기후위기에 대응하는 에너지산업 혁신성장 전략

2020년 10월 6일

박진호

한국에너지학회 수석부회장
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前) 산업통상자원R&D전략기획단 에너지산업 MD

목차

Part 1. 에너지 산업 및 정책 패러다임 전환

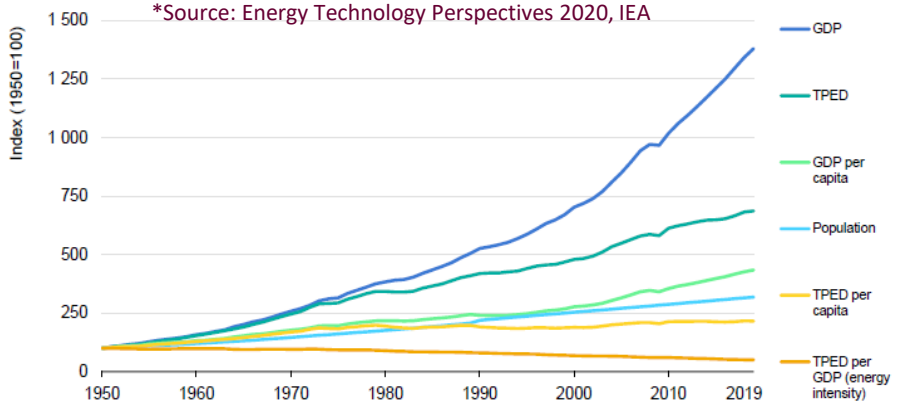
글로벌 에너지시장 동향

Energy demand has historically been driven by GDP and population, reaching a sevenfold increase from 1950.

World energy consumption rises nearly 50% between 2018 and 2050 in the reference case — with almost all of the increase occurring in non-OECD countries

Figure 1.1 Global total primary energy demand, population and GDP, 1950-2019

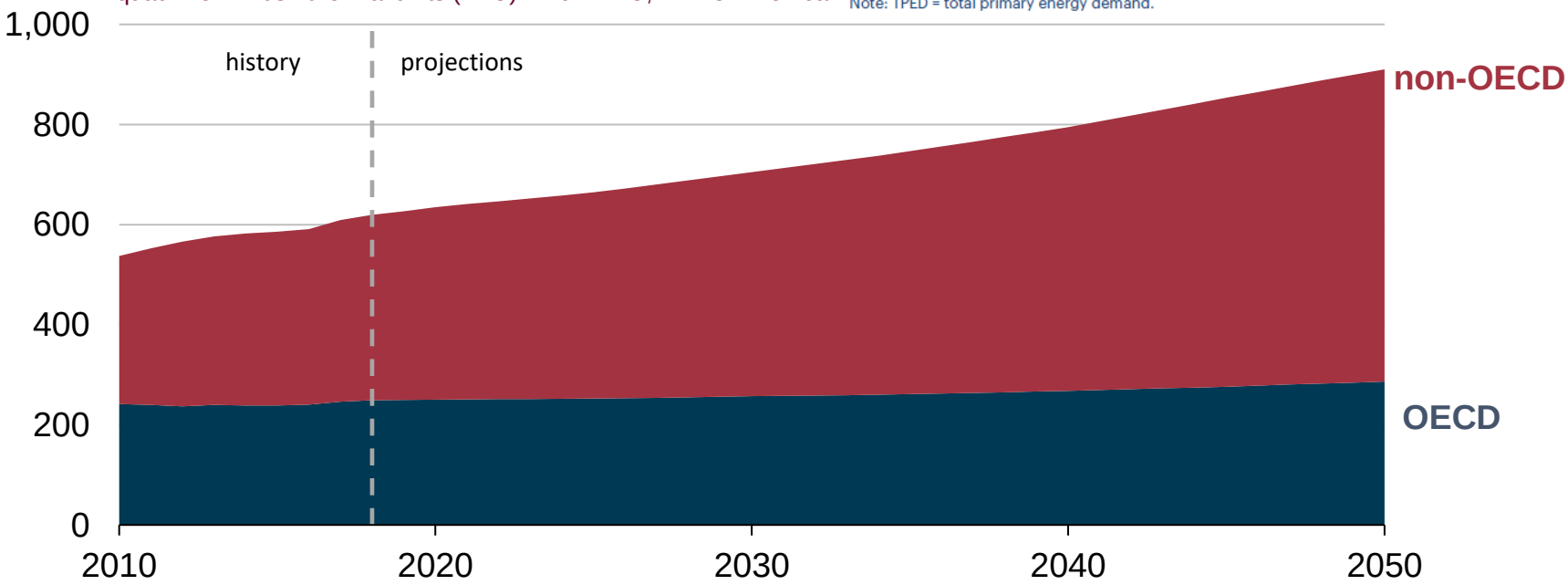
*Source: Energy Technology Perspectives 2020, IEA



World Energy Consumption quadrillion British thermal units*

quadrillion British thermal units (BTU) = 10^{15} BTU; 1 BTU = 252 cal

Note: TPED = total primary energy demand.



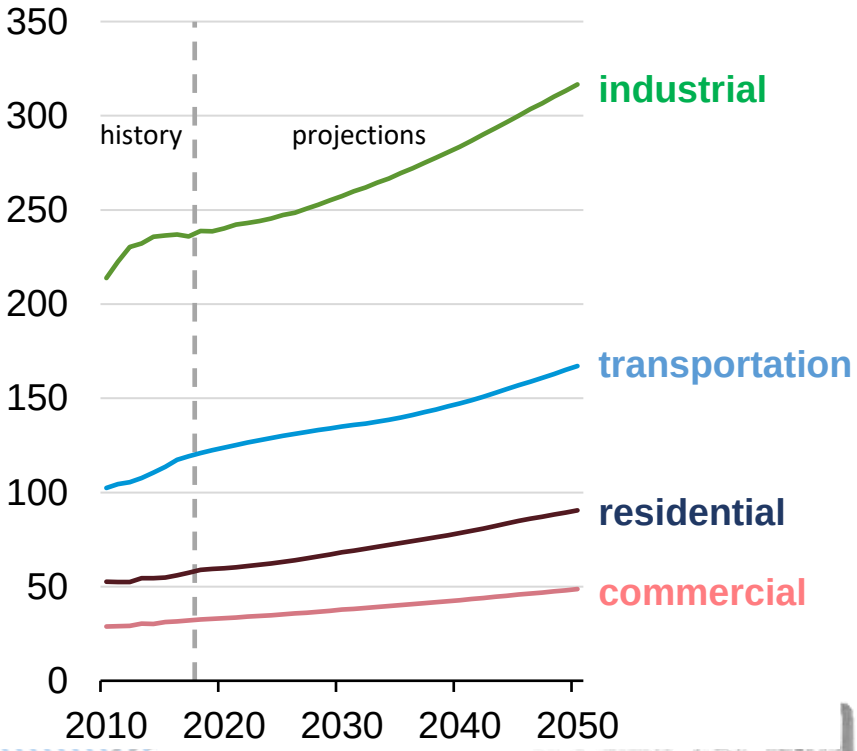
* Source: EIA, International Energy Outlook 2019

글로벌 에너지시장 동향

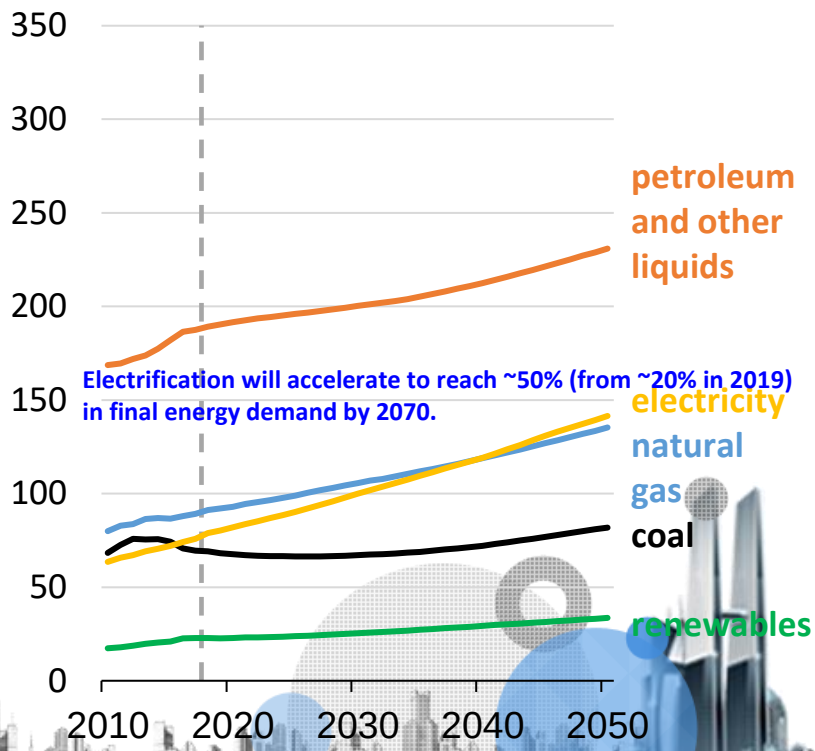
The industrial sector is the largest consumer of energy — and constitutes more than half of global energy consumption

While energy consumption in each end-use sector grows — end-use fuel composition increasingly shifts toward electricity

End-use energy consumption by sector, world
quadrillion BTU



End-use energy consumption by fuel, world
quadrillion BTU



* Source: EIA, International Energy Outlook 2019

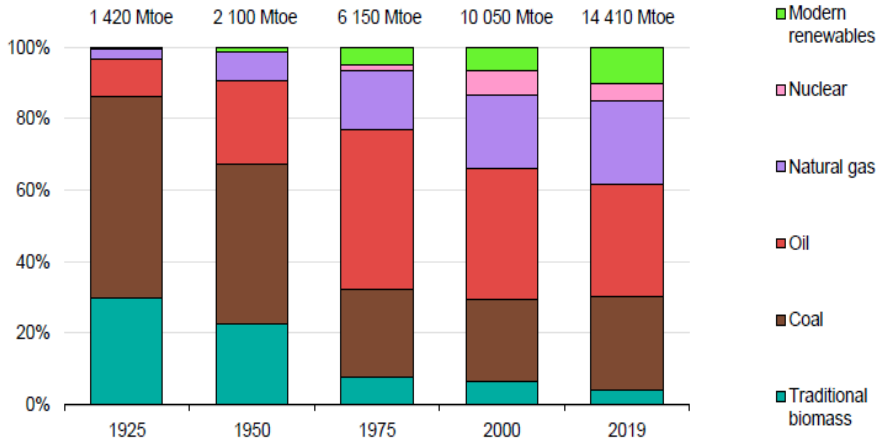
에너지소비와 온실가스

Coal and traditional biomass have declined over the last century while first oil then gas, nuclear power and renewables emerged in successive waves. Since 2000, the share of oil and nuclear has declined while that of coal has increased.

Energy-related CO_2 emissions generally have risen with energy demand since the 1970s; the Covid-19 is set to cause the largest decline in annual emissions over that period.

Power generation, where coal use is increasingly concentrated, is the biggest emitter of CO_2 worldwide, accounting for about 40% of total emissions.

Figure 1.3 Global primary energy demand by fuel, 1925-2019



Note: Modern renewables includes all uses of renewable energy with the exception of traditional use of solid biomass.

Figure 1.8 Global primary energy demand and energy-related CO_2 emissions, 1971-2020

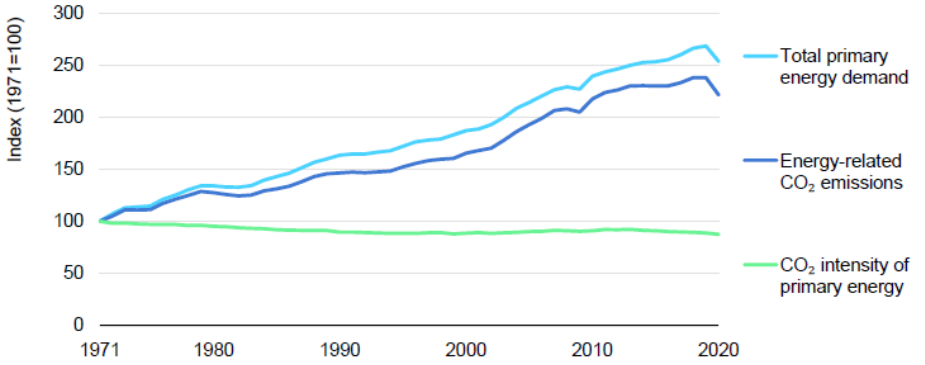
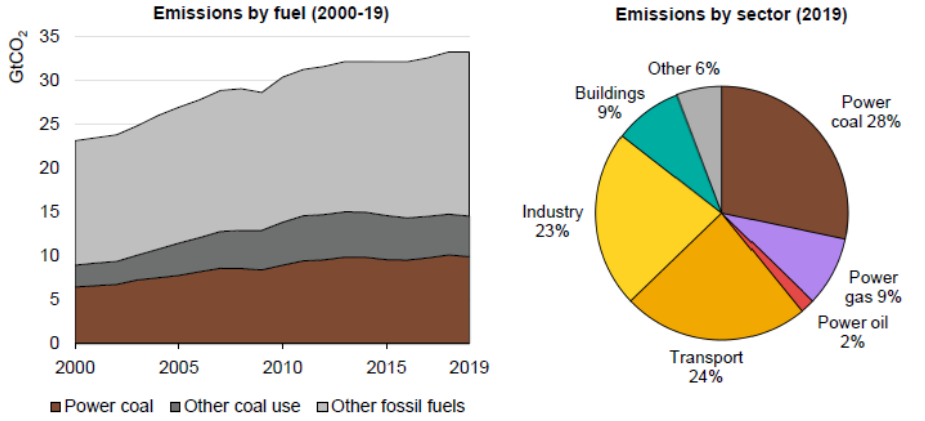


Figure 1.9 Global energy-related CO_2 emissions by fuel (left) and sector (right), 2000-19



*Source: Energy Technology Perspectives 2020, IEA

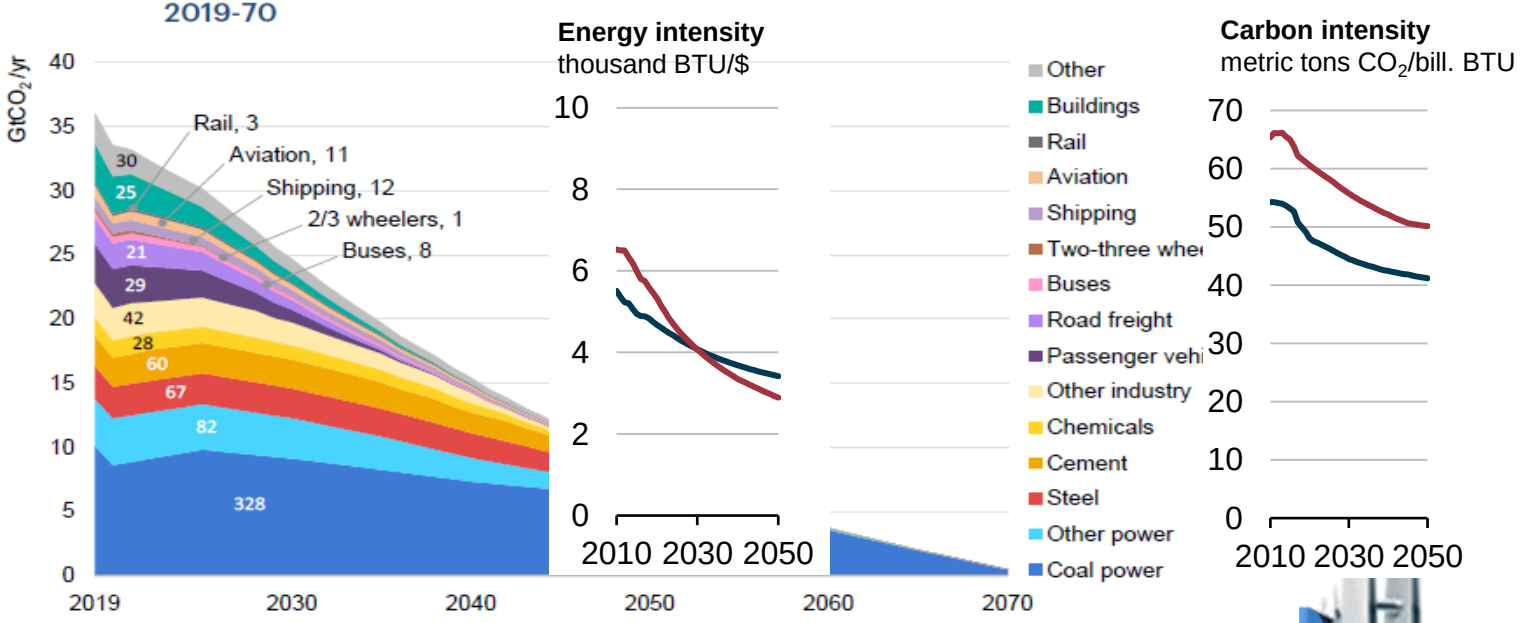
부문별 온실가스 현황과 전망

Assuming typical lifetimes and operating regimes, cumulative emissions from existing energy infrastructure could reach nearly 750 $GtCO_2$ by 2070. The bulk of cumulative emissions from existing infrastructure is expected to come from: Power (55%), Heavy Industry (26%), Transport (11%), Buildings (3%), …

Consumption of natural gas has been increasing more rapidly than coal consumption recently, and the increased use of renewables has further reduced the carbon intensity of energy as have the continuing use of nuclear power and gains in energy efficiency.

Although population and incomes continue to rise in both OECD and non-OECD countries — energy and carbon intensity are projected to continue to fall

Figure 1.11 Global CO_2 emissions from existing energy infrastructure by sub-sector, 2019-70

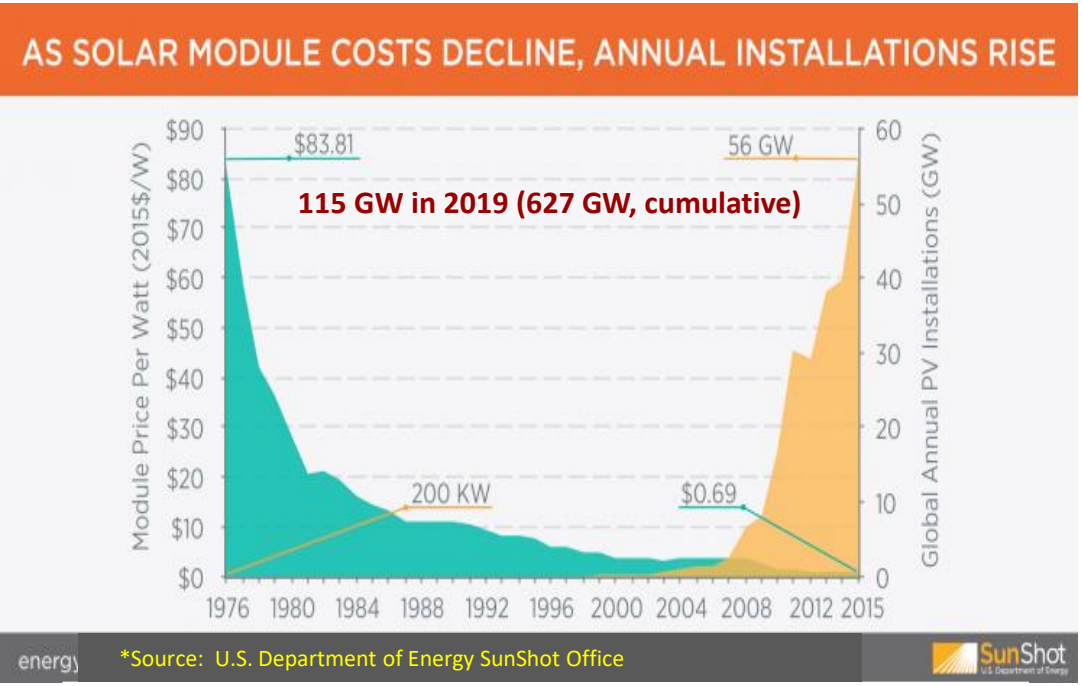


Notes: Includes assets under construction in 2019, the base year of this analysis. Numeric area labels on the graph denote cumulative emissions quantities by sub-sector in $GtCO_2$. Analysis includes industrial process emissions, and emissions are accounted for on a direct basis. Annual operating hours over the remaining lifetime are based on the level in 2019.

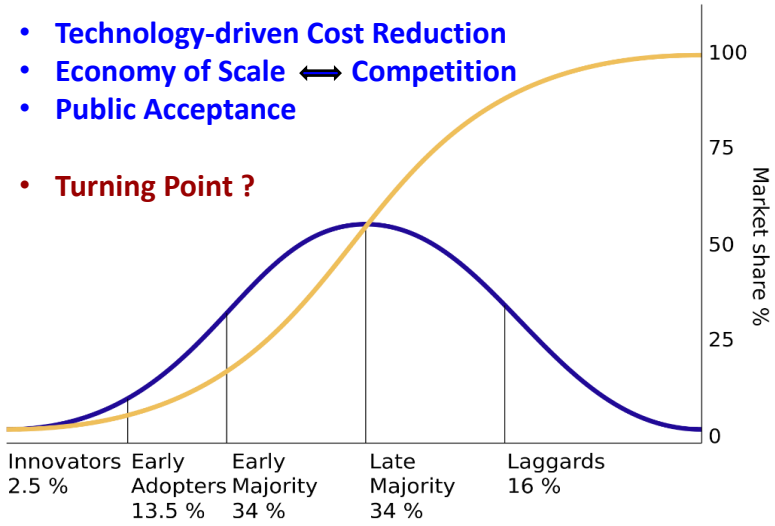
*Source: Energy Technology Perspectives 2020, IEA

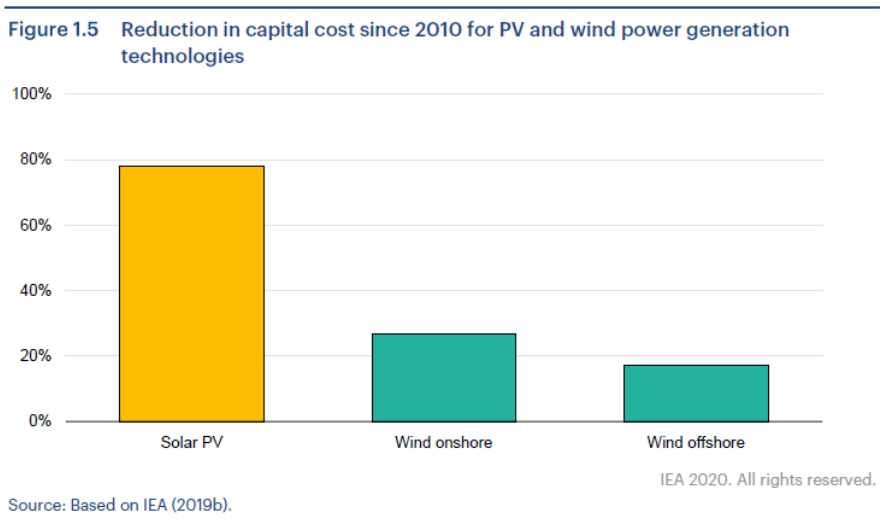
* Source: EIA, International Energy Outlook 2019

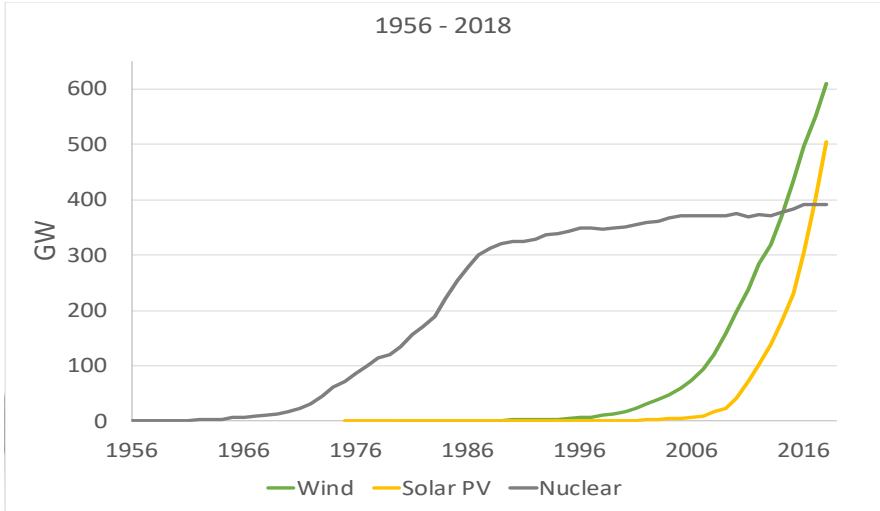
As Costs Have Declined, Annual Installations Have Risen - Economy & Business vs. Public Acceptance?



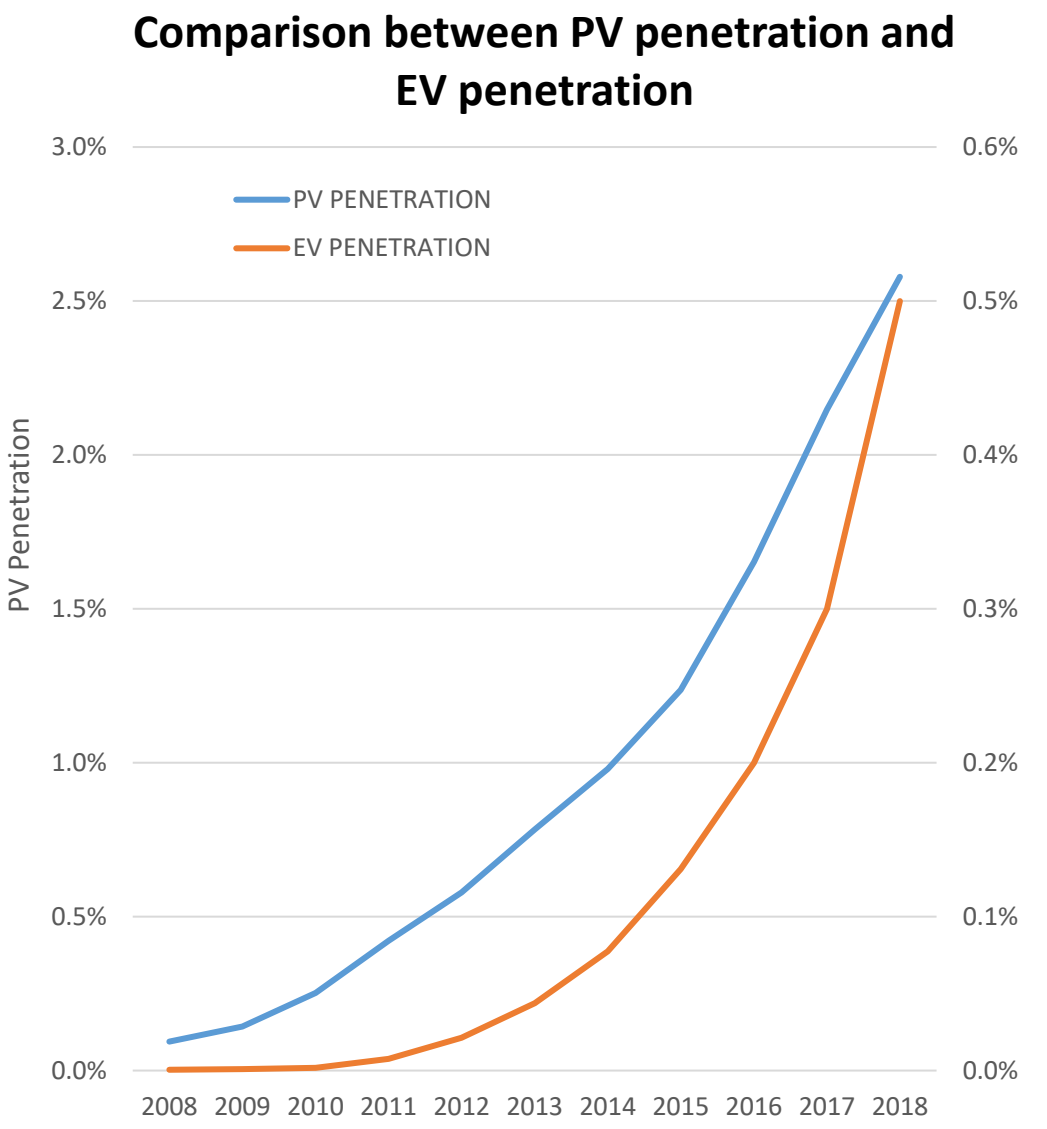
<Everett Rogers>
Diffusion of Innovations Theory







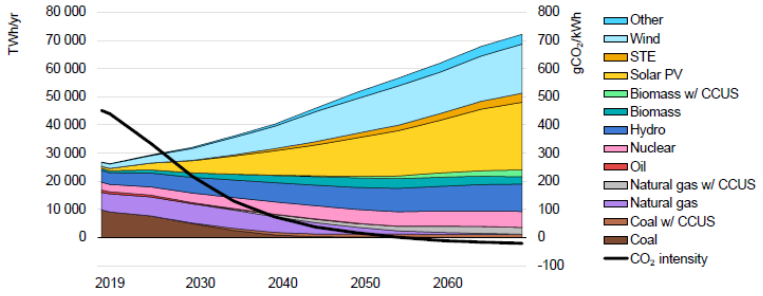
Electrification of Transport: A Joint Development



- In Europe, countries such as Norway or Iceland have reached, in 2018, respectively 46% and 17% of electric vehicle penetration.
- In the rest of the world, electric vehicles represent just below 5% of the car fleet in China and 2.5% in the USA.
- More than 2 million electric vehicles were sold in 2018, representing a 68% increase compared to 2017.
- But EV needs zero-carbon electricity to be really decarbonized.

Global power generation sector achieves net-zero emissions before 2060, largely from renewables which account for over 85% of the generation mix by 2070.

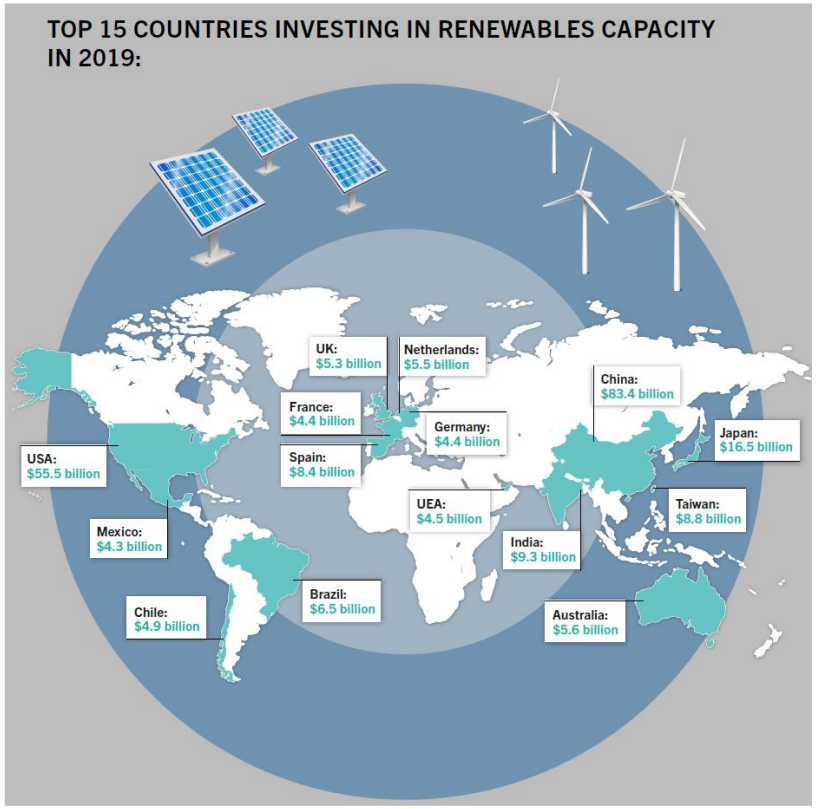
Figure 3.2 Global power generation by fuel/technology in the Sustainable Development Scenario, 2019-70

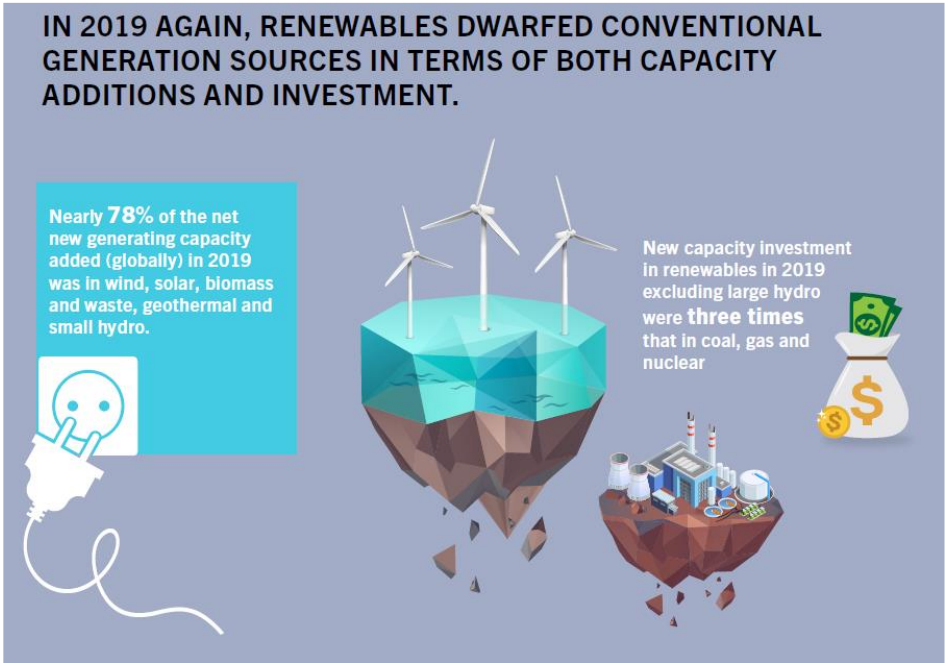


Notes: TWh = terawatt-hours; gCO_2/kWh = grammes of CO_2 per kilowatt-hour, STE = solar thermal electricity; PV = photovoltaic; CCUS = carbon capture, utilisation storage. Other includes geothermal power, ocean energy and hydrogen.

국내외 에너지시장 동향

OECD 중심의 에너지 전환 투자





*Source: FS-UNEF Collaborating Center, Global Trends in Renewable Energy Investment 2020

- OECD 국가 및 신흥경제국 중심으로 에너지전환 급속도로 진행
- 청정에너지·에너지효율 분야가 새로운 일자리 창출의 보고로 등극

주요 국가의 에너지 정책

COP21 이후 新기후체제가 대세이나, 탄소중립 관련 국가별 전략은 다양

(美) America First Energy Plan ('17. 1)

향후 7년 동안 300억달러 임금 인상 효과

- 기후규제 철폐
- 전통자원 개발
- 청정석탄 개발
- **에너지 독립***
- 환경 보호
- **State별 별도 에너지계획**

* 미국 내 석유/가스 생산 확대, 에너지 수출 활성화, 화석연료 규제 및 기후변화 대응 반대 등해 에너지 독립과 고용 확대를 추구하는 미국 최우선 에너지정책 ('17.6.1 Ml 탈퇴 선언)

(中) 전력부문 13.5계획 ('16~'20, '16.11)

샤오캉사회(小康事會) 전면 건설로 중산층 확대

- **전력공급 능력 확보***
- 발전원별 전원구성 개선
- 전력망 개발
- 전력 수급 조절 능력 강화
- 에너지 절약 및 오염 저감
- **탄소중립선언(2060)**

* 급속 성장 중인 중국 경제를 뒷받침하기 위한 전력공급 확대에 중점을 두고 있으며, 청정석탄 및 그린에너지 확대도 동시에 추구 (태양광, 풍력, 원전 분야 확대율 모두 세계 1위)

(EU) SET Plan 2016 ('16)

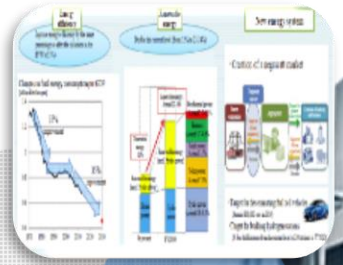
20-20-20 달성 위해 막대한 자금 투입

- **세계 신재생에너지 No. 1**
- **건물에너지 효율 향상**
- **탄소중립선언(2050)**
- 유연에너지 시스템 구축
- 산업에너지 효율화
- 지속가능 이동수단 확대
- 독일, 프랑스 등 국가별 별도 계획

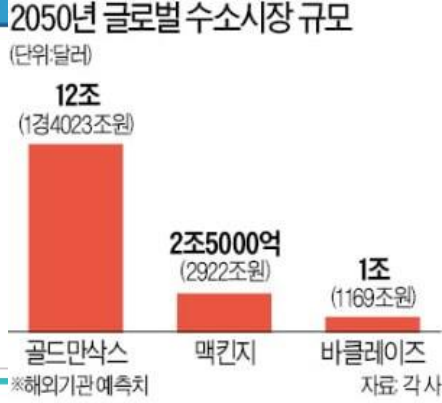
(日) 에너지 이노베이션 전략 ('16. 4)

신재생에너지 2배 이상 보급

- 전산업 Top-runner
- **저탄소 전원시장 창출**
- 신재생에너지 산업 재구축
- IoT 활용 에너지산업 혁신
- 5차에너지기본계획
- **Post 2030 수소사회 전략**



주요 국가별 수소경제 로드맵



EU / 독일

- **재생에너지 기반 수전해 그린수소 생산시설 구축 확대**
  - * EU : '30년까지 40GW 규모 / 독일 : '40년까지 10GW 규모
- **그린수소 이용 확대 및 수소 활용분야 확장**
  - * 그린수소 인증 기준 마련, 철강·석유화학 등 산업분야에 그린수소 활용 확대

일본

- **재생에너지 활용한 수소 공급시스템 구축**
  - * 수소차 80만대, 수소버스 1,200대, 충전소 900개소('30)
- **해외 공급처 다변화 및 국내 수전해 기술 강화**
  - 호주 ➡ 갈탄 개질
  - 브루나이 ➡ 천연가스 개질
  - 노르웨이 ➡ 수전해
  - 사우디 ➡ 원유 수소 추출

호주

- **그린수소 단가 저감, 에너지전환 관련 수소 기술 향상**
  - * 아시아 시장 Top3 수소수출국
  - * 국제적으로 인정받는 인증제도 확보

미국

- **수소차량 다변화(승용, SUV, 트럭 등), 연료전지 발전 확대, 수소터빈 등 전분야 기술 확보 및 경쟁력 제고**
  - * 수소차 120만대, 물류차량 30만대, 충전소 5,800개소('30)
  - * 수소발전 Grid Parity 달성('30)

사우디

- **재생에너지 활용 세계 최대 4GW급 수전해 그린수소 생산시설 구축 및 수출국 위상 확보**
  - * 풍력·태양광 활용 650톤/일 그린수소 생산 계획('25)

UAE

- **재생에너지 확대로 저가 수전해 수소 생산**
  - * 두바이 5GW 규모의 태양광 발전소 구축('30)
  - * "UAE 2050 에너지 전략" 발표(재생E 전력비중 50%)

Clean Energy 관련 정의 및 이슈

The International Energy Agency (IEA) defines low-carbon energy technologies as: renewable energy sources (renewables), nuclear power; carbon capture, utilization and storage (CCUS); hydrogen derived from low-carbon energy sources; technologies that improve the efficiency of energy transformation (e.g. switching from incandescent to light-emitting diode [LED] lighting); other non-fossil power and storage options; and cross-cutting technologies that result in minimal emissions of CO_2 and pollution. Clean energy sources are growing in importance, but they still account for only around one-fifth of energy supply worldwide. In other words, the energy system in its present state is unsustainable. 출처: Energy Technology Perspectives 2020_IEA_September, 2020

Environment, Social, and Corporate Governance (ESG) refers to the three central factors in measuring the sustainability and societal impact of an investment in a company or business. ESG criteria help to better determine the future financial performance of companies (return and risk). It is increasingly important for financing.

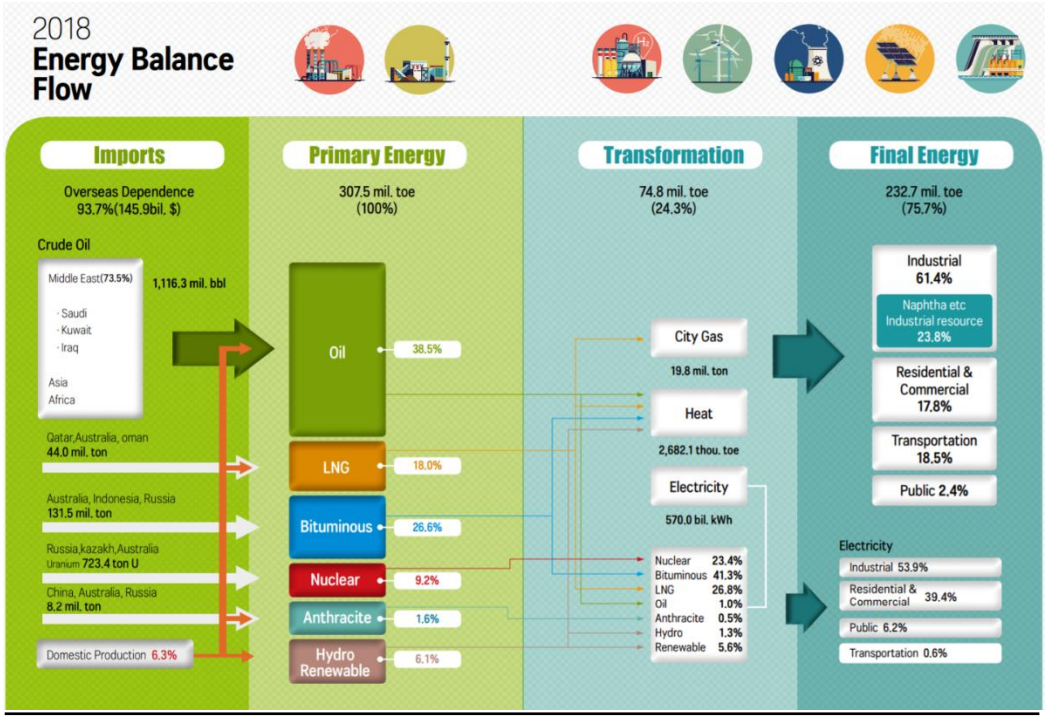
Green Financing (UNEP), Sustainable Financing (EU TEG) are trying to set the criteria for financing low-carbon energy projects. Some includes "Do no significant harm" index.

RE100 Company Alliance : Over 263 companies as of October, 2020
CF100 : Google by 2030, Apple by 2030, etc. Carbon Free 100 is different from RE 100.

Part 2. 국내 에너지 산업 현황 및 이슈

한국의 에너지 수지 및 믹스

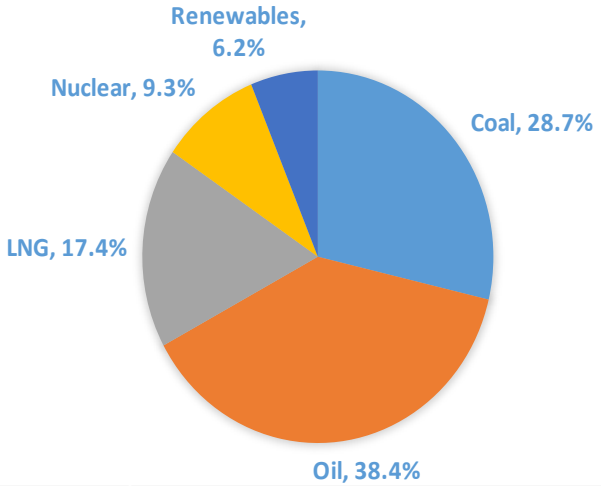
In 2018, a total of 307.3 Mtoe primary energy was supplied, and 237.9 Mtoe final energy was consumed. Energy consumption became stagnant since 2012; NRE electricity supply has been increasing but still minimal in the energy mix. The industrial sector consumed the most (61.5%), followed by the transportation sector (17.9%), residential/commercial sector (17.5%), and public sector (3.1%). In the power generation mix, fossil electricity occupies 68.6%; nuclear 22.5%; renewables 8.9%.



'12	184.8	278.8(0.7%)	70.6(25.3%)	208.2(1.1%)
'13	178.7	280.4(0.6%)	70.1(25.0%)	210.3(1.0%)
'14	174.1	283.1(0.9%)	69.2(24.5%)	213.8(1.7%)
'15	102.7	287.7(1.6%)	69.3(24.1%)	218.4(2.1%)
'16	80.9	294.8(2.5%)	68.8(23.3%)	226.0(3.5%)
'17	109.5	302.1(2.5%)	68.2(22.6%)	233.9(3.5%)
'18	145.9	307.5(1.8%)	74.8(24.3%)	232.7(-0.5%)

*(%) is increase in primary energy supply with respect to the previous year; transformation (%) means % loss from primary energy to final energy.

KOREA 2018



2018 Data	Measure
Power gen., total	**Power generation, total (GWh): 593,639**
Renewables, fossil and nuke electricity gen.	Fossil (GWh and %): 407, 415 – 68.6%
	Nuclear (GWh and %): 133,506 – 22.5%
	Renewables (GWh and %): 52,718 – 8.9%
Of RE production (hydro, wind, PV, biomass, & other renewables)	Hydro (GWh & %): 3,374 – 6.4%
	Wind (GWh & %): 2,465 – 4.7%
	PV (GWh & %): 9,208 – 17.5%
	Biomass (GWh & %): 9,363 – 17.8%
	Other renewables (GWh & %): 28,308 – 53.6%
Growth rate of total RE gen. (% per year) over the past 5 years	2014: +25.39% 2015: +37.93% 2016: +9.65 2017: +14.68% 2018: +13.07%

한국의 GDP 동향 및 제조업 기여도

실질 및 명목 경제성장률 동향

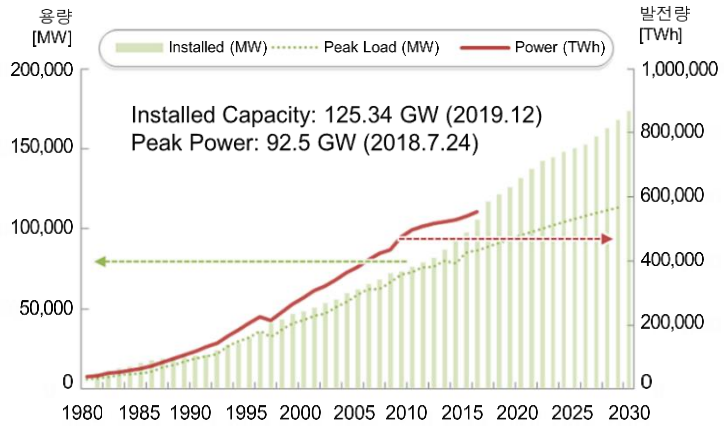
*출처: 한국은행 경제통계시스템(2019)

한국의 전력 수급 상황

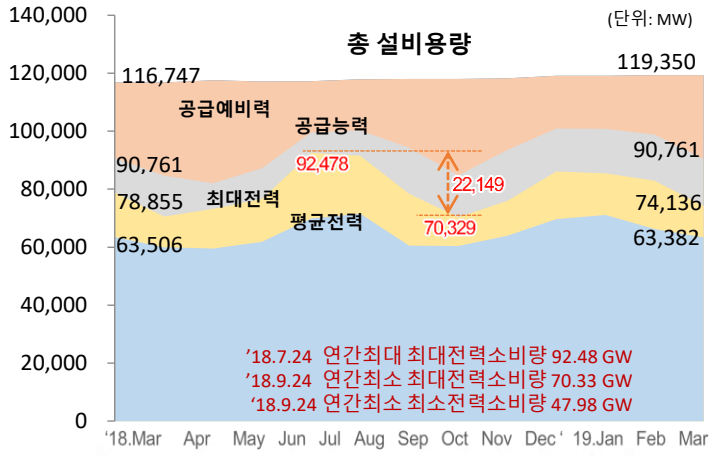
설비용량 120 GW 시대 도래, '12년 이후 에너지 소비 증가율 정체, 최종에너지 중 전기 비중 ~19%

최종 에너지 소비: 산업부문 61.4%, 수송부문 18.5%, 가정·상업 부문 17.8%

설비용량 및 발전량



연간 전력공급 및 소비 패턴



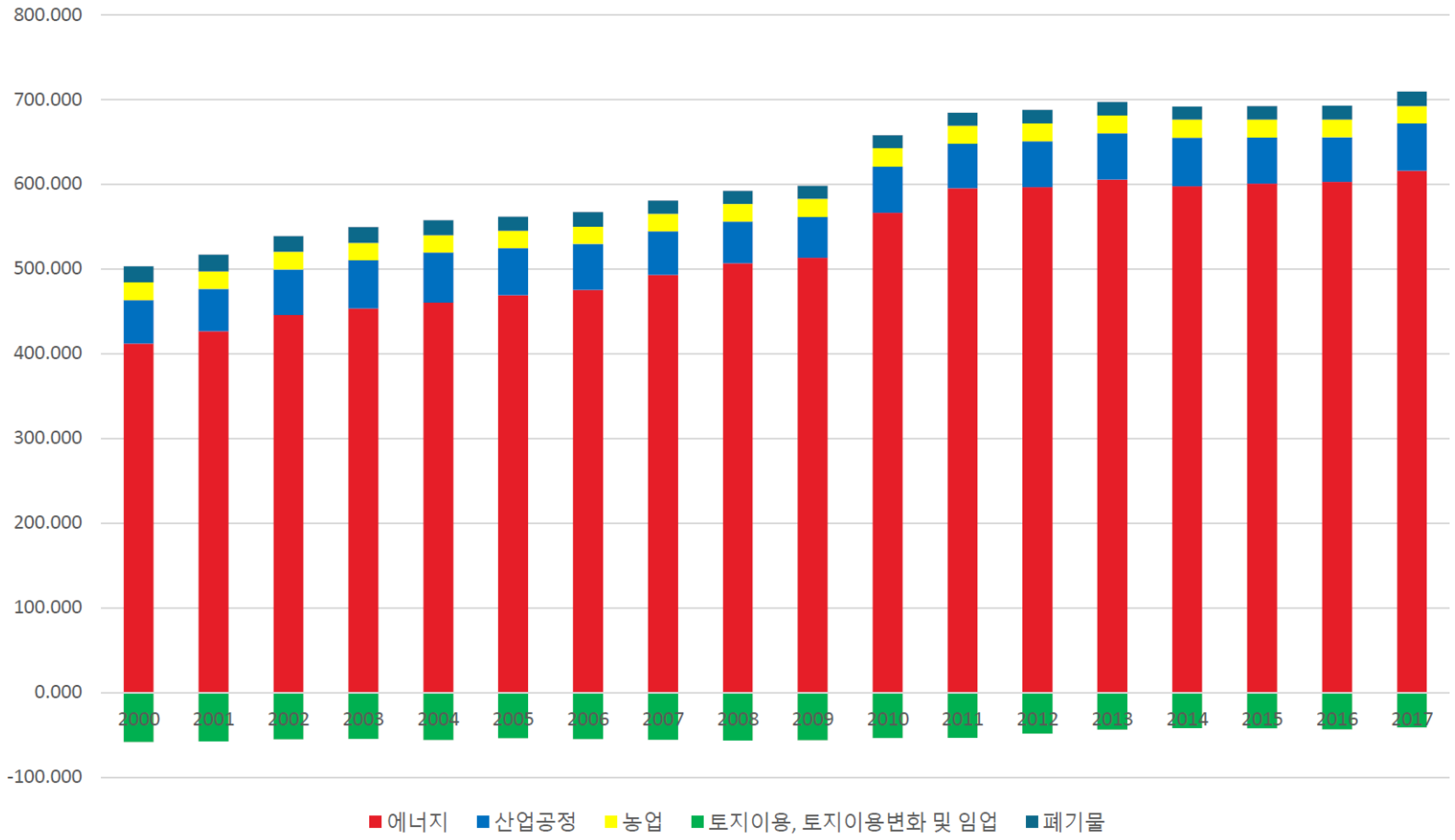
*Source: 전력통계속보(2019.12)

□ 연간 2회의 피크부하와 20 GW 이상의 최고-최저 차이 패턴

□ 현재의 피크부하 대응 방식의 전력수급 전략 수정 필요

*Demand-side management & national-level peak shifting and/or shaving became necessary.

한국의 온실가스 배출 현황



*출처: 국가온실가스 배출통계 추이(통계청, 2019.11.14)

한국의 에너지산업 현황

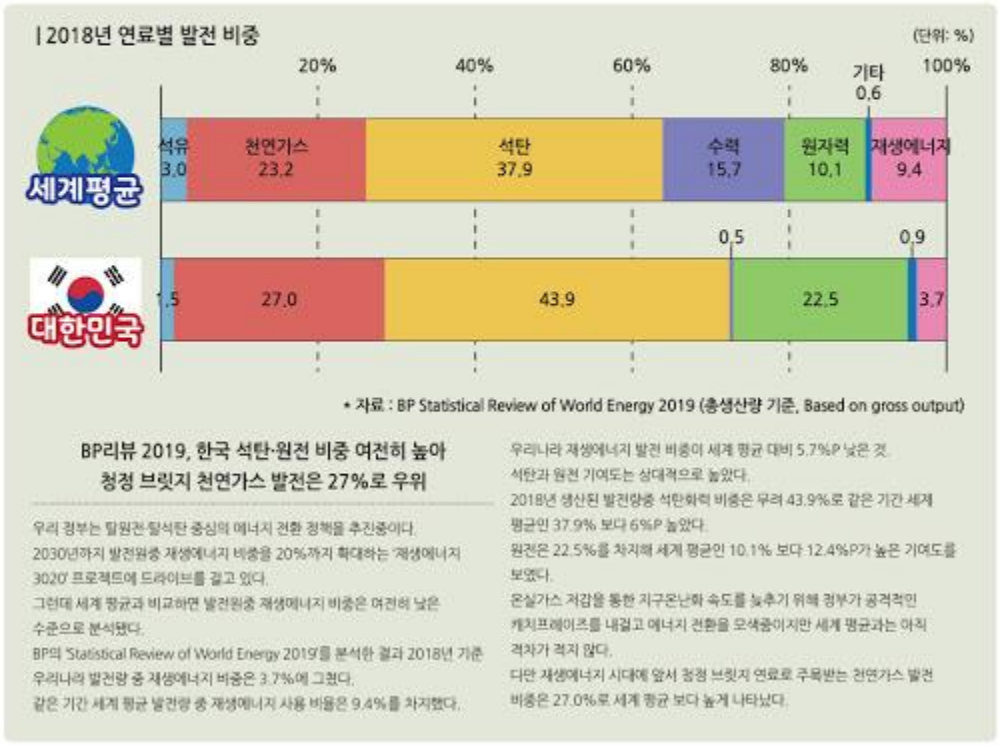
재생에너지 보급 미흡, 에너지 新산업 생태계 미성숙

[에너지그래픽]

지앤이타임즈 Green Energy & Environment

세계 평균과 아직 격차 큰 재생에너지 발전

| 기사·디자인 | 이진영 기자
diosia01@gnetimes.co.kr



BP리뷰 2019, 한국 석탄·원전 비중 여전히 높아
청정 브릿지 천연가스 발전은 27%로 우위

우리 정부는 탈원전·탈석탄 중심의 에너지 전환 정책을 추진중이다.
2030년까지 발전원중 재생에너지 비중을 20%까지 확대하는 '재생에너지 3020' 프로젝트에 드라이브를 걸고 있다.
그런데 세계 평균과 비교하면 발전원중 재생에너지 비중은 여전히 낮은 수준으로 분석됐다.
BP의 'Statistical Review of World Energy 2019'를 분석한 결과 2018년 기준 우리나라 발전량 중 재생에너지 비중은 3.7%에 그쳤다.
같은 기간 세계 평균 발전량 중 재생에너지 사용 비율은 9.4%를 차지했다.

우리나라 재생에너지 발전 비중이 세계 평균 대비 5.7%P 낮은 것.
석탄과 원전 기여도는 상대적으로 높았다.
2018년 생산된 발전량중 석탄화력 비중은 무려 43.9%로 같은 기간 세계 평균인 37.9% 보다 6%P 높았다.
원전은 22.5%를 차지해 세계 평균인 10.1% 보다 12.4%P가 높은 기여도를 보였다.
온실가스 저감을 통한 지구온난화 속도를 늦추기 위해 정부가 공격적인 캐치프레이즈를 내걸고 에너지 전환을 모색중이지만 세계 평균과는 아직 격차가 적지 않다.
다만 재생에너지 시대에 앞서 청정 브릿지 연료로 주목받는 천연가스 발전 비중은 27.0%로 세계 평균 보다 높게 나타났다.

태양광전력:
2.23% (2019F)

☞ 에너지원 전반의 공급 최적화와 소비구조혁신을 포괄하는 광의의 에너지전환 및 혁신성장 관점에서 새로운 에너지산업 정책 패러다임 필요

국내 재생에너지 확대 관련 이슈

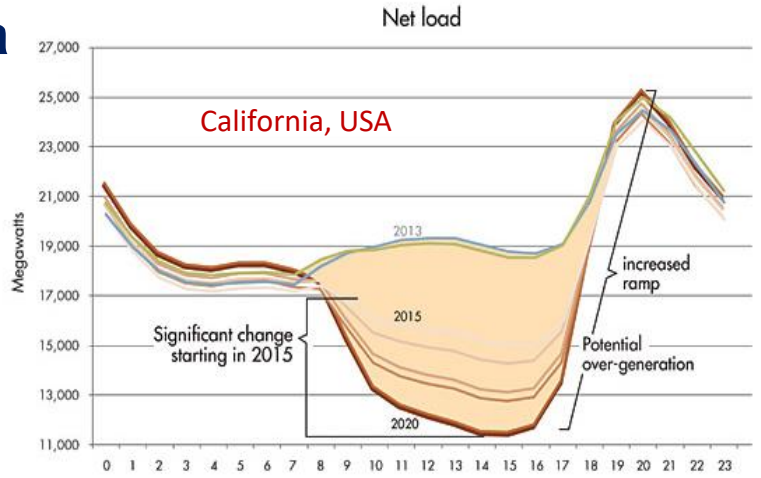
Existing Grid Infrastructure & Market System Not Yet Ready for RE

Existing electricity grids and substations are not fully ready for transmission & distribution of ever-increasing renewable electricity – not enough grids where RE is largely generated; not fully distributed RE power sources.
Current market system for electricity transaction is not optimized for distributed sources such as renewables.

National-level Peak Shifting in Korea

Increase of solar power causes Korean-style Duck Curve to occur, which shifts peak load time from 3 pm to 5 pm.

There are variety of solutions to mitigate the duck curve, and the most common method is using energy storage systems and the way in which the system is connected to other systems to increase system inertia – Energy storage, DR, financial incentives & strategic curtailment, forecasting tools, microgrids, etc.



Curtailment of RE in Jeju Island

Power generation capacity of Jeju Island is 1,350 MW, of which the renewable energy generation capacity is 436 MW (about 32% - Wind 266 MW, Solar 160 MW, and Others 8.8 MW).
As of 1 pm on 2018-11-22, out of total 610 MWh of Jeju Island, the amount of renewable energy generation was 309 MWh, accounting for 49%.

Due to the high fluctuations in the output of renewable power generation, the curtailment operation is required, and the number of curtailments of renewable power generation on Jeju Island is gradually increasing to 6 times in 2016, 16 times in 2017, 17 times in 2018 and to 19 times in 2019.

Year	Number of Curtailments	Amount of Curtailment (MWh)
'15	3	152
'16	6	252
'17	16	1,301
'18	17	1,366
'19 (~6.3)	19	3,975

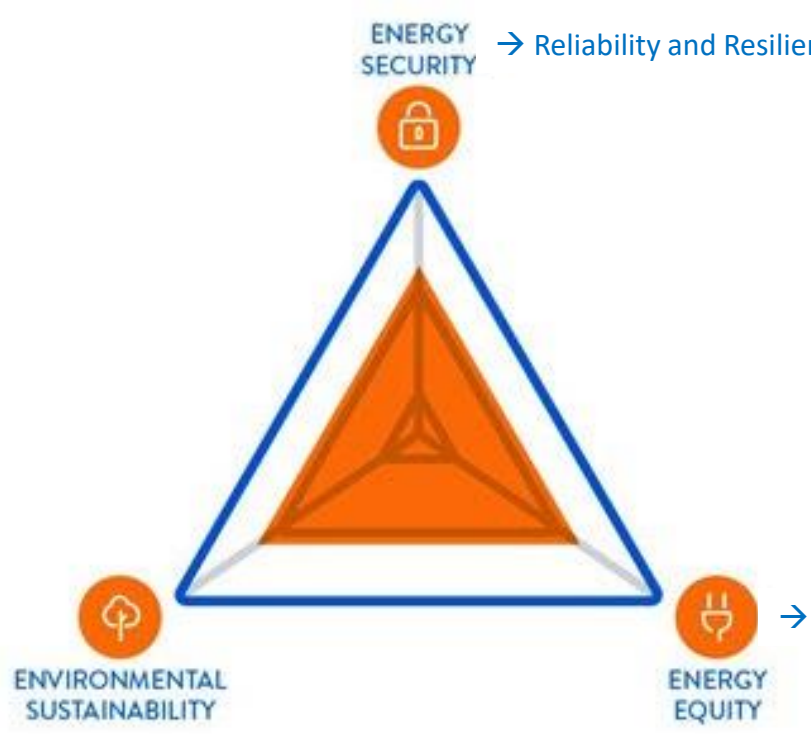
Part 3. 한국의 에너지산업 혁신성장 전략

정부의 에너지정책 수립 제한 조건

2018 세계 에너지 Triangle 순위

TOP 10
OVERALL RESULTS

1. Denmark
2. Switzerland
3. Sweden
4. Netherlands
5. United Kingdom
6. Slovenia
7. Germany
8. New Zealand
9. Norway
10. France



*Energy Equity: Accessibility and affordability of energy within a country or region

제3차 에너지기본계획

에너지 전환을 통한
지속가능한 성장과 국민 삶의 질 제고

에너지산업의 혁신성장 전략

에너지산업 포트폴리오 재구축
(新기후체제 연계)

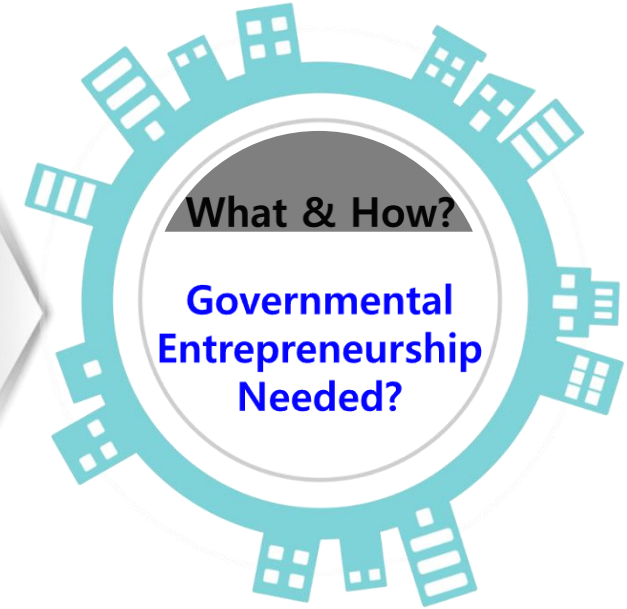
에너지정보화를 통한 효율증진 및 新산업 창출
(디지털 및 A ICBM, Grid Modernization)

주력에너지산업 활력 제고
(다운스트림역량 활용 수출 촉진 및 수소 등 주력산업 연계 신산업 육성)

미세먼지 및 원전안전성 적극대응
(국민불편해소 및 원전산업 고도화)

As-Is 주력산업 Supporter

To-Be 新성장동력 산업



<산업간 시너지 및 동반상승 효과 창출 가능성>

태양광	⟺	반도체/디스플레이
풍력	⟺	조선/철강/해양플랜트
수소	⟺	자동차/조선/석유화학/철강/시멘트
가스터빈	⟺	기계/항공/원자력/석탄
마이크로그리드	⟺	배터리/전력반도체/시스템반도체

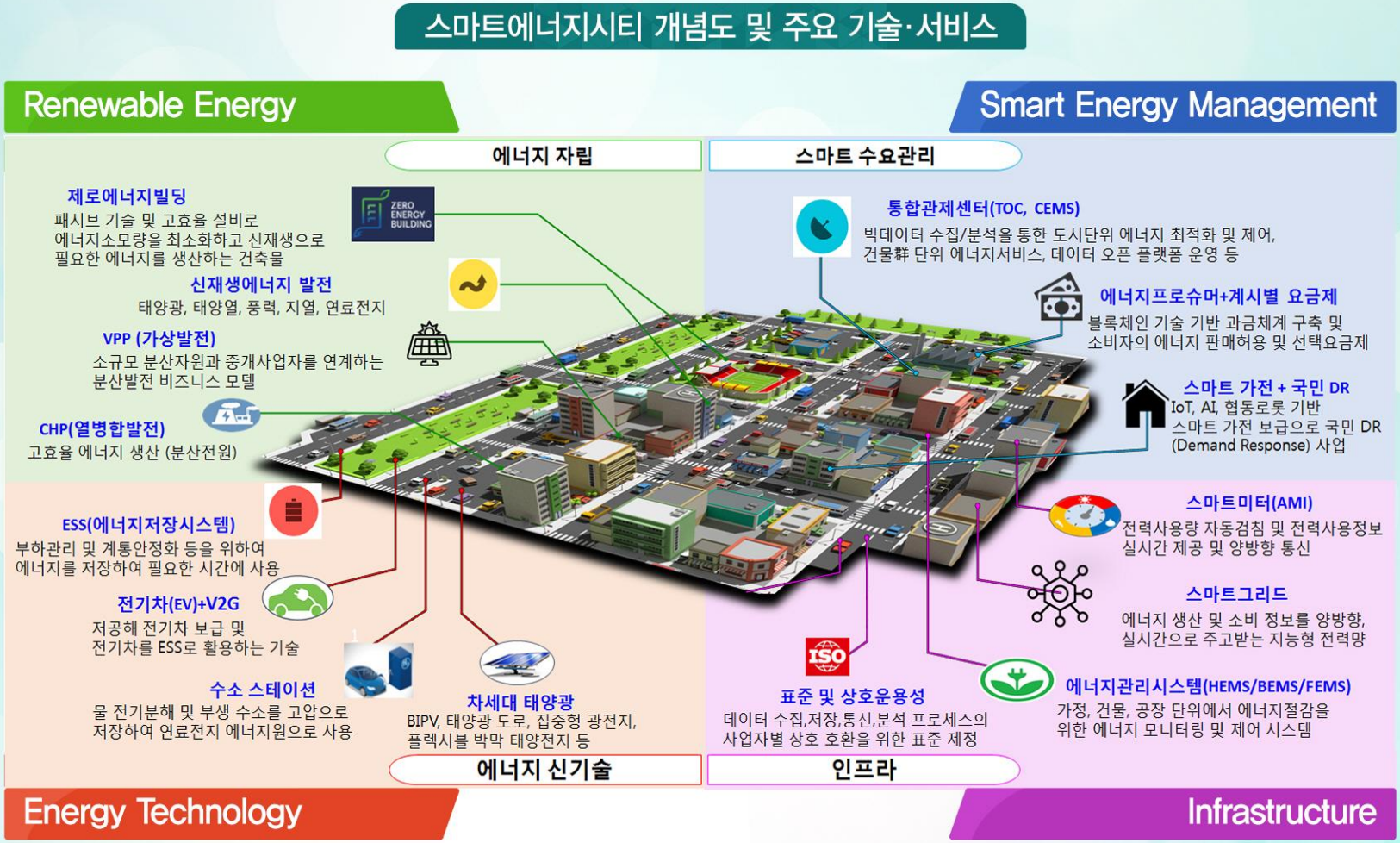
스마트에너지 네크워크 구축 전략

스마트에너지 네트워크란?

개념

❖ Digital 기술*을 기반으로 에너지 이용을 효율화하고, 자원소비와 운영비용을 줄이는
지속가능한 저탄소 미래도시형 에너지 시스템 – 빅데이터 기반 에너지플랫폼

*A.I.C.B.M (AI, IoT, Cloud, Big data, Mobile)

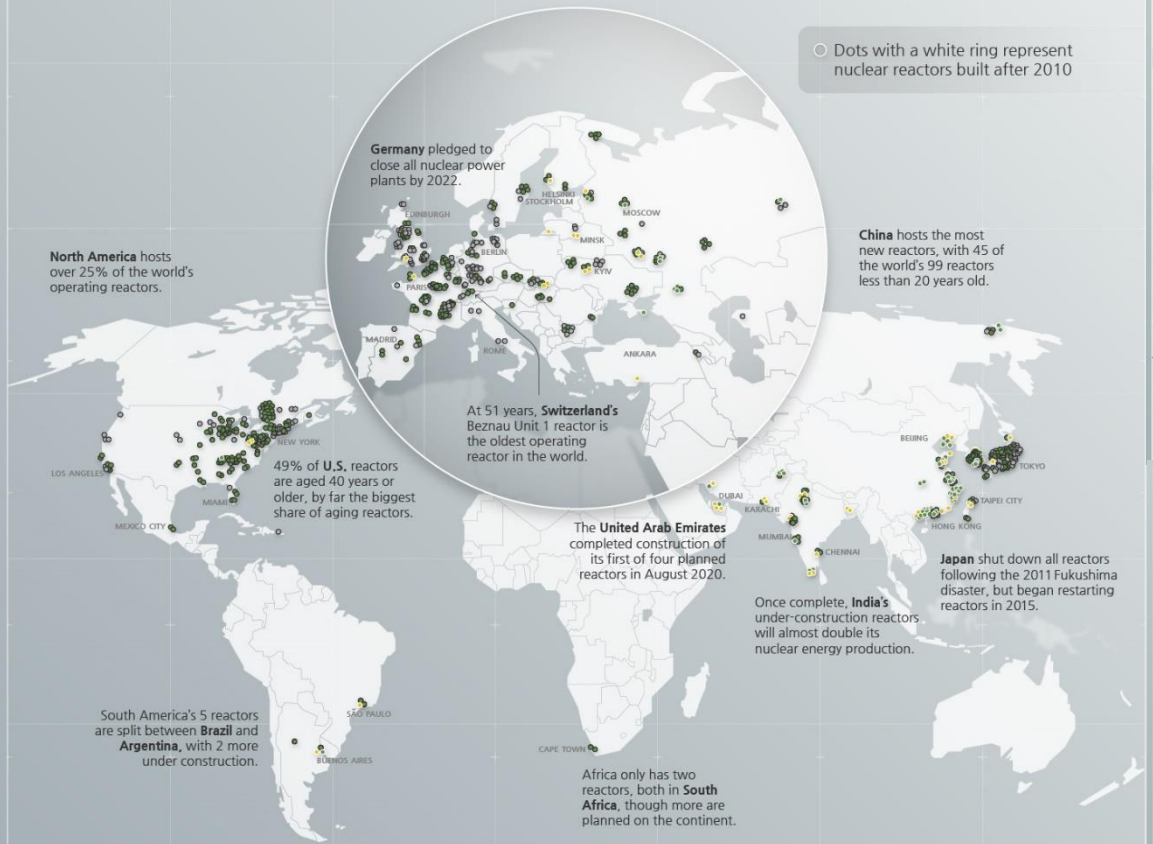


THE WORLD'S NUCLEAR REACTOR LANDSCAPE

Some countries see nuclear energy as an environmental danger. Others are embracing it as a climate-change fighting solution.

UNDER CONSTRUCTION | OPERATING | SHUTDOWN

Here's a look at which countries have nuclear reactors, and how the landscape is shifting across different regions.

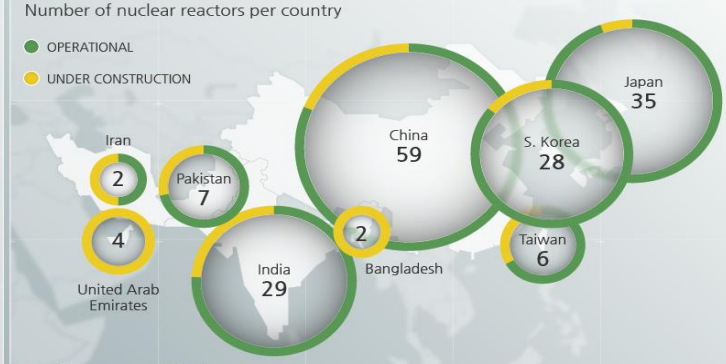


Global Nuclear Reactors and Electrical Capacity 2000-2019

Gigawatt

Asia's Growing Nuclear Footprint

Number of nuclear reactors per country



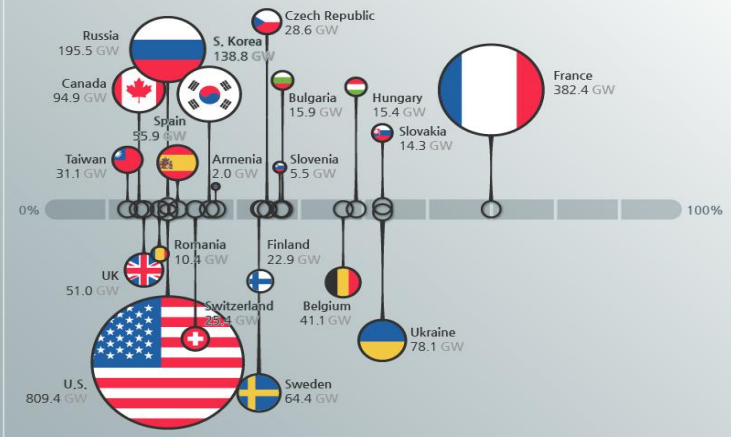
Total Percentage of Global

31%	29%	65%	64%
Operational reactors	Total net electrical capacity	Under construction	UC electrical capacity (MW)

China and **India** are driving the most growth, while other Asian countries are also ramping up nuclear reactor construction.

Top 15 Nuclear Energy Producers

By % of Country's Electricity Production



VISUAL CAPITALIST

Source: International Atomic Energy Agency

/visualcapitalist @visualcap visualcapitalist.com

A New Generation of Nuclear Reactors – a Turning Point ?

For those parties interested in the benefits of nuclear power, past accidents have also led towards a push for innovation in the field.
That includes studies of miniature nuclear reactors **(SMR)** that are easier to manage, as well as full-size reactors with robust redundancy measures that won't physically melt down. Additionally, some reactors are being designed with the intention of utilizing accumulated nuclear waste—a byproduct of nuclear energy and weapon production that often had to be stored indefinitely—as a fuel source.
With some regions aiming to reduce reliance on nuclear power, and others starting to embrace it, the landscape is certain to change.

The U.S. Department of Energy (DOE) has thrown its support, and millions of dollars, behind nuclear power, in an effort to revive the nation's nuclear industry. But while new reactor designs, including small modular reactors, are being developed, the problem of disposal of spent nuclear fuel remains a challenge.

Leslie Dewan: A co-founder and CEO of Transatomic Power, a company founded in 2011 that worked to design and develop a molten salt reactor before its design data was placed into the public domain. *TIME* selected Dewan as one of "30 People Under 30 Changing the World."

제3차 에너지기본계획 중점과제-4 : 에너지산업의 글로벌 경쟁력 강화

- **(미래 유망분야)** 세계 원자력 에너지 추세에 따라 원자력 관련 미래 유망분야에 대한 비전 제시 및 연구 산업기반 조성
  - 핵융합, 중소형 원자로, 우주 해양 등 극지 동력원, 방사선 등 원자력 분야의 미래 유망분야 발굴 육성

탈탄소화 관련 Global Consensus

어떻게 진정한 카본제로 에너지를 구현할 것인가?

- 에너지 생산 및 소비와 관련한 온실가스 배출이 전체의 75%(국내 90%) 정도 차지
- 따라서, 에너지 분야 탄소배출 제로화 전략이 많은 국가의 가장 중요한 정책 요소
- 탄소제로를 만족하는 에너지를 구현하기 위한 네 가지 주요 전략은,

OECD (Optimize, Electrify, Capture, and Decarbonize)

1. Reduce energy use through improved efficiency (**optimize**)
2. Shift energy demand to electricity and away from combustion of fossil fuels (**electrify**)
3. Direct capture and utilization of CO_2 (**capture**)
4. Shift entirely to zero-carbon technologies to generate electricity (**decarbonize**)

- 위 네 가지 전략은 모든 주요 에너지 소비 부문 즉, 산업/수송/건물 및 에너지 전환 (발전) 부문에 모두 적용되어야 할 것임

경청해주셔서 감사합니다.

Thank you for listening !