, pursuant to the 3rd 5-year Green Growth Plan)

  - Nurturing of domestic Green Finance experts is another urgent task to be tackled. Domestic financial institutions have limited overseas infrastructure investment capability or experience compared to the overseas counterparties, and experts to fill the gap need to be developed. A specialized graduate school for green finance experts will be launched for model operation this year (Graduate School for Green Convergence Science Expert Development by Ministry of Environment), which requires thorough design, supervision and support for the institution so that the original goal of nurturing green finance experts is achieved, preventing the budget for the program being wasted.

6.2 Policy Agenda for Expansion of Renewable Energy

- 2050 Zero Carbon Emission means zero use of fossil fuels. Even though we reduce the use of fossil fuels, if the renewable energy does not fill the required gap, then Zero emission will lose its meaning. In other words, a drastic supply of renewable energy would decide whether we could achieve the zero emission or not.
- As for the renewable energy, at least 400GW of solar PV, 100GW of wind-power, 50GW of pumped storage power, and over 20% of additional renewable energy needs to be supplied within 30 years, reflecting the energy conversion - storage - reuse.
- Supply of site, construction of transmission networks, and licensing are the keys in the expansion of renewable energy, and they should be covered by the public sector while the construction of power plant and sales are performed through competition in the private market.
- Investment would naturally follow when the business model for the generation and sales of electricity in private sector is prepared. Hence, what is required is the policy to facilitate the citizen's participation, for the righteous transition.
- Each organization playing the public roles such as supply of site, construction of transmission network, and licensing, ultimately the fundamental restructuring of the Electricity market is inevitable. Hence, the direction of the electricity industry restructuring should be set to allow more opportunity for people to invest in renewable energy, create profit, and find jobs.
- By creating public organization specializing in supply of site, construction of transmission network, and licensing, the private sector's power plant construction cost can be lowered, which will lead to higher economic feasibility of the renewable energy and active investment and competition in the private sector.
- To facilitate prosumers in the renewable energy, the sales of the energy by the private sector is inevitable. KEPCO should leave the power generation and sales to the market but expand the investment in transmission to become a platform provider so that the players in the power generation, sales, and intermediary operator freely carry out their businesses. The power generation and sales function of KEPCO should be spun-off or sold to the private sector.

- As energy is, in nature, the public goods having significant impact on the industries as well, there must be a neutral agency such as Monetary Policy Committee, to play a rule-maker's role in energy sector (electricity, gas, thermal). (Refer to the FERC of US, OFGEM of UK).
- In terms of technology investment, massive investment in direct current transmission network technology, and power electric technology such as inverter-converter is required.

6.3 Policy Agenda for Market Improvement

- Power Exchange Korea is an administrator, just as the Power Exchange in Europe or the Stock Exchange. When the Electricity market becomes open, the free transactions would follow, and would be segmented into annual / seasonal / monthly/weekly contract and day-ahead contracts.
- Real-time Electricity market will also be segmented from the capacity market to the balancing market. The balancing market can be segmented into frequency / voltage compensation market, such as 1st balancing Electricity market with power supply within 30 seconds, 2nd balancing market within 15~30 minutes supply, and 3rd balancing market with power supply within 1~2 hours. The unit of electricity transaction is also expected to be further divided from current 1 hour to 15minutes and 5 minutes.
- Power Exchange is a market-place where the power generator and wholesale/retailors can trade once the Electricity is reorganized and liberalized, and the role will be strengthened.
- Not only Electricity , but also thermal / hydrogen energy will be traded in real-time. Power exchange will be evolved into an energy network platform that will comprehensively managing energy network trade and real-time pricing, weather forecasting and projection on renewable energy generation.

Speech by President Moon, Jae-in at the Cabinet Meeting about 2050 Carbon Neutrality

(3 November, 2020)

Ⓚ 2050 Carbon Neutrality is an unavoidable choice, but it is a huge challenge to our industries.

- The world is moving toward to the common goal of overcoming climate crisis, and this can become a new growth engine and job creating opportunity through technology/industrial structure innovation.
  - * Target of Carbon neutrality is set on 2050 for EU, US, and Japan, and 2060 at China.
- Achieving Carbon Neutrality by 2050 is a not an easy goal considering our industrial structure. However, for the future of our Country, we need to accelerate the transition to low-carbon society in all direction.
  - * (obstacle) Manufacturing oriented industrial structure, high cost for alternative energy, dependency on fossil fuel

Ⓚ We need to revisit the national plan including energy transition roadmap, and need to build strong foundation for acceleration of the process

- Revisit the energy transition roadmap from the fossil fuel-based energy to green renewable energy and GHG reduction plan.
  - * Promote decarbonate green hydrogen economy, expand the portion of the renewable energy, build green industry ecosystem.
- Accelerate innovative decarbonation new technology in industry and alternative fuel development.
  - • Pursue grand transition to low-carbon guiding ·transportation, circular economy (minimum input of energy, recycle ·reuse) and develop measures to protect the company and workers.
- Build strong implementation system to achieve carbon-neutral goal.
  - • Expand the efforts of Seoul, Gwangju, Chungcheongnam-do, Jeju have set carbon-neutral target and leads the way, which should be expanded to other local governments, and induce the participation and cooperation by the private sectors.
  - • Develop detailed action plan and reach out to people to build sympathy, and to the industry for further communication.
  - • Both the ruling and the opposition parties agreed to the 'Emergency resolution to cope with the climate crisis' with the goal of reaching '2050 carbon neutrality,' active support by the National Assembly and efforts by the government is required.

6.4 Closing Comment

- This study is performed as a part of practical efforts to overcome the climate crisis in Korea, under the support of EU. The purpose was to inform the seriousness of climate crisis in Korean society and to study the possibility of carbon neutrality by 2050. Decarbonization policy agenda were identified in 4 core sectors including Electricity , Industry, Building, and Transportation, referencing the overseas cases including Europe. We want to announce that this study has the constraint from short time and limited budget, and it needs to be understood as a social movement rather than am academic research, and as a part of practical efforts of making the 2050 Carbon Neutrality one of the key agenda in Korean Society.

- This study started in early 2020 under the collaboration with the EU-Korea Climate Action, following the suggestion of the Energy Transition Forum working on the 2050 Carbon Neutrality. Within the Energy Transition Forum, there were some voices that Zero emission by 2050 in Korea is an audacious suggestion. However, at the same time, we felt the need of suggesting the direction the Korean Society should take to meet the 1.5 ℃ scenario required by the UN.

- The Energy Transition Forum is a knowledge and information sharing platform found in April 2019 to share the awareness on the climate crisis and energy transition within Korean society, continuously raised issues on the seriousness of climate crisis, necessity, and methodology of energy transition in various ways including seminar, press release, and newsletters. The EU-Korea Climate Action project is funded by the European Union and aims at strengthening networking, dialogue and cooperation among Korean stakeholders and between Korea and the EU to enhance climate action at the non-state actors ' level.

- The pause in our lives caused by COVID-19 in 2020, paradoxically gave us an opportunity to look into the reality of the climate crisis, and the awareness on the severity of climate crisis is unfolding in Korean Society. Law makers aspiring to resolve the climate crisis entered the National Assembly through 2020 General Election, and they successfully raised the climate crisis as one of the major agendas of politics in Korea. On 5 June last year, of the total 228 local governments, 226 heads, excluding 2 local governments where the head office is vacant, of the local governments announced a 'Climate Crisis Emergency Declaration', and on 24 September, the National Assembly adopted a 'Climate Crisis Emergency Response.' President Jae-in Moonon 28 October announced the '2050 Carbon emission neutrality target' at the National Assembly and specifically suggested the '2050

Carbon neutrality and policy agenda' at the cabinet meeting, announcing the '2050 Carbon neutrality' as a Government level goal.

- This study, led by the researchers in the Energy Transition Forum, consists of an analysis of existing scenarios, reduction targets and suggested methodology per sector and policy agenda, reflecting the opinion from / discussion with the experts from Europe and Korea. The fact that various arguments and perspectives exist regarding how to define and achieve the Carbon Neutrality 2050 within the Energy Transition Forum, and that projecting the future, the year 2050 is not easy were the challenges of this research. However, the belief that all possibilities for the future are open, and the fact that the 2050 Carbon Neutrality Plan by European nations such as Germany, UK and France was based on the social commitment to achieve the carbon neutrality by the society became the driving force behind this study.

- With the rapid changes in social perception on the climate crisis in Korea which is reflected in the 2050 Carbon Neutrality announcement , we hope that this study serves as a steppingstone in the journey of coping with the climate crisis and carbon neutrality in Korea. We also hope to witness additional and more detailed research and discussions on the agenda and methodologies used to achieve set goals for each sector covered in this report in order to realize the 2050 Carbon Neutrality.

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