

유럽의 넷제로 달성 방안의 시사점: 비용, 일자리, 기술적 가능성 등등

김지석

중장기 국민정책제안 발표
2035년부터 무공해·하이브리드차만 판매 허용
경유 값은 휘발유의 95~100% 수준까지 인상
전기요금체계에 환경비용·연료비 변동 반영해야
반기문 위원장 “경제·환경 상충 시대 지났다”



McKinsey
& Company

Net-Zero Europe

Decarbonization pathways and
socioeconomic implications



요점 먼저

돈은 문제 안 됨: 일부 비용 늘지만 다른 부문 절감

Europe can reach net-zero emissions at net-zero cost.

Reducing GHG emissions would raise the cost of doing business in some sectors; savings in others would make up the difference. If these costs and savings were passed along to consumers, the average cost of living would decline slightly for low- and middle-income households.

11백만 - 6백만 = 5백만개 신규 일자리 만들어짐

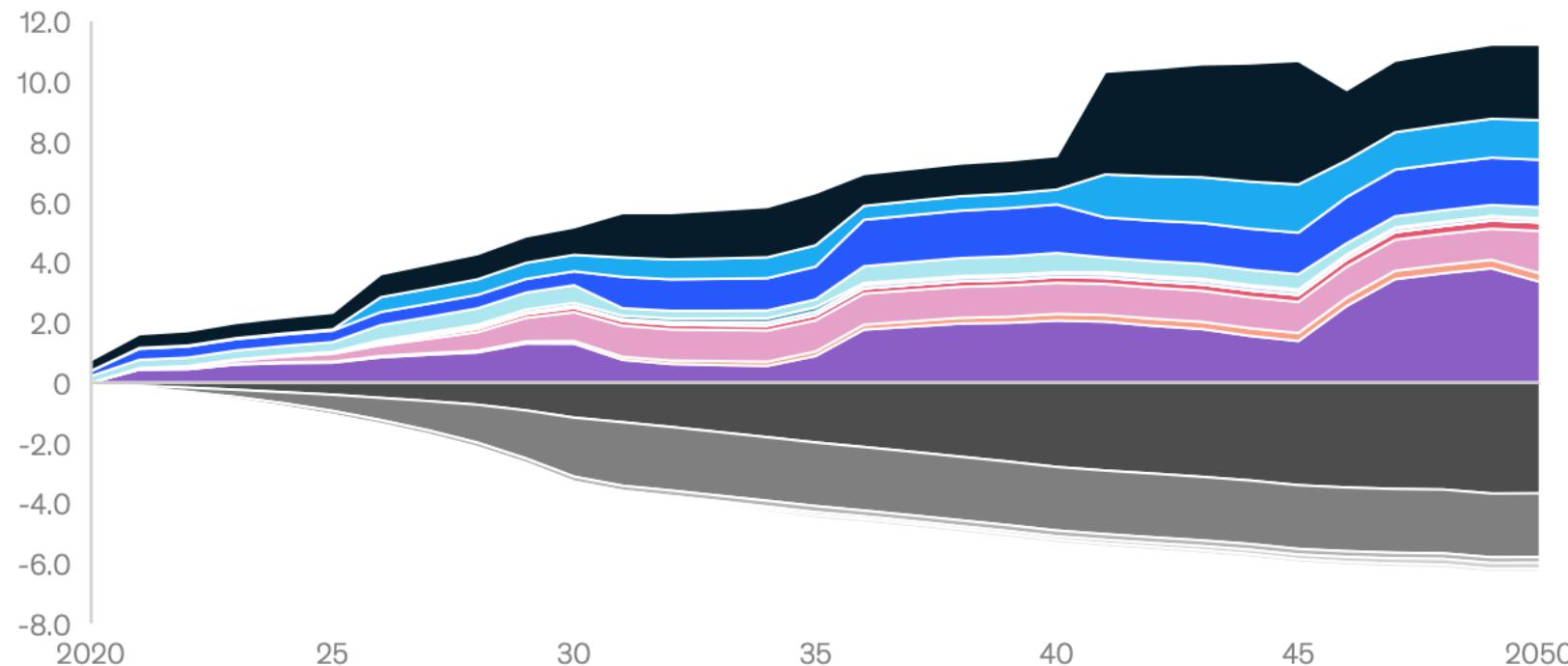
The transition would yield a net gain of 5 million jobs.

Reaching net-zero emissions would create 11 million jobs and eliminate 6 million jobs through 2050. Up to 18 million people could need training and transition support.

태양광, 배터리, 풍력, 건물 vs 산업, 기존 수송, 원자력

Total¹ job gains and losses by sector in EU-27

Millions



Gains

Solar	Gas	New transport tech
Battery	CSS	Industry cleantech
Wind Offshore	Hydro	Buildings
Wind Onshore		Agriculture

Losses

Other Non-RES	Coal
Biomass	Conventional transport
Nuclear	Industry

동시 저감 → 전기, 수송(자동차), 건물, 산업 순으로 넷제로

**Sectors would need to reduce
emissions in parallel and
reach net-zero in sequence.**

The power sector would reach net-zero emissions first, in the mid-2040s, because most of the necessary technology is available now. Transport would approach its target in 2045, followed by buildings in the late 2040s, industry in 2050, and then agriculture.

지금 있는 기술로 절반 이상은 줄일 수 있어

More than half the emissions reductions could be achieved with mature and early-adoption technologies.

About 25 percent of emissions reductions would come from pilot-stage technologies, such as carbon capture and storage, and 15 percent from technologies now in the R&D phase. Accelerating the development and deployment of zero-carbon technologies will be critical.

에너지 시스템, 토지 이용 재설정해야

Energy systems and land use would need to be reconfigured.

By 2050, consumption of oil, gas, and coal would decline by more than 90 percent; power demand would double; and renewable sources would generate more than 90 percent of electricity, up from 35 percent now. Some 30 Mha of marginal lands would be used to produce biomass.

석탄, 석유, 가스 사용량 90퍼센트 감소

전력 사용량 2배 증가, 재생에너지 90% 이상 (현재 35%)

협력을 통해 비용 절감 가능

Decarbonizing Europe will cost less if the burden is shared effectively.

Regions where mitigation is especially economical could pursue faster reductions, thereby reducing the overall cost. For example, the Nordics, which have large natural carbon sinks, could help offset residual GHG emissions elsewhere.

매년 1조 유로 투자 필요 – 연료비 등 절감으로 회수 가능

Nearly €1 trillion must be invested per year; cost savings would offset increased capital spending.

An average of €800 billion per year in capital spending—roughly a quarter of all EU capital outlays—would need to shift from carbon-intensive technologies to low-carbon technologies. An additional €180 billion would need to be invested each year. That sum would be offset by savings in operating expenses.

투자 활성화 위한 정책 도입 필수 – 탄소세 1톤당 100유로

Policy interventions would be required to stimulate investment.

Just half of the investments needed for a net-zero pathway would turn a profit. Government financing of around €4.9 trillion could close the gap. Alternatively, a carbon price of €50/tCO₂e would make three-quarters of the necessary investments profitable, and a carbon price of €100/tCO₂e would make 85 percent profitable.

에너지 안보/ 경쟁력 좋아짐
탄소 중립 제품 수입은 늘어날 수도

Energy security and competitiveness could increase.

Europe would become effectively energy independent, but could become more dependent on imports of climate-neutral technology components or materials. At the same time, the EU has a major opportunity to accelerate R&D, retain leadership, and penetrate new export segments.

모든 이해 관계자가 당장 시작해야 함

All stakeholders must take action now.

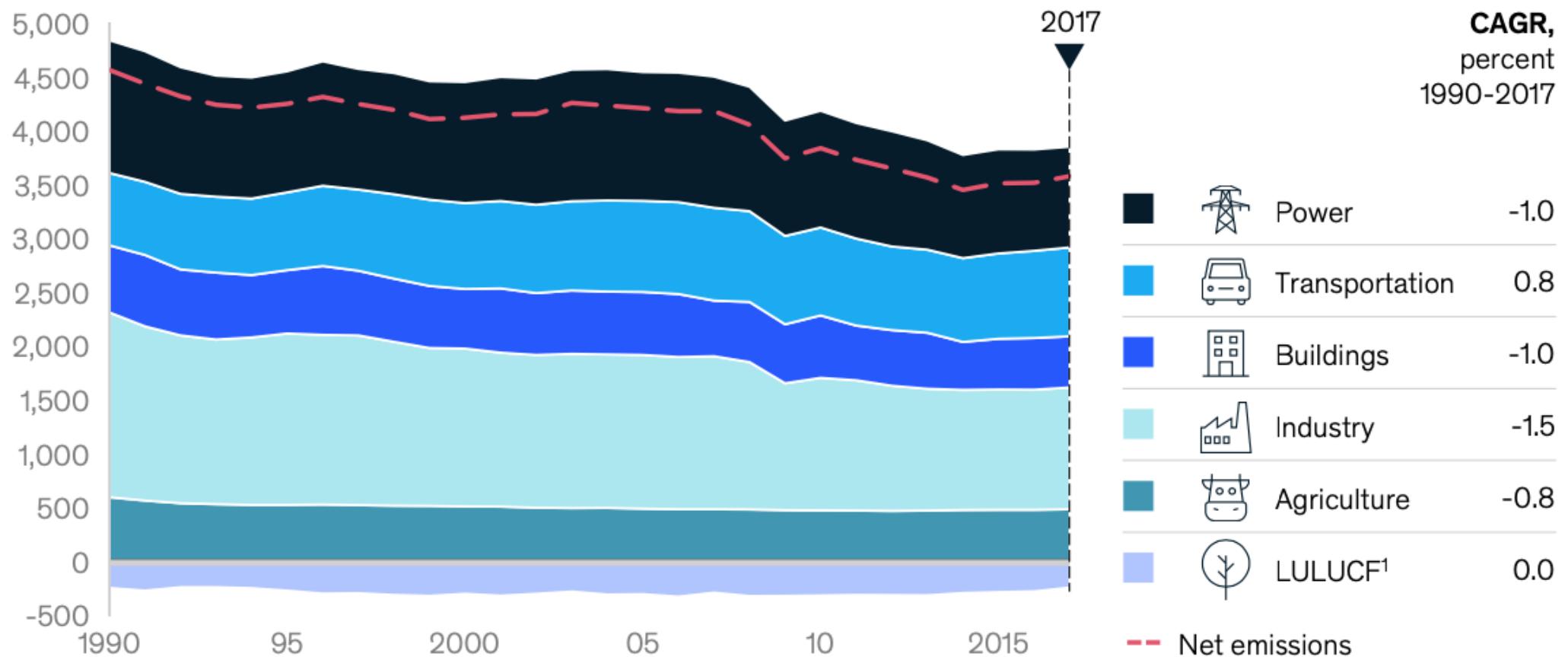
Near-term actions include scaling up existing technologies and businesses to reduce GHG emissions over the next decade, accelerating innovation and investment to enable reductions after 2030, and investing in research and development of technologies that will complete the transition to climate neutrality by 2050.

디테일

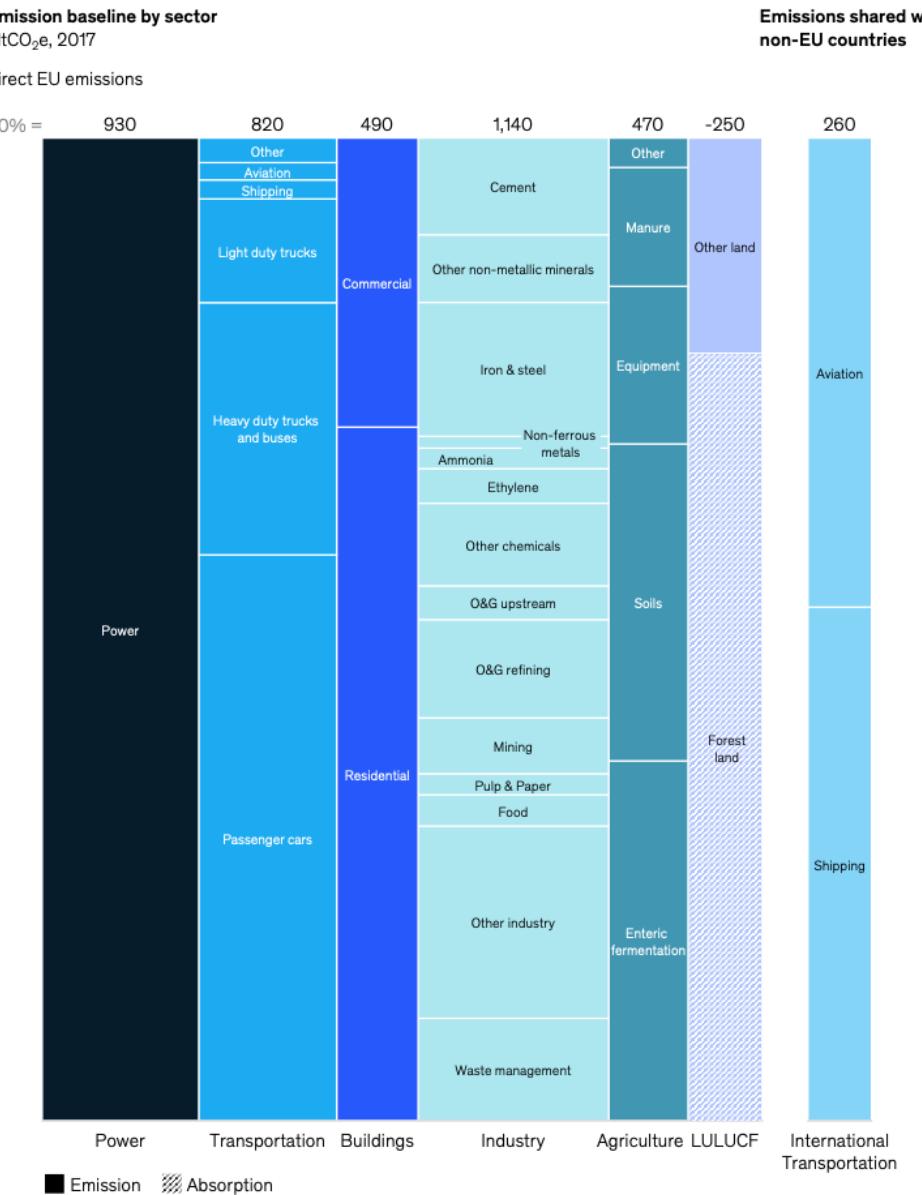
다섯개 분야에서 온실가스 배출

Historic emissions by sector

MtCO₂e



숲 빼고는 전부 배출원 : 4,110 vs -250 (숲)

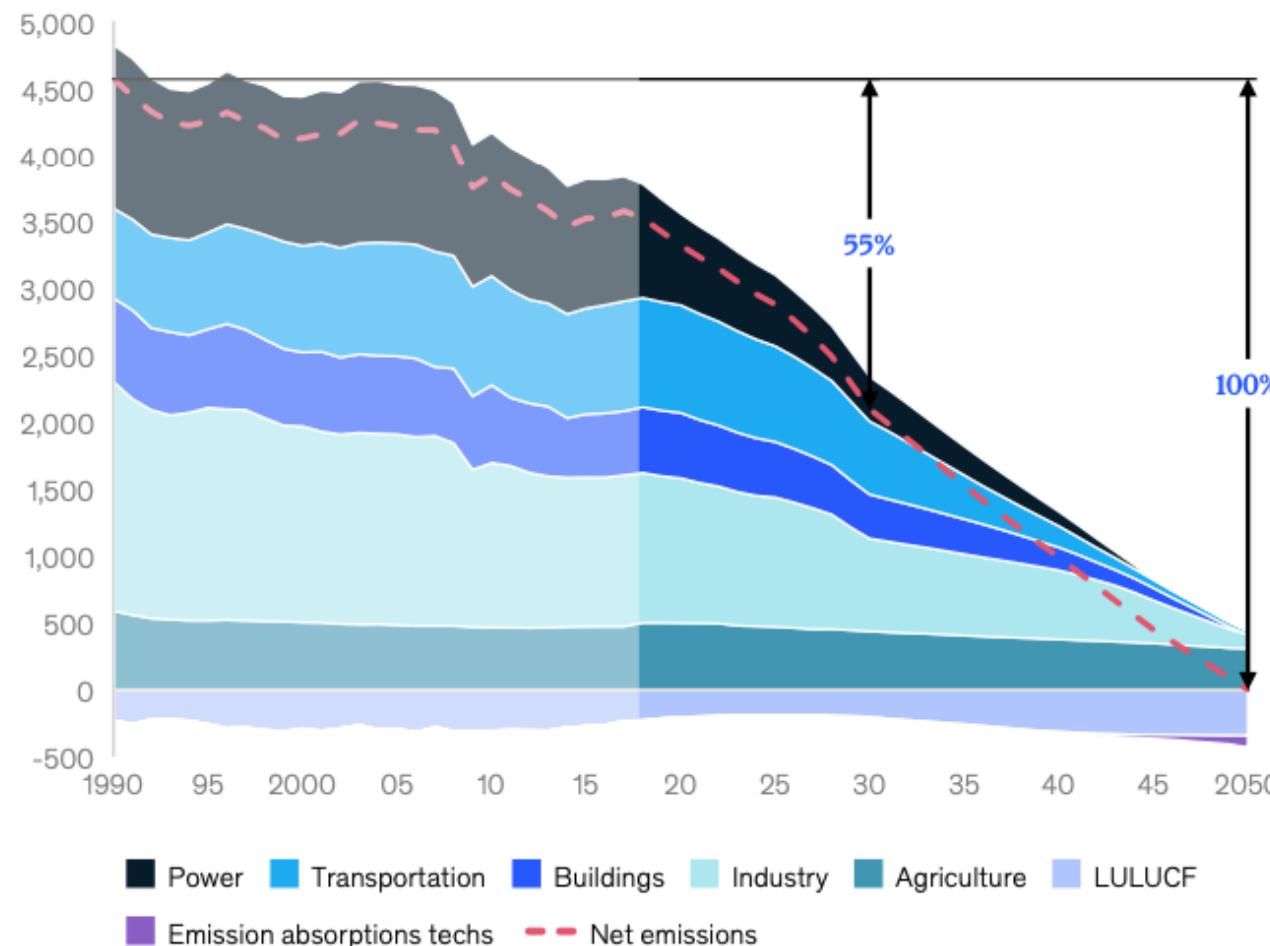


전력 산업이 가장 먼저, 최대한 감축 후 숲+a로 마무리

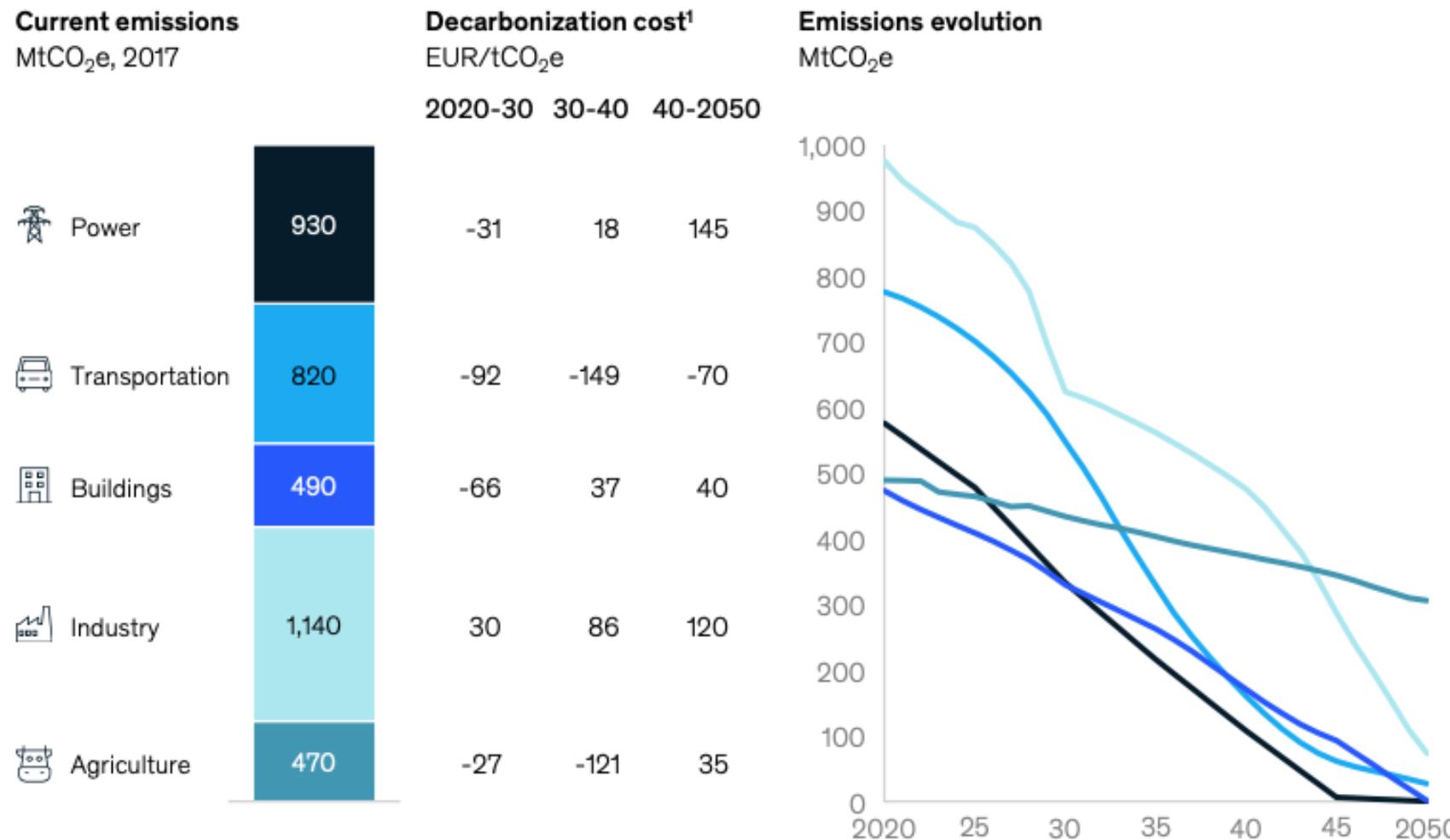
The power sector would reach net-zero emissions before the others.

Total emissions per sector in cost-optimal pathway for EU-27

MtCO₂e, excluding international aviation and shipping



2040까지 분야별 감축 비용은 마이너스 (산업 제외)



1. Weighted average

Source: McKinsey, UNFCCC

감축 수단은 대략 8가지

Exhibit 19

The EU could use eight decarbonization levers to reach net-zero emissions by 2050.



Demand-side measures and circularity

Lower the demand for primary resources by increasing circularity of products, e.g., reuse, recycling



Energy efficiency

Decreasing the energy intensity of equipment or infrastructure, e.g., building insulation or heat recovery improvements



Electrification and carbon neutral power

Replace fossil fuel with renewable electricity, e.g., from wind and solar farms



Carbon neutral hydrogen as fuel or feedstock

Replace carbon-intensive fuel or feedstock with carbon neutral hydrogen, e.g., in ammonia production



Biomass as fuel or feedstock

Replace the fuel or feedstock with sustainably-produced biomass or biogas, e.g., bio-based feedstock in chemicals production



Carbon capture and storage or use (CCS/U)

Use of technology to capture the CO₂ emitted in processes or fuel consumption for storage (CCS) or use (CCU)



Land use or agricultural practice changes

Change land use or agricultural practices to reduce net emissions, e.g., through afforestation (for negative emissions) or changing livestock feed



Other innovations

Innovative processes e.g., electrochemical production process
Non-fossil fuel feedstock change, e.g., change in cement feedstock

태양광, 풍력을 이용한 전기화가 가장 큰 역할

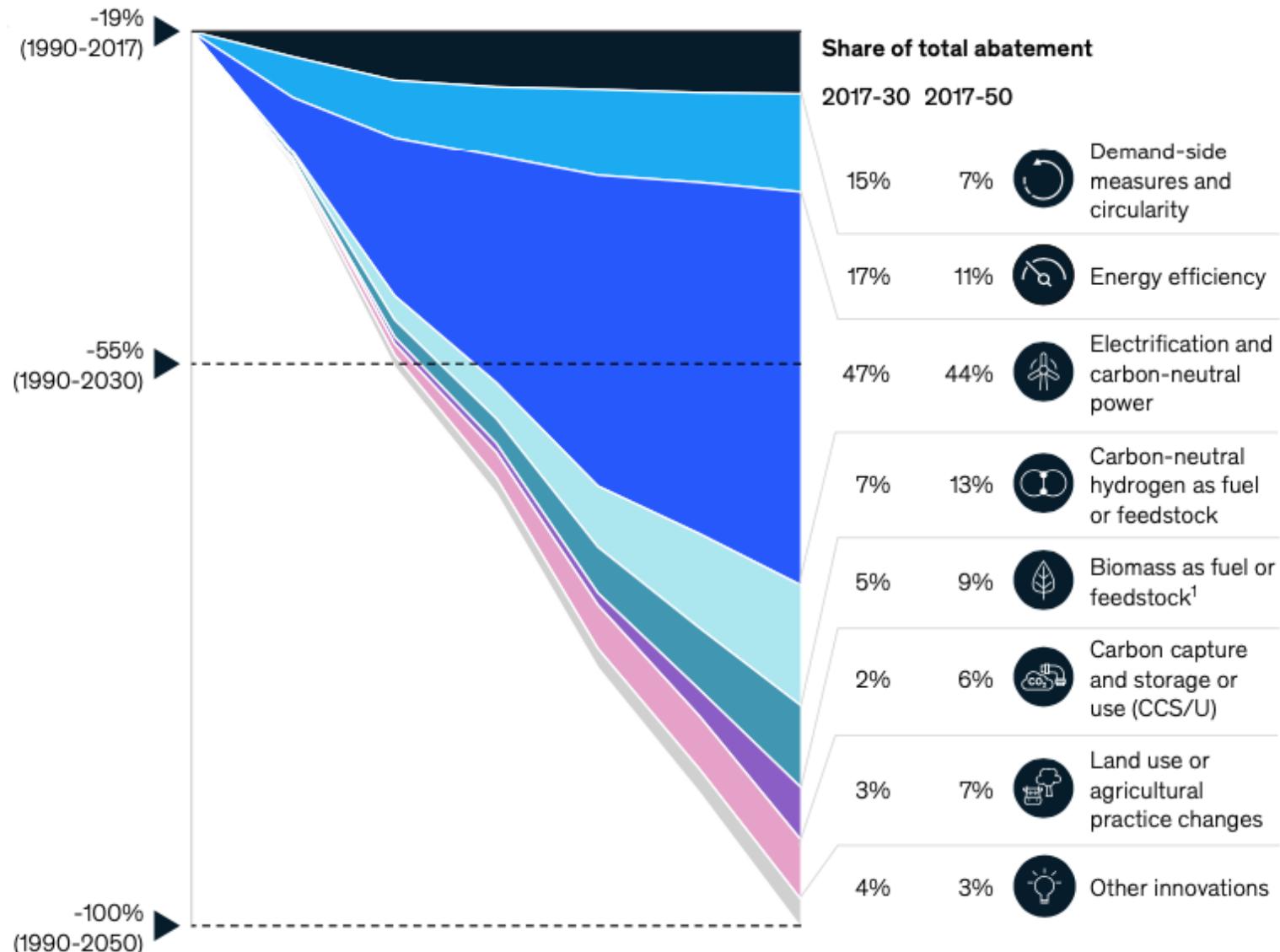
2030년까지
55% 감축

(수소도 태양광, 풍력 필요)

Exhibit 5

Through 2030, nearly two-thirds of emissions reduction could be achieved with energy efficiency and electrification.

GHG abatement, relative reduction of CO₂e vs 1990 in EU-27



핵융합은 아무도 진지하게 논의하지 않아



이경수 국제핵융합실험로(ITER) 국제기구 사무처장이 프랑스 카다라슈의 ITER 공사현장 앞에 섰다. [사진 ITER국제기구]

국제핵융합실험로 건설 이끄는 한국인 이경수 ITER 사무처장

“3년 전 바닥 기초공사에 머물러 있었는데, 이젠 꼭대기 콘크리트 지붕까지 덮었습니다.”
‘인공태양’무한 청정 미래 에너지’로 불리고 있지만, 한때 ‘사기’또는 ‘망상’으로까지
의심받았던 핵융합발전 연구개발(R&D)이 5부 능선을 넘어섰다. 국가핵융합연구소(NFRI)
는 11일 프랑스 남부 소도시 카다라슈에서 건설 중인 국제핵융합실험로(ITER)가 최근
공정률 절반을 넘어 58% 가까이 도달했다고 밝혔다.

애초 2007년 공사를 시작하면서 2017년에 완공한다는 계획을 잡았지만, 제대로 진행된 게 없었다.

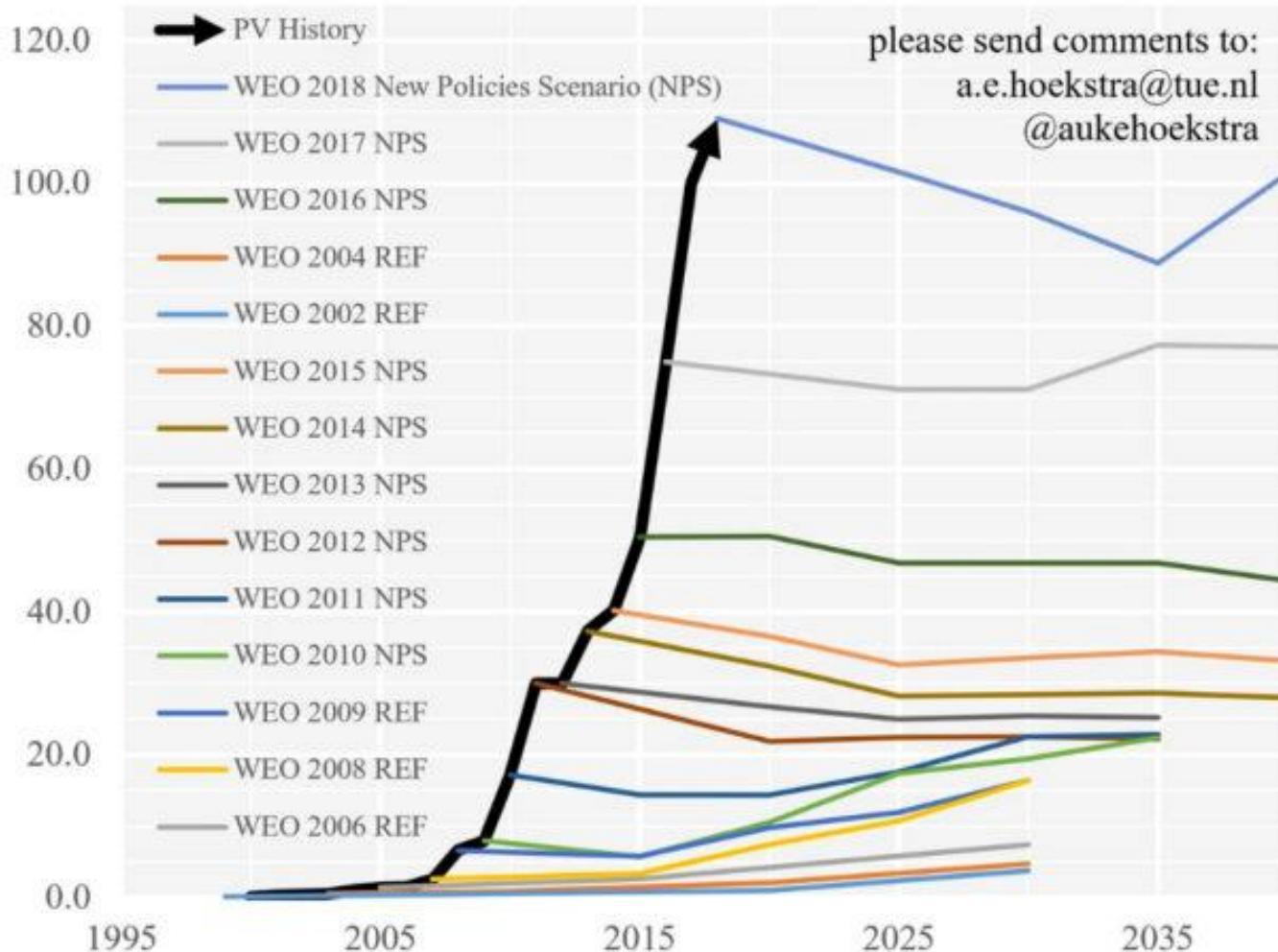
“2045년까지 ITER로 에너지를 안정적·효율적으로 생산할 수 있는지에 대한 실험을 계속한다. 현재 계획으로는 2045년이면 ITER 프로젝트는 끝난다.

7개 참가국들은 이 과정에서 얻은 기술을 통해 각자 데모 버전의 핵융합발전소(실증로)를 건설하게 된다.”

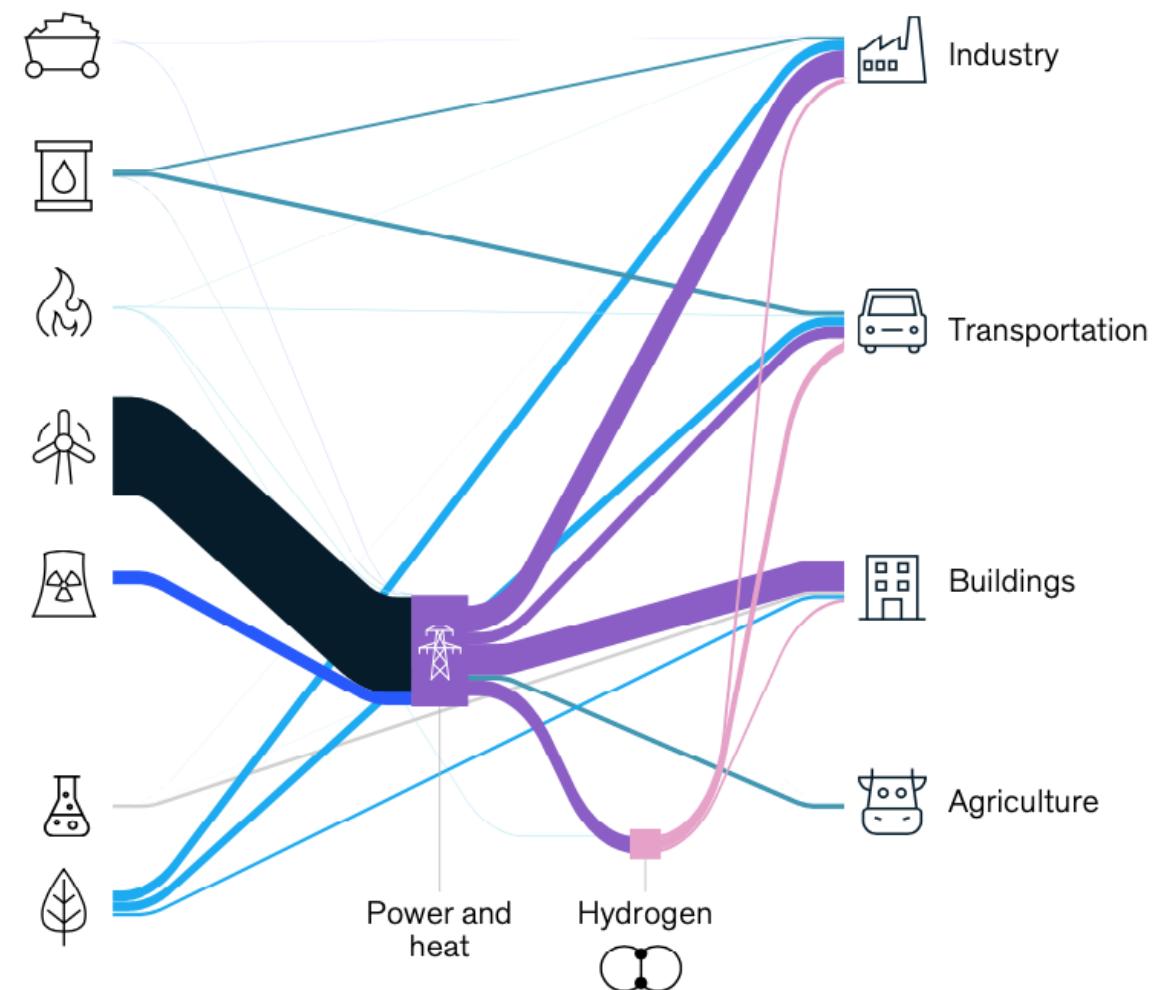
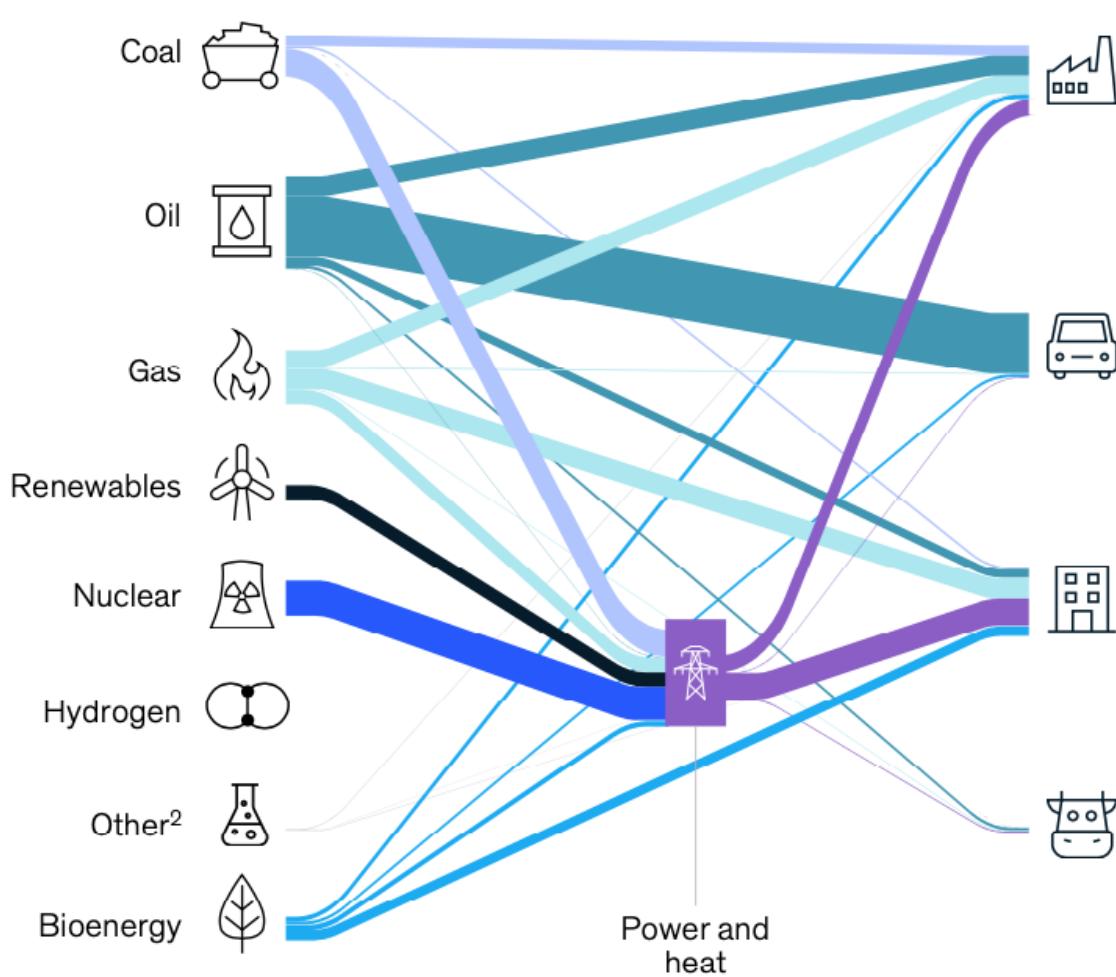
[출처: 중앙일보] [단독] “사기 · 망상이라던 인공태양 국제핵융합 실험로, 공정률 50% 넘겼다”

IEA의 편파적 + 틀린 전망

Annual PV additions: historic data vs IEA WEO predictions
In GW of added capacity per year - source International Energy Agency - World Energy Outlook



전기화의 미래: 현재 vs 2050



국제에너지기구 – 넷제로 로드맵 마련하기로

FT Financial Times

IEA chief: Net zero by 2050 plan for energy sector is coming

IEA chief: Net zero by 2050 plan for energy sector is coming. Global tracking and accountability will be required to address climate change. Fatih ...

1 day ago



IPE.com

Net-zero asset owner group calls for 'fully developed' IEA 1.5

...

Members of the UN-convened Net-Zero Asset Owner Alliance have called on the International Energy Agency (IEA) to include a fully developed ...

3 days ago



<https://www.ft.com/content/6c5e29e1-283e-4df8-a402-ce09fcec3bda>

향후 10년이 중요, total transformation, speed & scale

But long-term targets alone will not put emissions into decline rapidly enough to reach net zero by mid-century.

Nothing short of a total transformation of our energy infrastructure is required — a worldwide undertaking of unprecedented speed and scale. That calls for decisive action over the next decade.

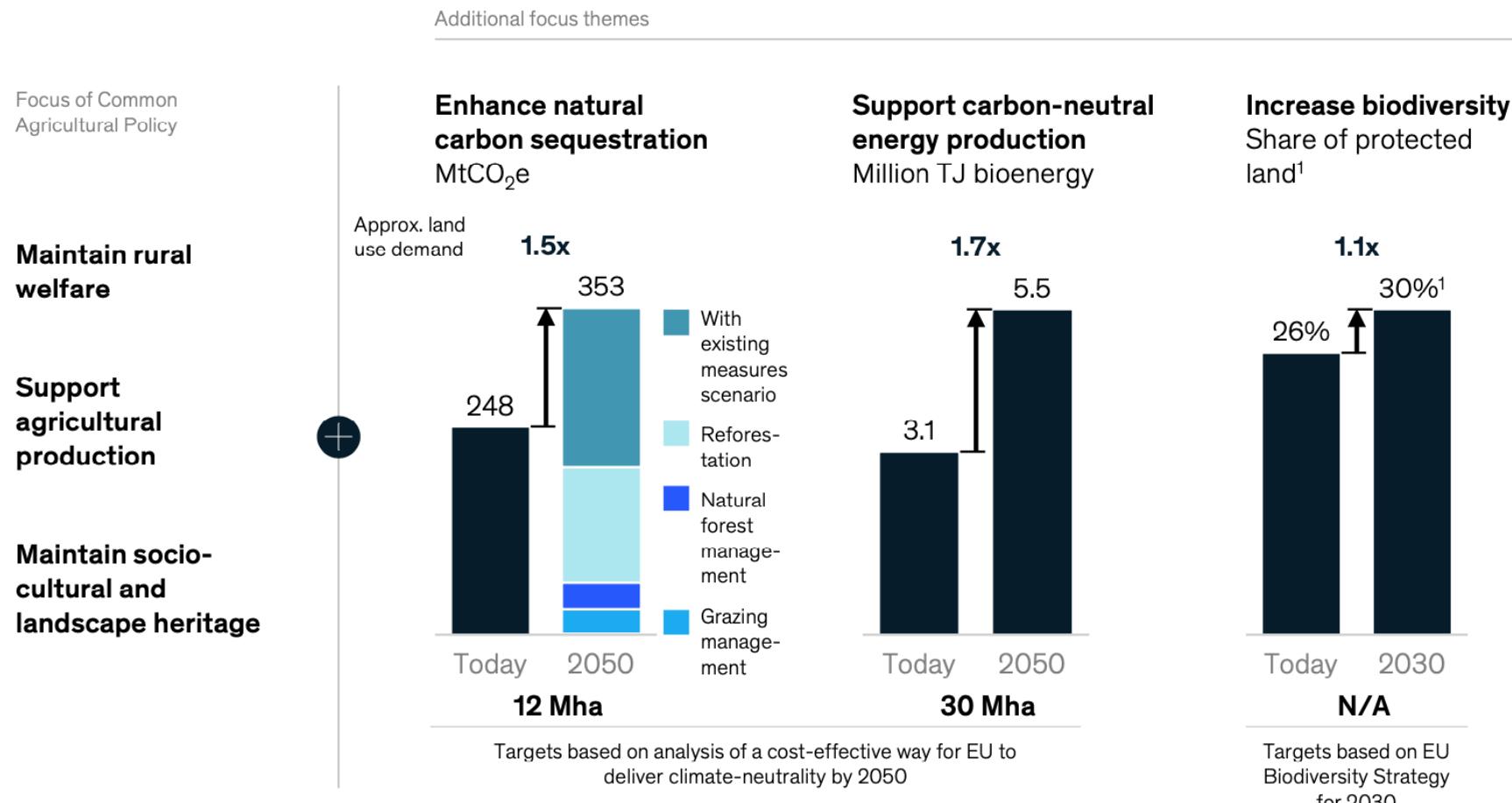
It would mean, by 2030, increasing electric cars' share of annual sales from 3 per cent to over 50 per cent; expanding the production of low-carbon hydrogen from 450,000 tonnes to 40m tonnes; and boosting investment in clean electricity from \$380bn to \$1.6tn.

전기차 3% → 50% (사실 이것도 엄청나게 부족해)

구원 투수 - 숲

Exhibit 7

On the cost-optimal pathway, land use would support carbon sequestration and bioenergy production.



숲이 대량으로 죽어가고 있는 건 일단 패스...

www.dw.com › germanys-forests-on-the-verge-of-colla... ▾

[Germany's forests on the verge of collapse, experts report ...](#)



Forest dieback is a condition in trees or woody plants in which peripheral parts are killed, either

... **Forest dieback** has many symptoms: falling **off of** leaves and needles, discoloration ...

Previous diebacks were regionally limited, but starting at the end **of** the 1970s a decline took

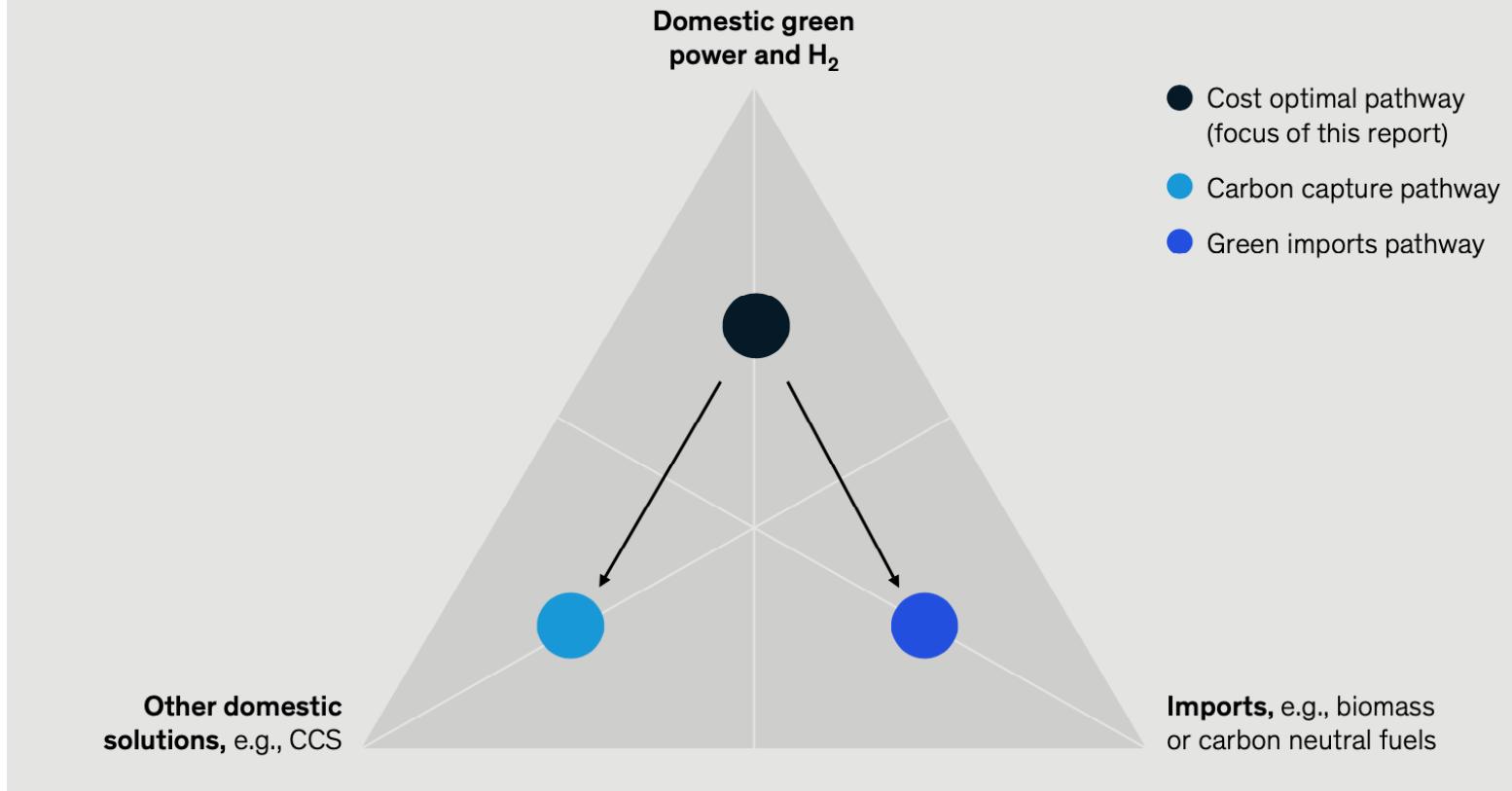
over the **forests of** Central Europe and parts of ...

[Definition](#) · [History](#) · [Hypothesis](#) · [Global climate change](#)

그린 수소가 상대적으로 가장 싸게 먹힐 듯

Exhibit 8

There are two main alternatives for the EU energy system to our cost-optimal pathway.

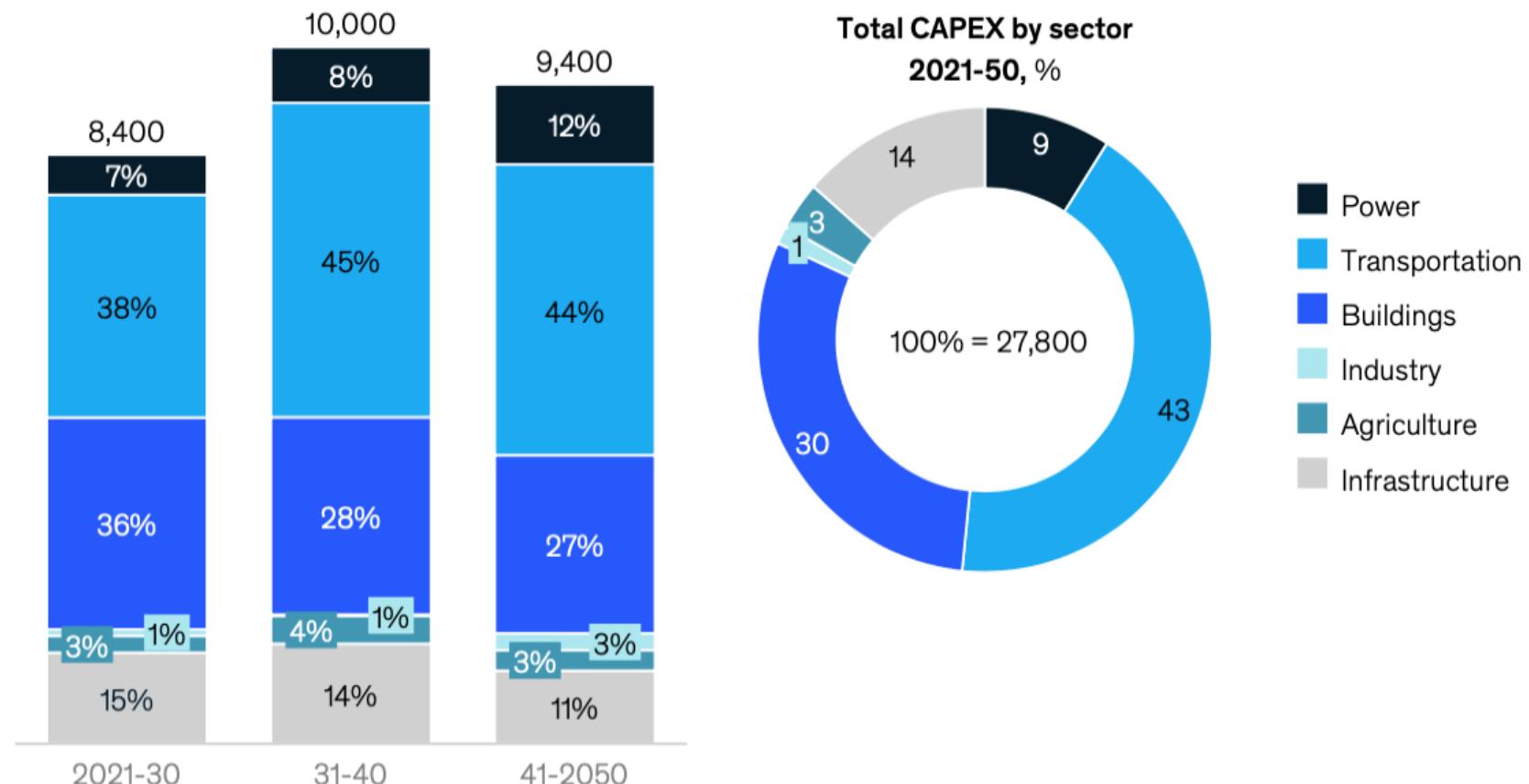


전력, 수송 (주로 자동차), 건물에 투자금 집중

Exhibit 9

Reaching net-zero would require an estimated €28 trillion in investments over the next 30 years.

Total CAPEX in EU-27, bn EUR (total within time bracket)

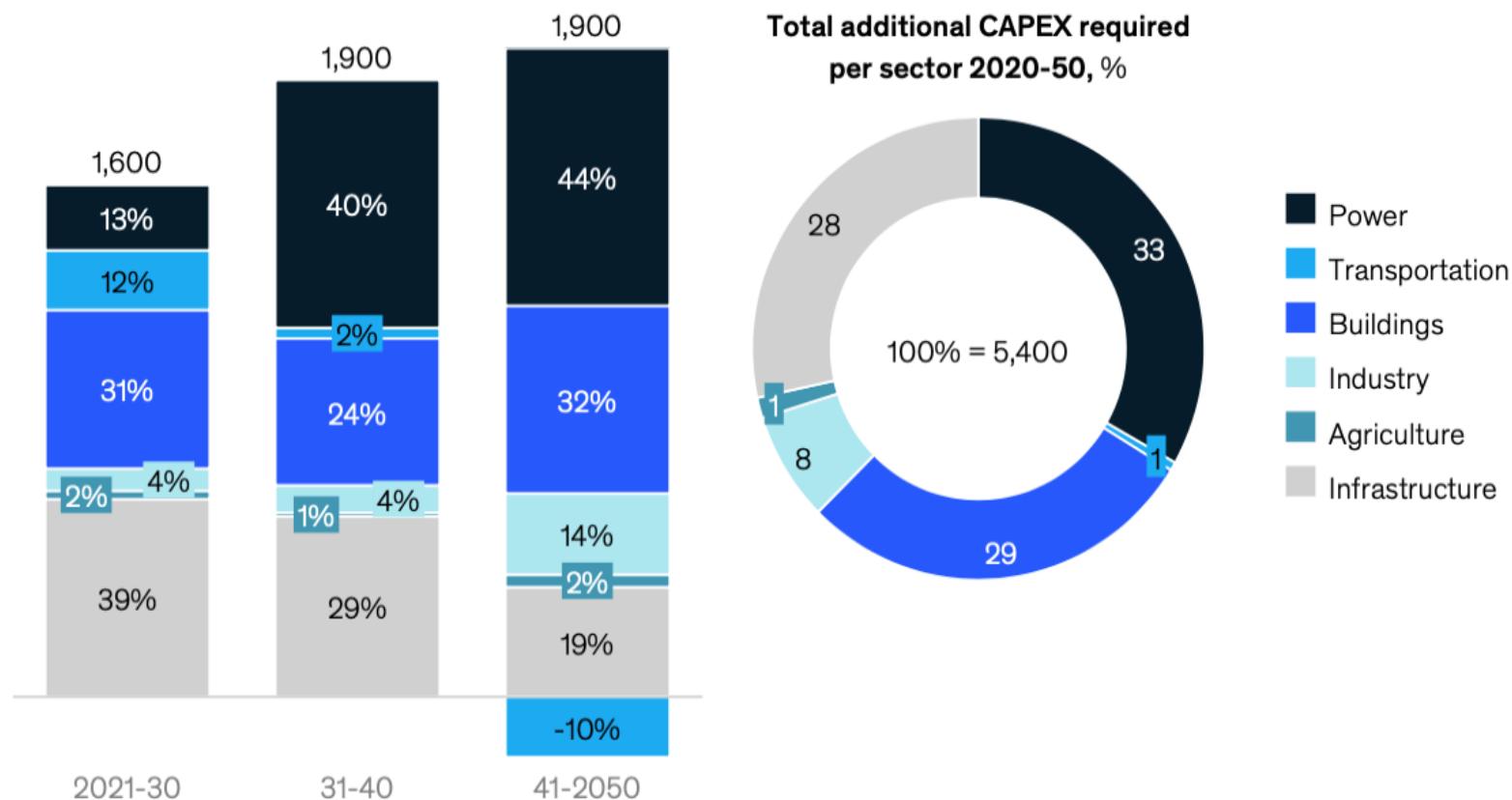


28조 유로 투자금 중 80%는 원래도 필요한 투자

Exhibit 10

About €5.4 trillion of the €28 trillion is incremental, compared to no climate action.

Additional CAPEX in EU-27, Bn EUR (total within time bracket)

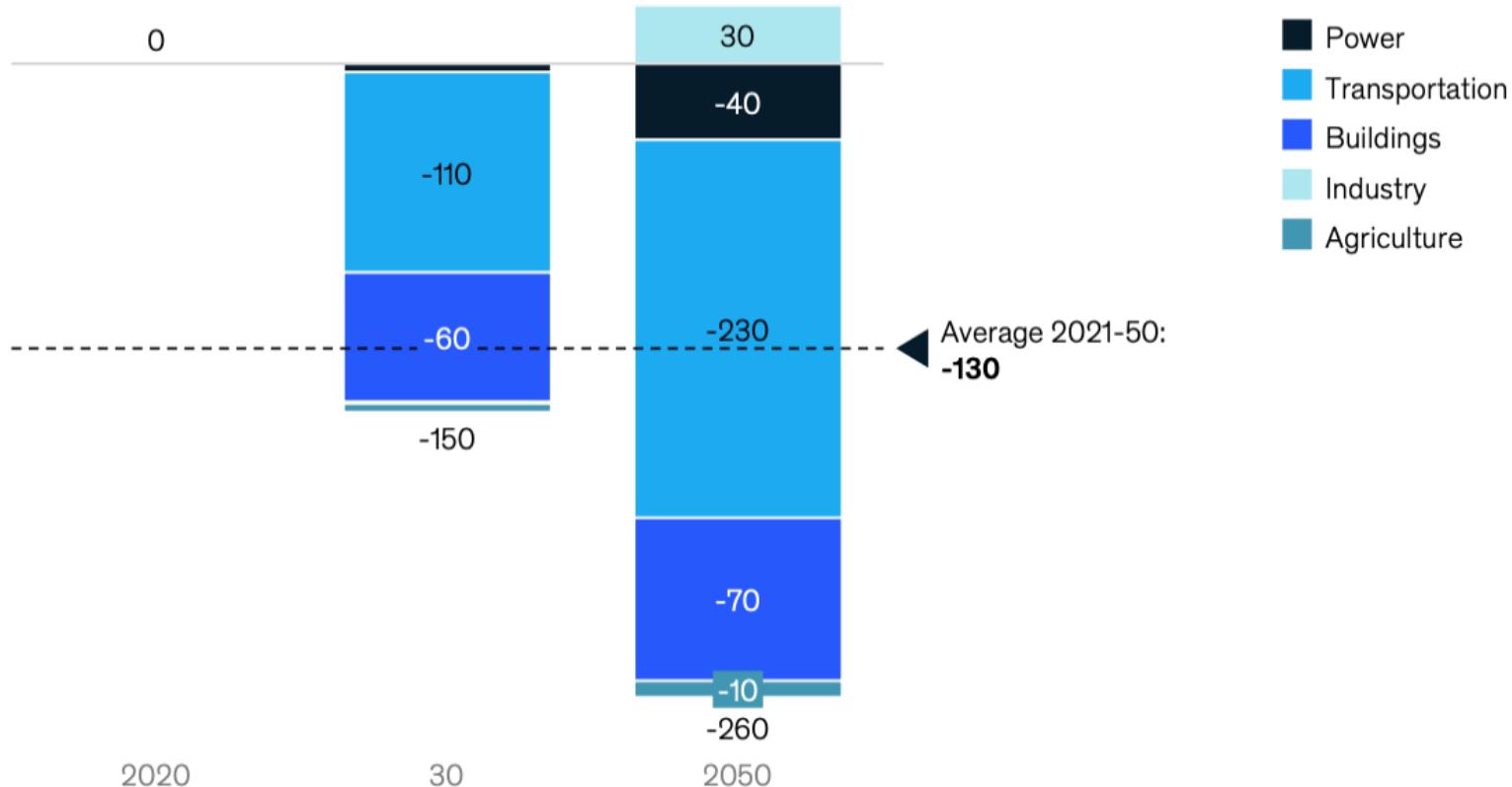


투자 필요하지만 투자로 관리비 절감 효과 커

Exhibit 11

Implementing clean technology would lower the EU's operating costs.

Total OPEX^{1,2} in EU-27, Bn EUR p.a.



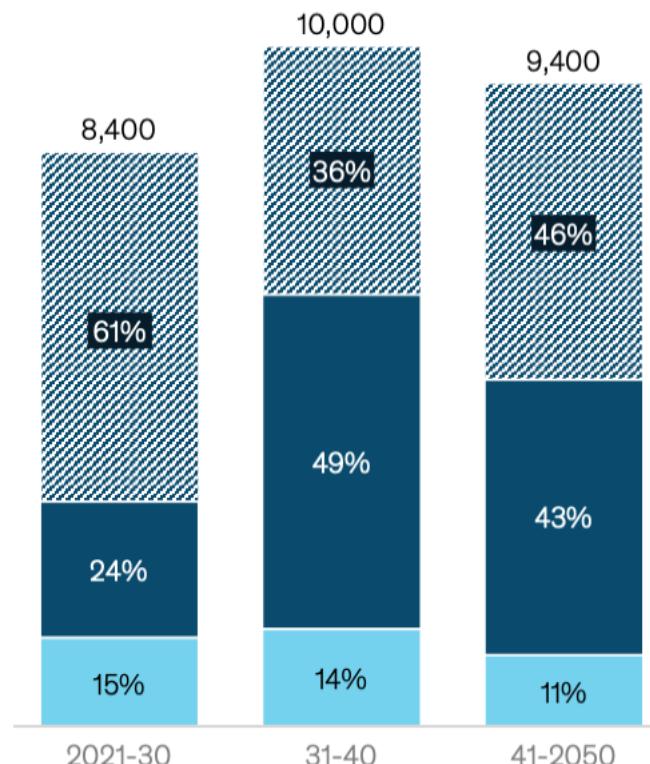
투자금 중 절반 정도는 특별한 정책 도움 없이도 이익

Exhibit 12

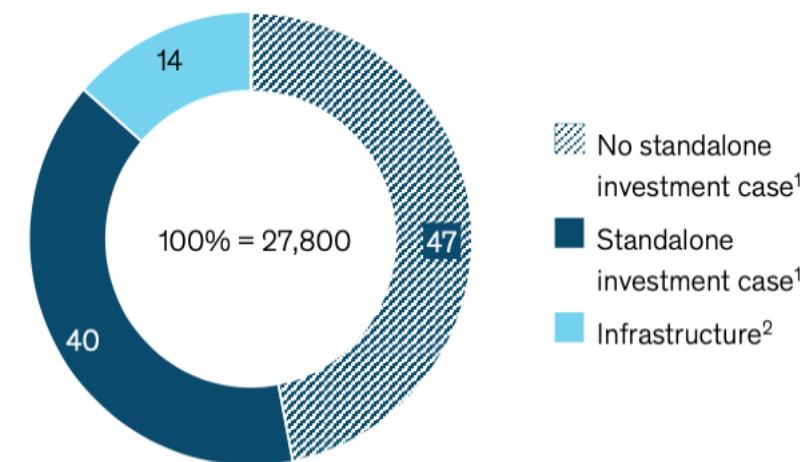
About half the required investments do not have positive investment cases for their stakeholders.

Emissions-reduction investments by type of investment case for individual stakeholders

Total CAPEX in EU-27, Bn EUR (total within time bracket)



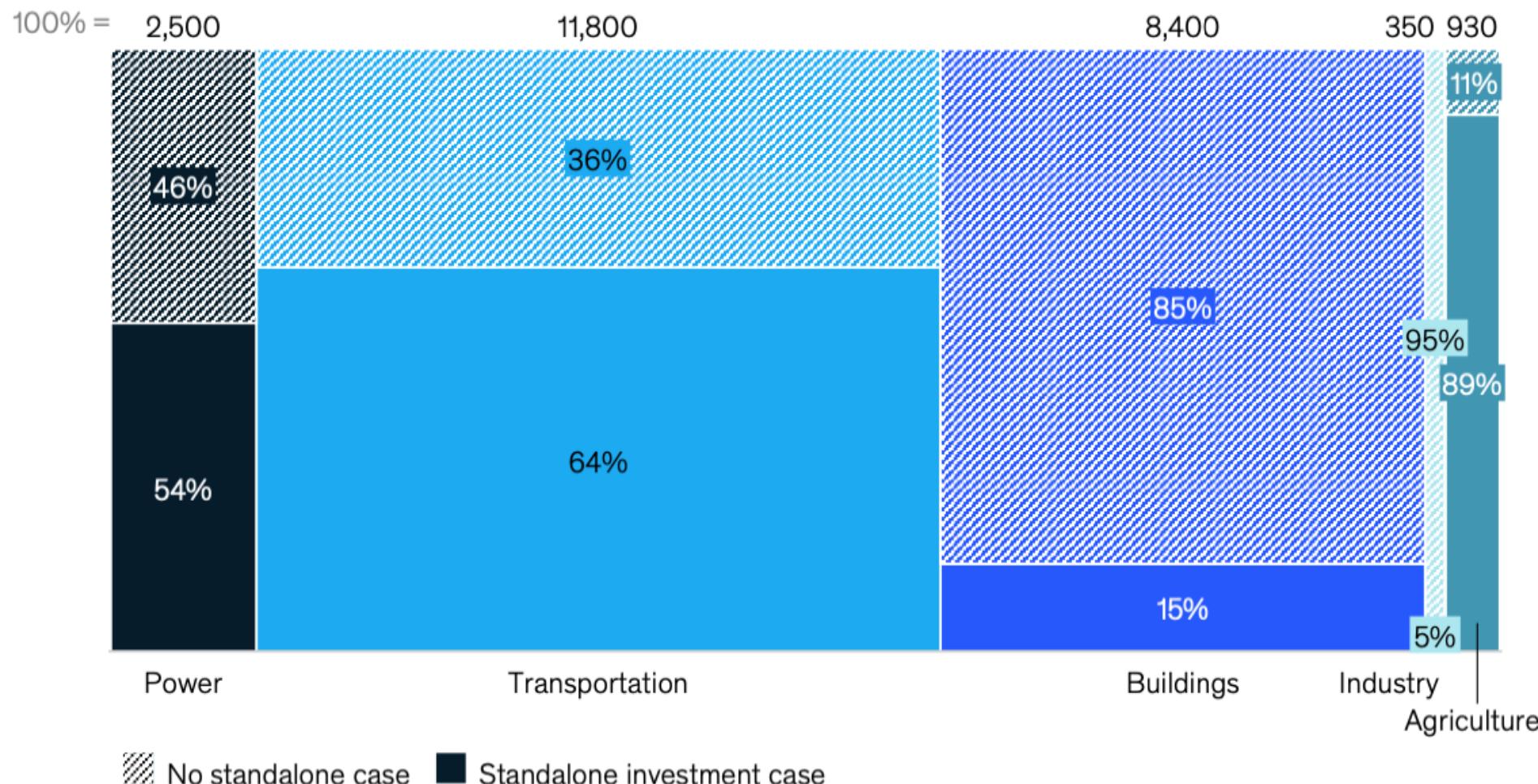
Share of total investments by type of investment case, 2020-50, %



탄소세 정책 없이도 돈 되는 정책/안되는 정책 비율

Emissions-reduction investments by type of investment case for individual stakeholders by sector

Total CAPEX¹ in EU-27, total for 2020-50, Bn EUR



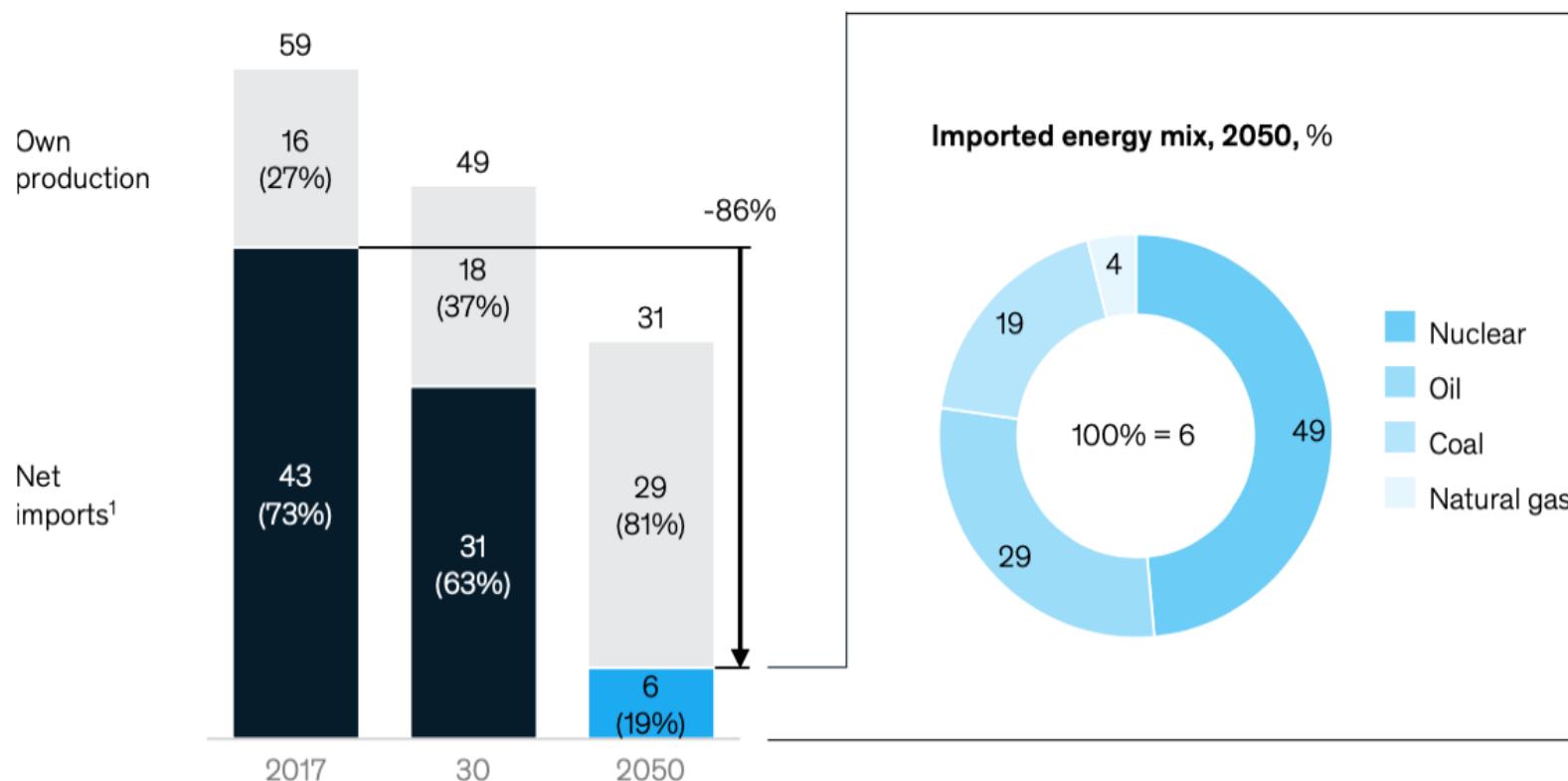
굿바이 만수르 – 화석연료 수입량 80% 이상 감소 예상

Exhibit 13

As a result of decarbonization, EU fossil fuel imports could decline more than 80%.

Million TJ

Trade balance of fossil fuels in 2017 and evolution under cost-optimal pathway in EU-27

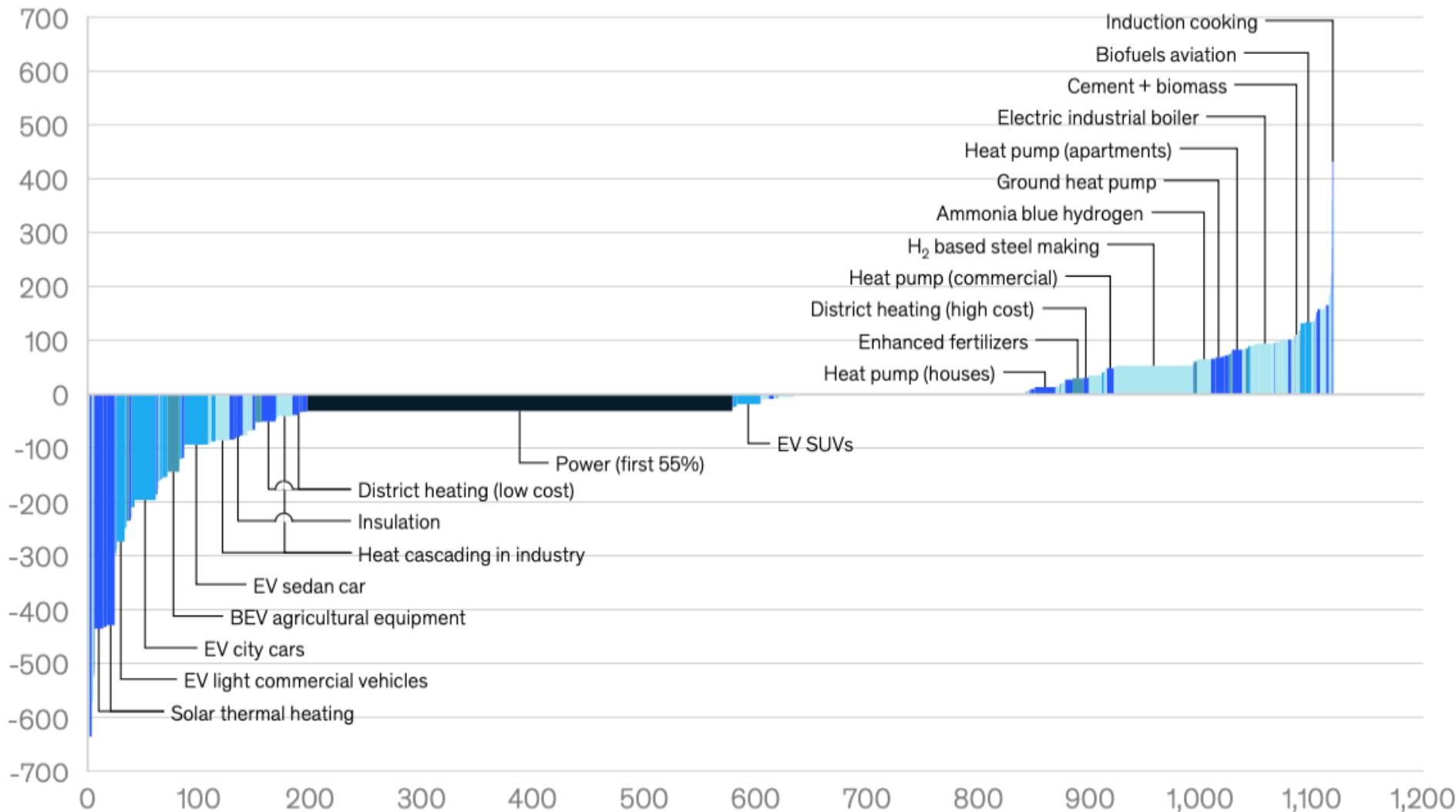


감축비용

2
0
3
0

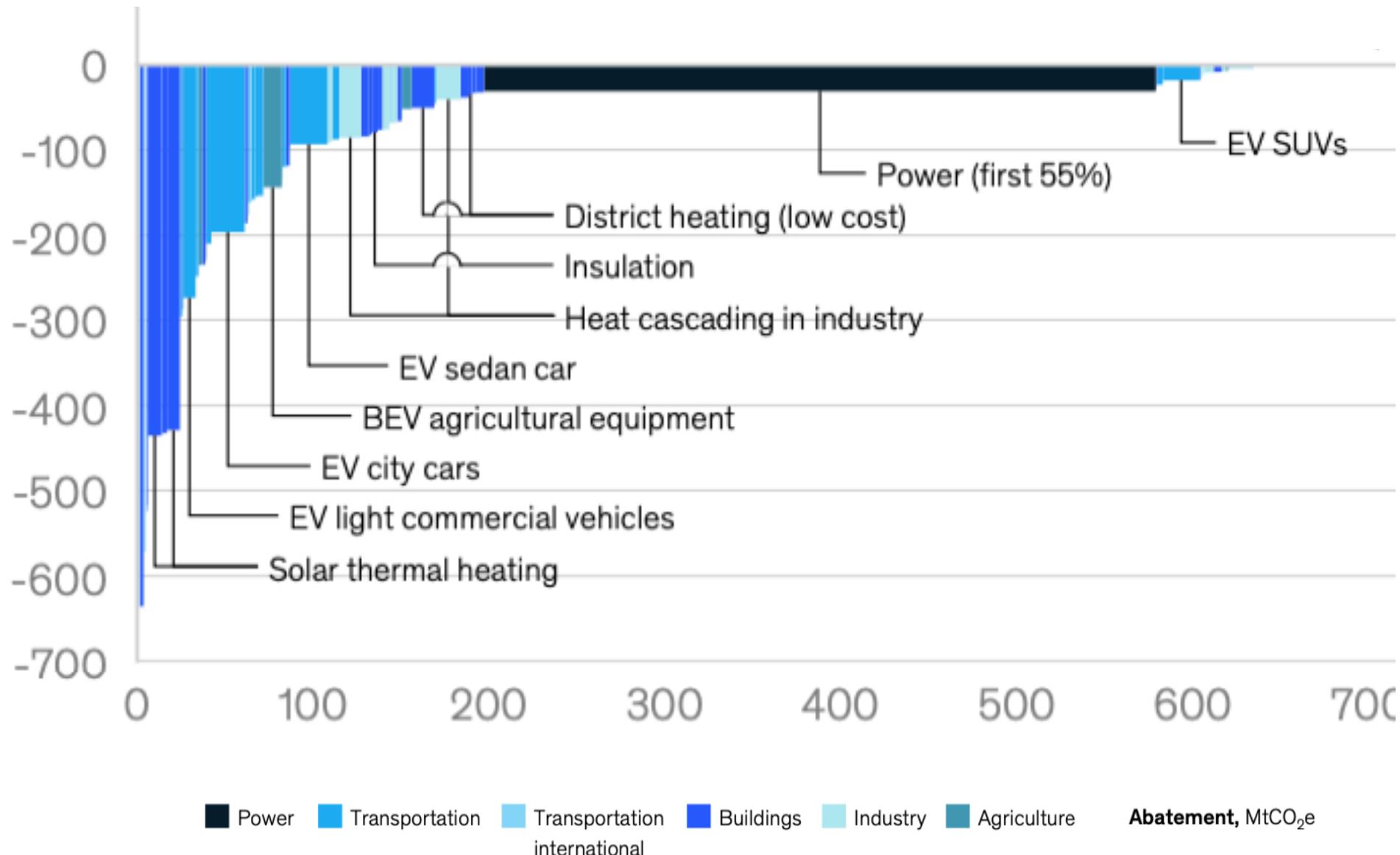
A: 2030 abatement cost curve

Abatement cost, EUR/tCO₂e

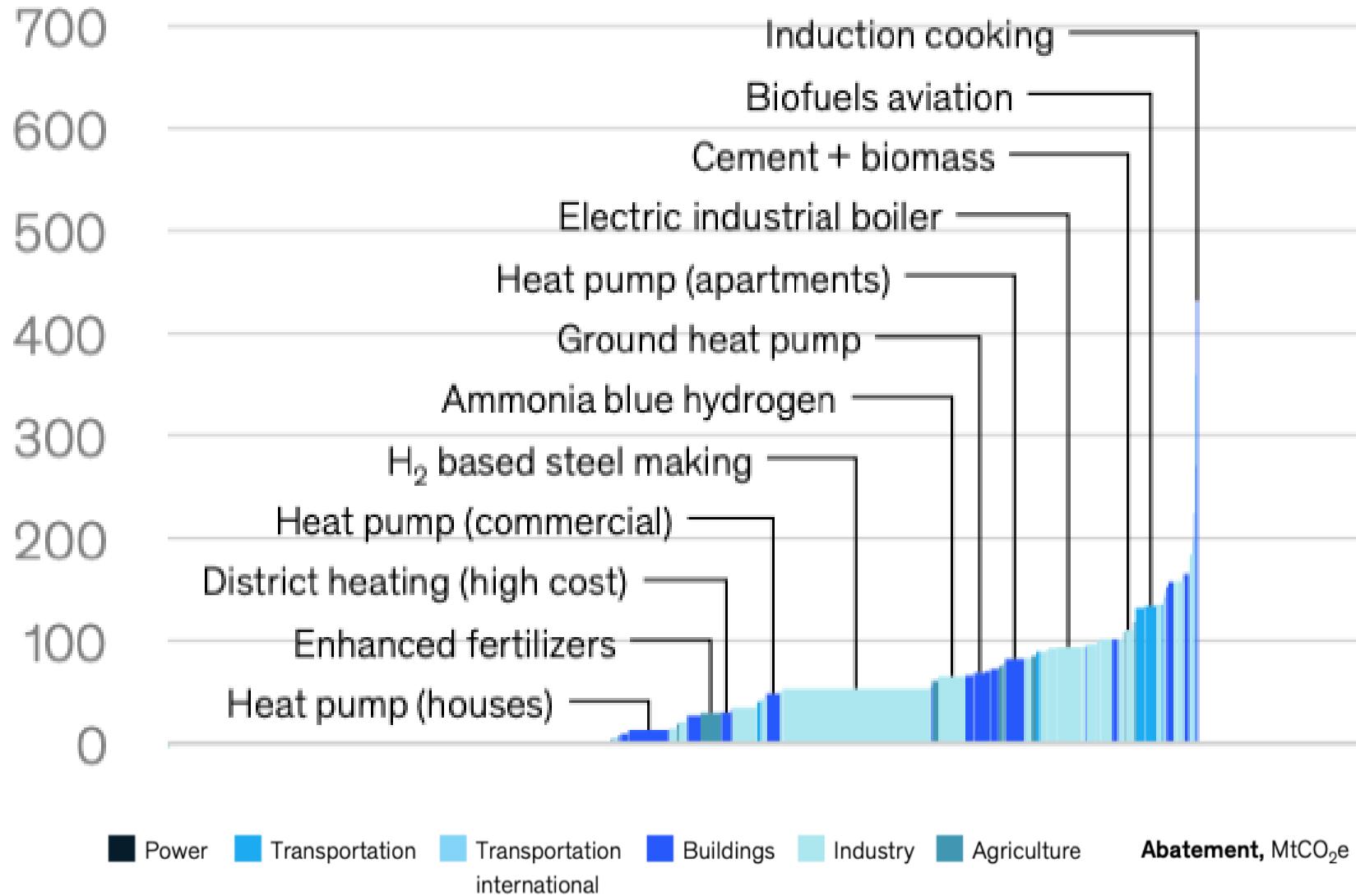


■ Power ■ Transportation ■ Transportation international ■ Buildings ■ Industry ■ Agriculture **Abatement, MtCO₂e**

2030 감축 비용 - 무조건 이익인 분야



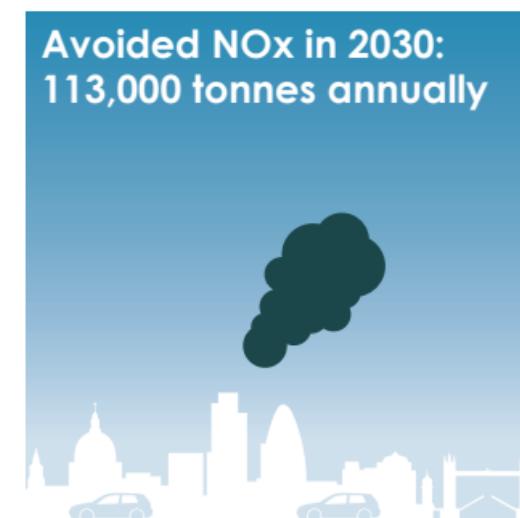
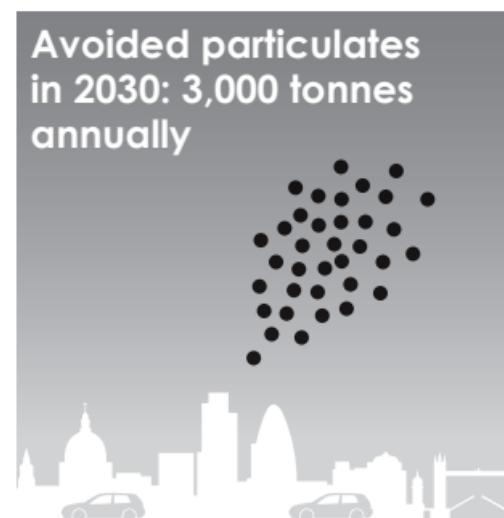
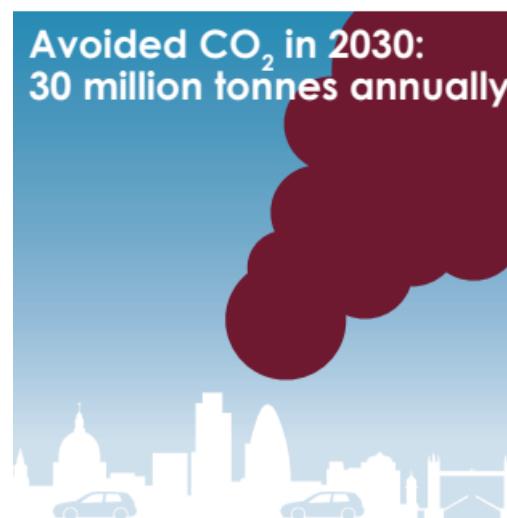
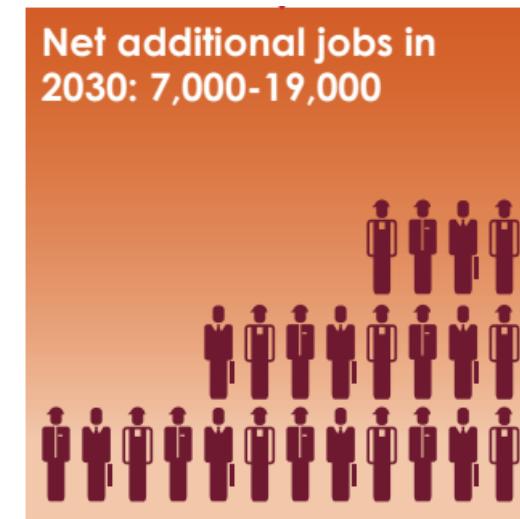
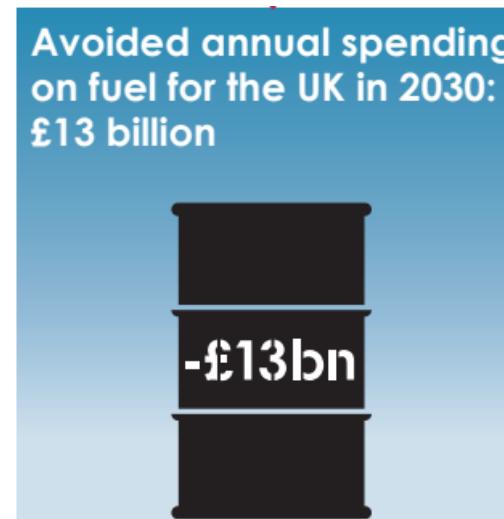
2030 감축 비용: 돈이 좀 들어가는 분야



전기차가
확산 되면



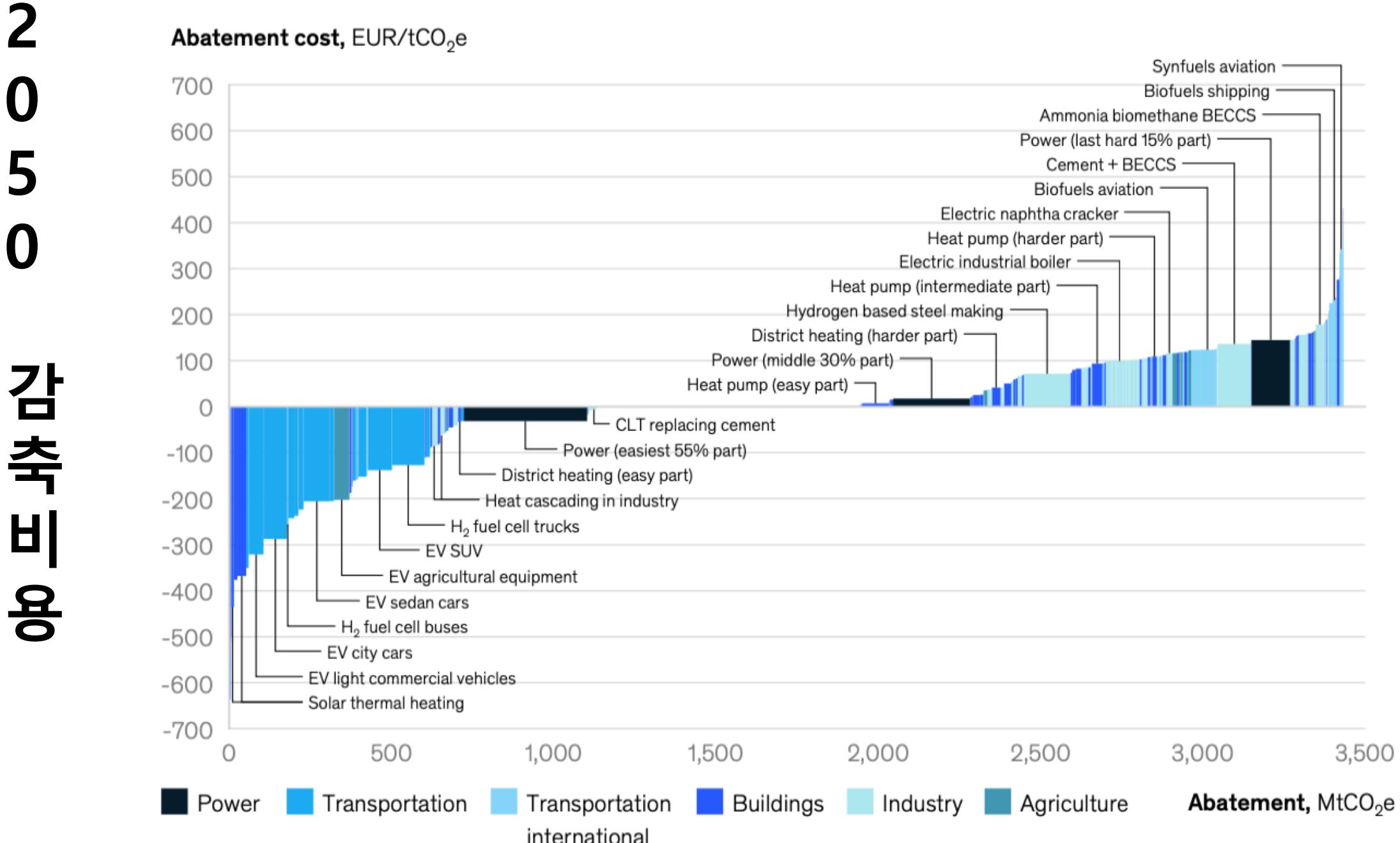
국민은 이익, 손해는 자동차 회사/정유사/주유소/기재부



감축비용

B: 2050 abatement cost curve

Abatement, MtCO₂e

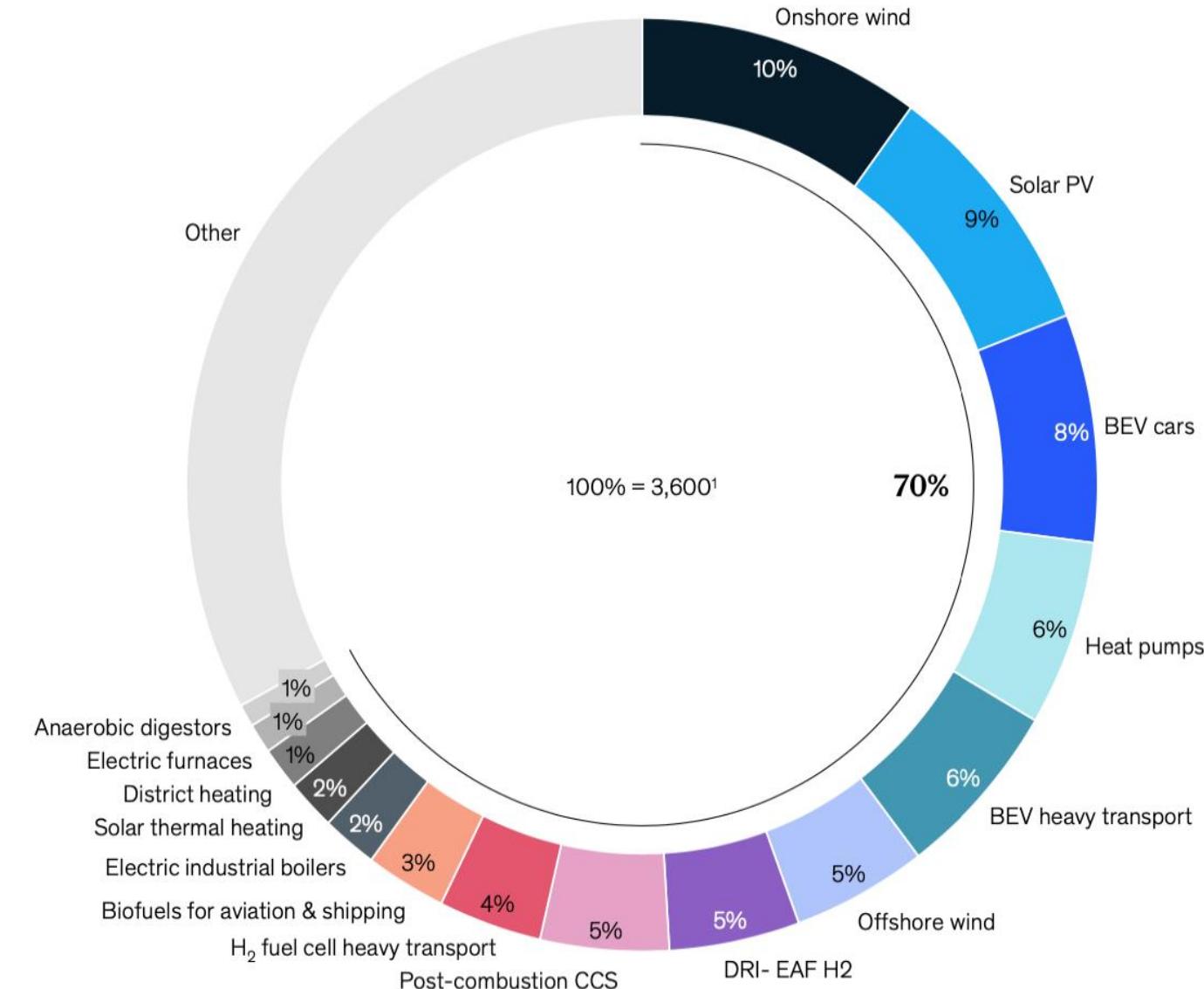


가장 도움이 되는 분야/기술

Exhibit 21

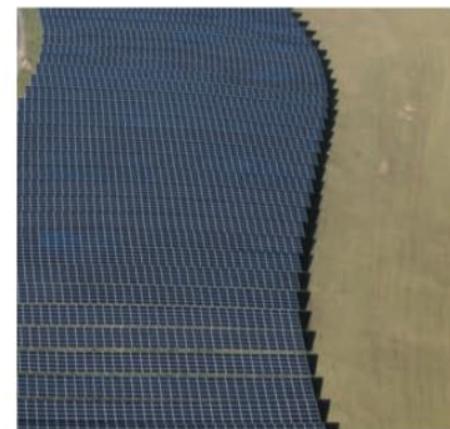
Onshore wind, solar power, and battery electric vehicles make the biggest contributions to reaching climate-neutrality on the cost-optimal pathway.

Percent of total MtCO₂e abatement for EU-27, 2020-50





이런게 기후 위기
시대의 친환경



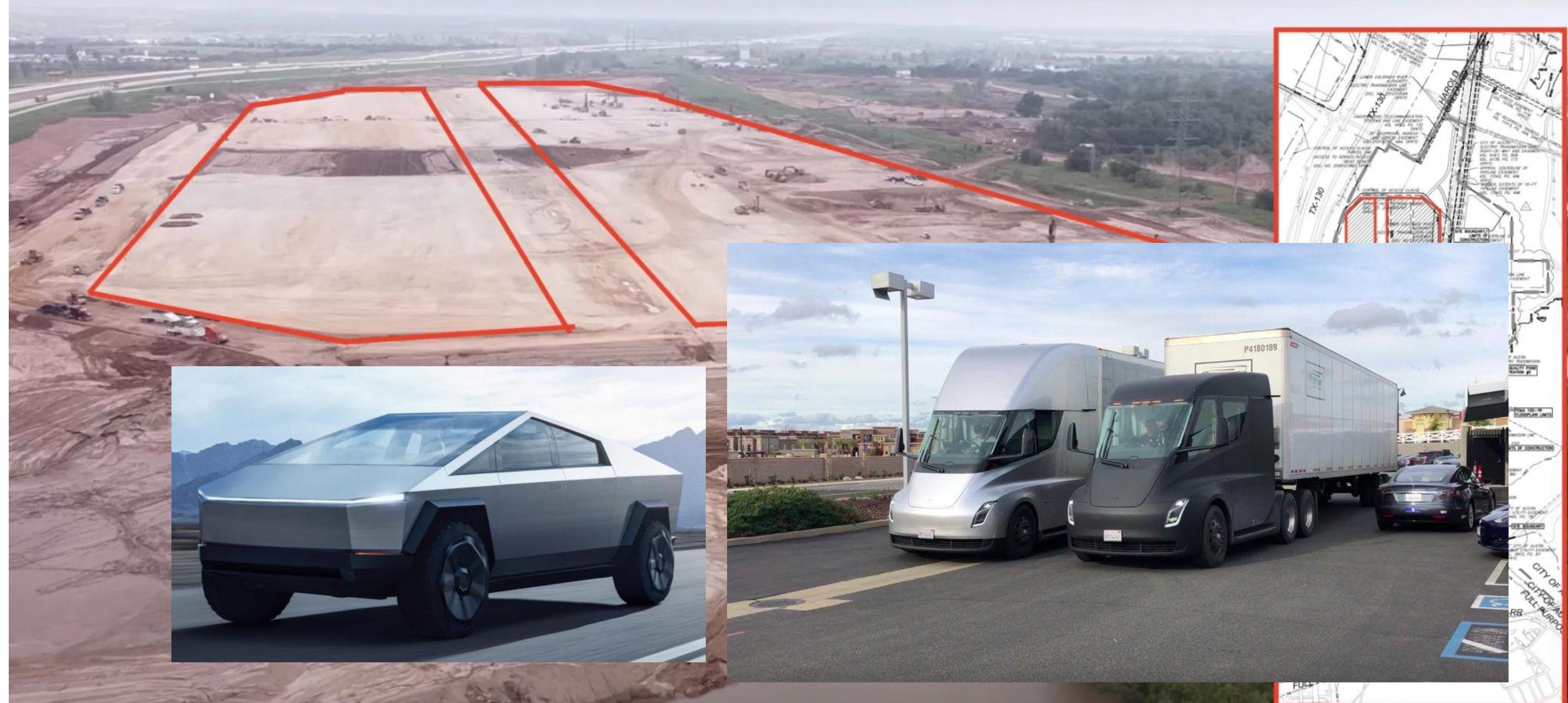
Tesla is ordered to stop tree-clearing expansion at Giga Berlin over hibernating snakes

Fred Lambert - Dec. 8th 2020 6:01 am ET  @FredericLambert



Tesla Gigafactory Texas plans revealed, showing massive buildings with interesting shape

Fred Lambert - Sep. 16th 2020 3:16 pm ET  @FredericLambert



이런 행동 변화도 따라주면 추가로 15% 감축 가능

Exhibit 22

12 behavioral changes not included in the cost-optimal pathway model could lower EU emissions another 15 percent.



Power

1 Enhanced demand flexibility

Over 10% of additional power demand from transportation and buildings are flexible intra-day



Transportation

2 Reduced car usage in urban areas

Shift 20% of urban car PKT¹ to buses

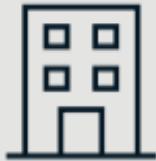
3 Last-mile delivery interventions

Reduce LDT/MDT² trucks VKT³ by 15%

4 Modal shift from air to rail

Shift 95% of short-haul flights PKT to rail

냉난방 덜쓰기, 시멘트 대신 목재 사용하기



Buildings

5 More attentive energy use

Lower room temperatures by 2° Celsius; reduce electricity demand by 10%

6 Increased uptake in smart meters

Over twice as many smart meters by 2050 (90% vs 40% in base)⁴

7 Shift to independent energy sources

25% of detached houses move off-grid



Industry

8 Wood displacement of cement

Over 65% of cement demand replaced by CLT

9 Higher plastics recycling rate

Up to 70% plastics recycling

고기 섭취 확 줄이기, 음식 쓰레기 줄이기, 숲 확장



Agriculture

10 Diet shift away from meat

50% of EU citizens become flexitarian⁵

11 Reduce food waste by half

(5-15% wasted today in different categories)

12 Additional LULUCF

Using 12 Mha of land freed up from productivity gains and 15 Mha from above two levers for LULUCF

농업 관련 들여다 보기

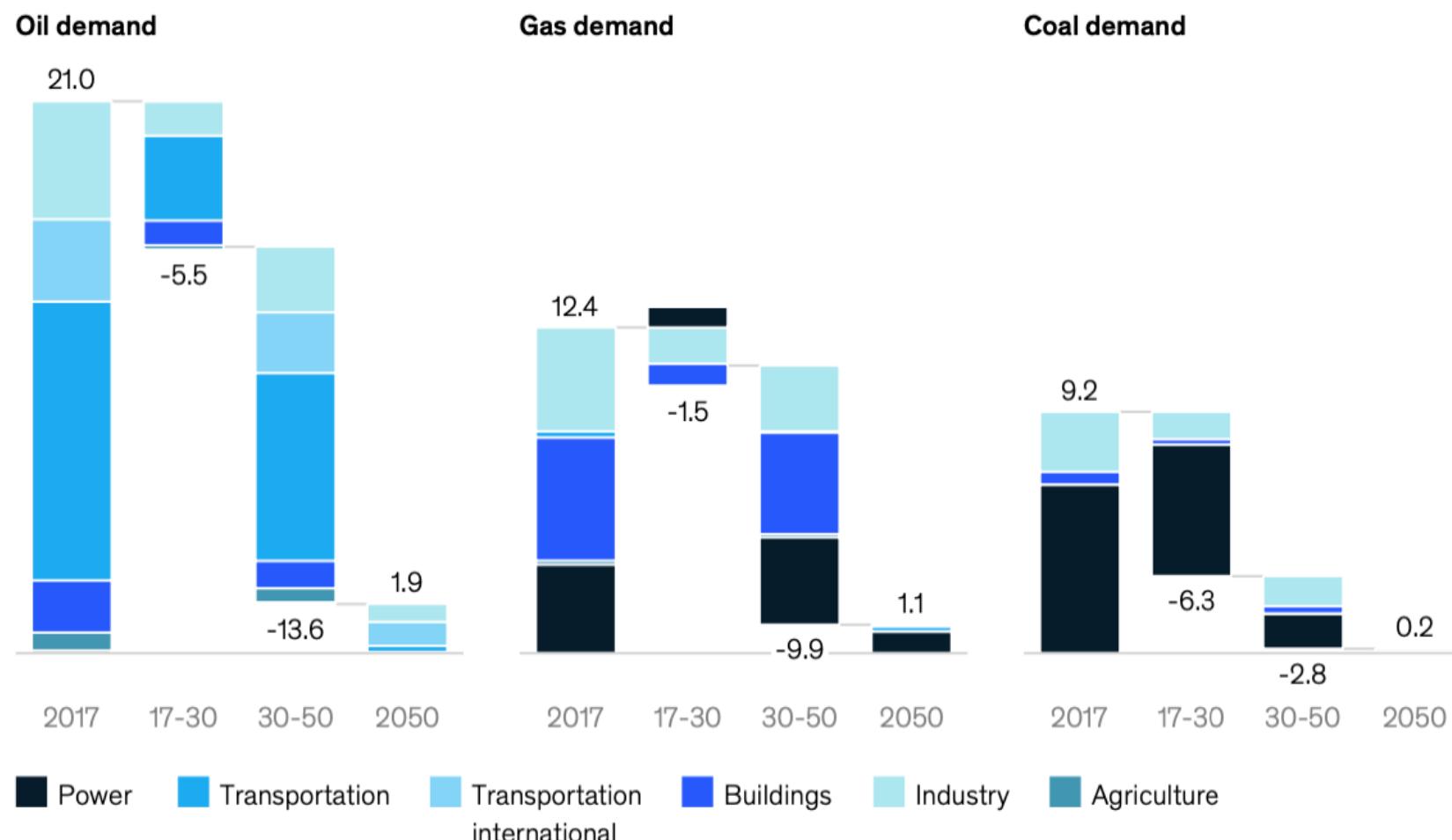


석유, 석탄은 내리막길만, 가스는 살짝 늘었다가 사라짐

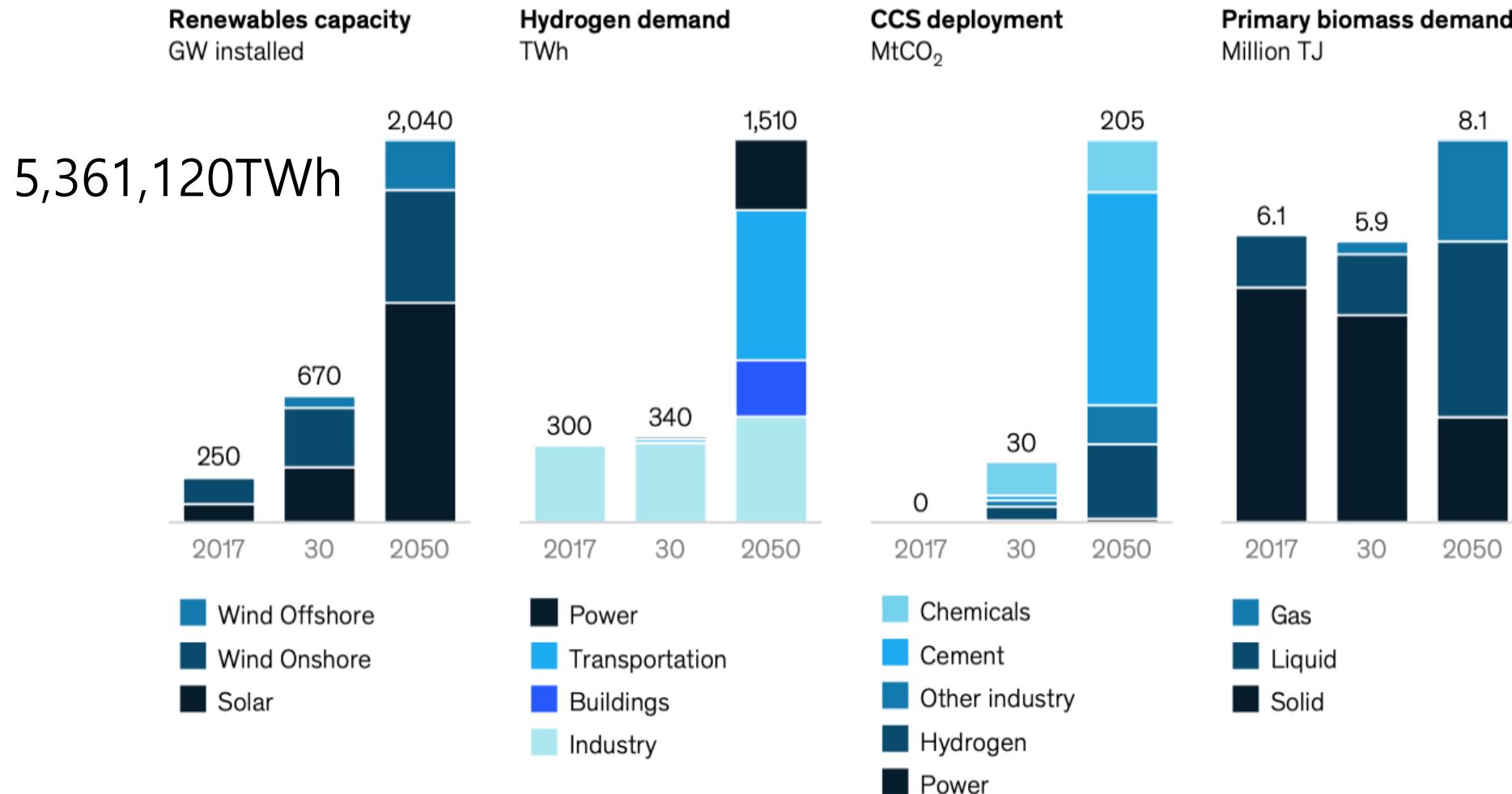
Exhibit 25

On the cost-optimal pathway, natural gas use would rise in the short-term, but low-carbon renewables would replace nearly all fossil fuel usage by 2050.

Total primary energy demand for EU-27, million TJ



핵심 기술 4가지 – 태양광/풍력 역할이 가장 커

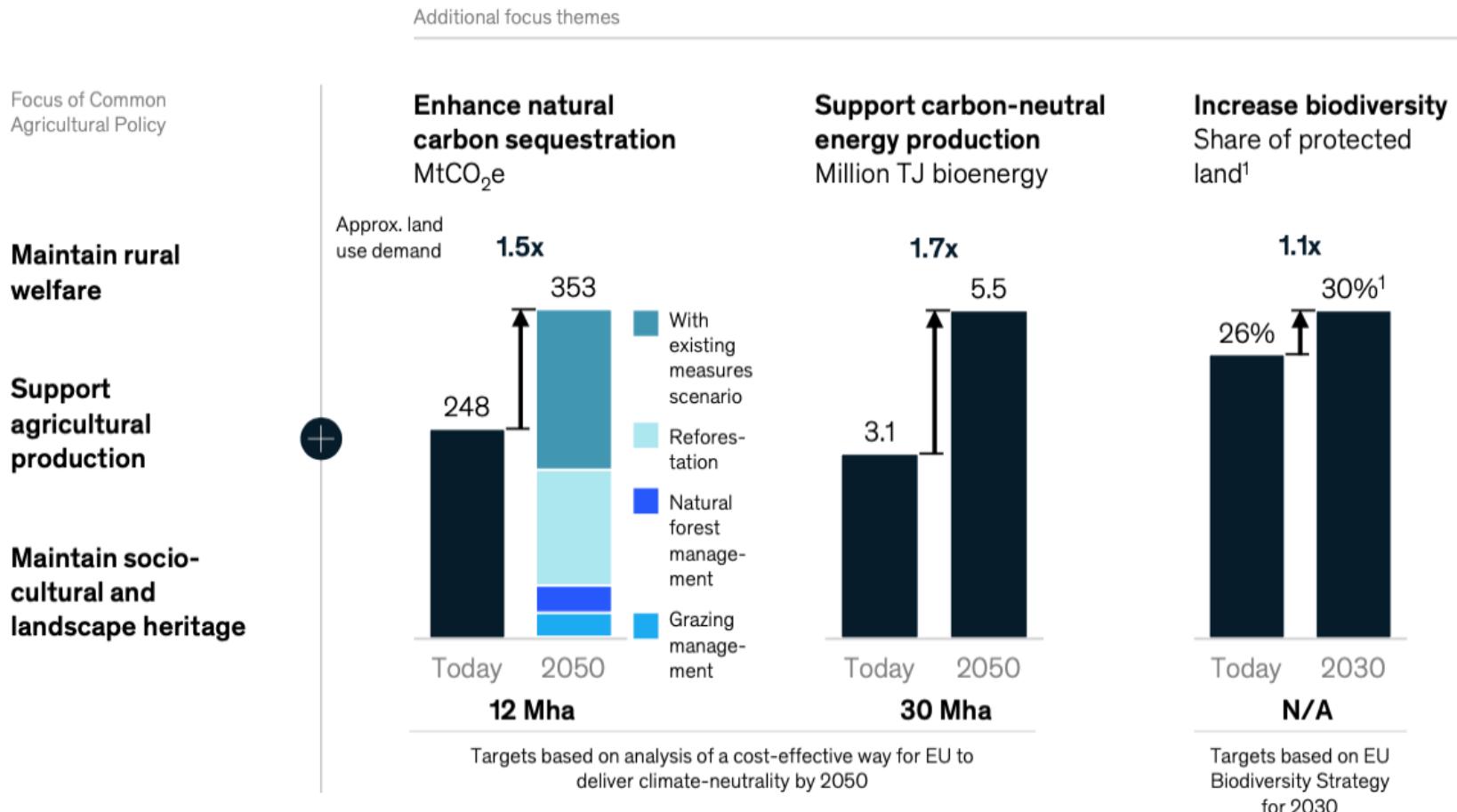


Source: McKinsey

제한된 땅으로 이것도 하고 저것도 해야 함

Exhibit 27

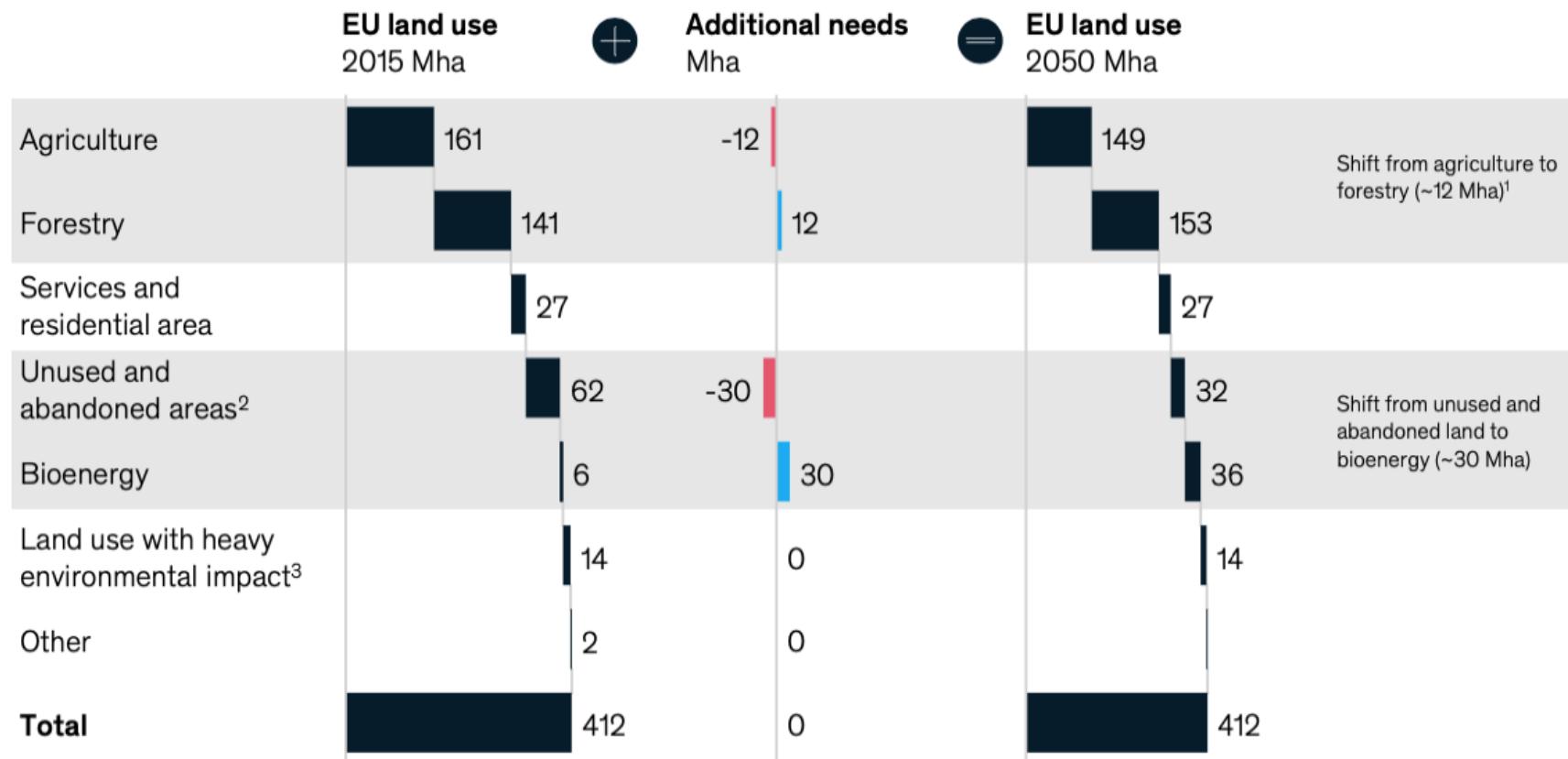
On the cost-optimal pathway, EU land-use policies have to balance multiple competing objectives.



농업/토지 이용 - 온실가스 줄이기 힘들어

Exhibit 28

The cost-optimal pathway involves a slight shift from agriculture to forestry, plus the cultivation of energy crops on 30 million hectares of low-value, abandoned land.

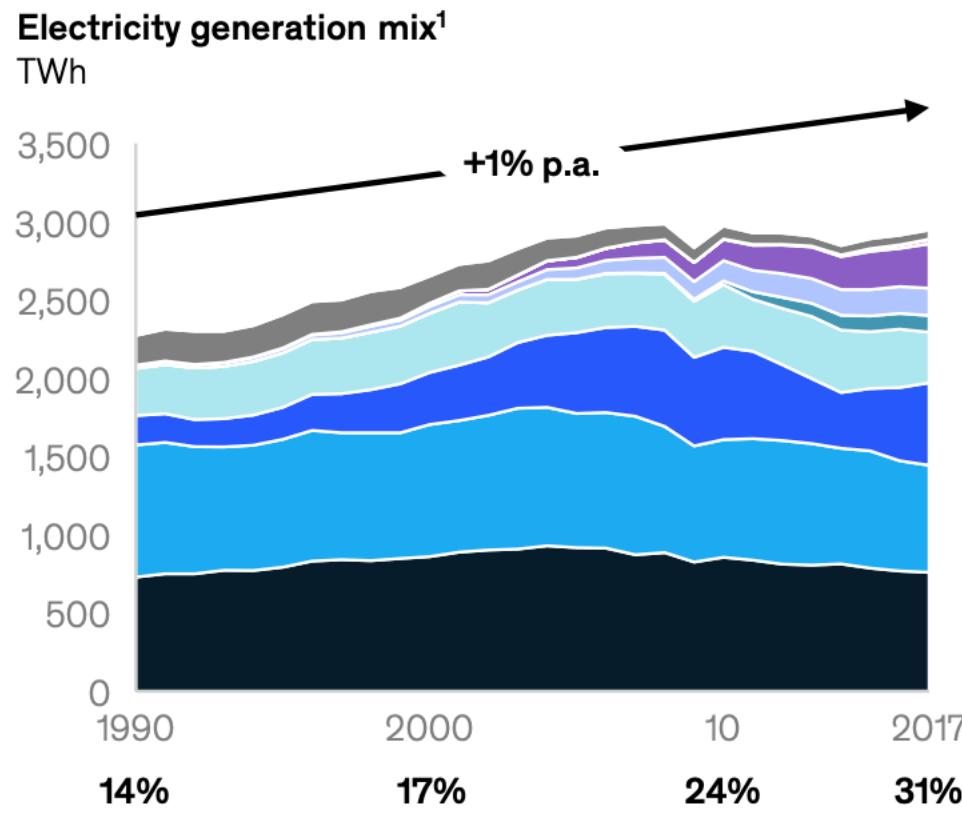


이런게 친환경 농업

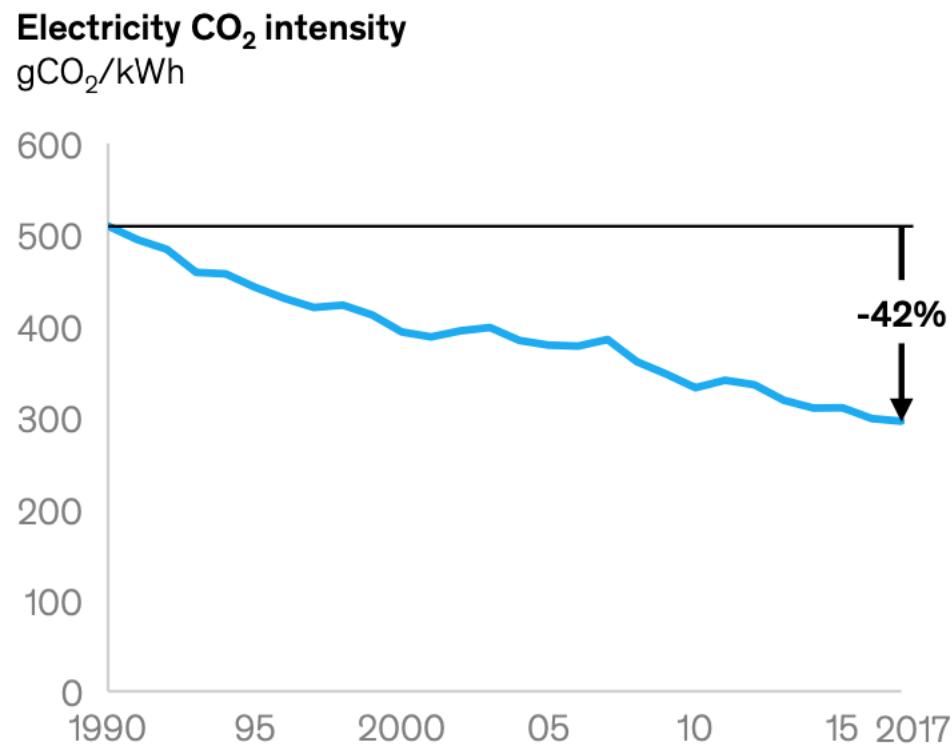


전기 생산당 CO₂ 줄이는게 관건: 유럽은 42% 줄어

Power sector baseline for EU-27



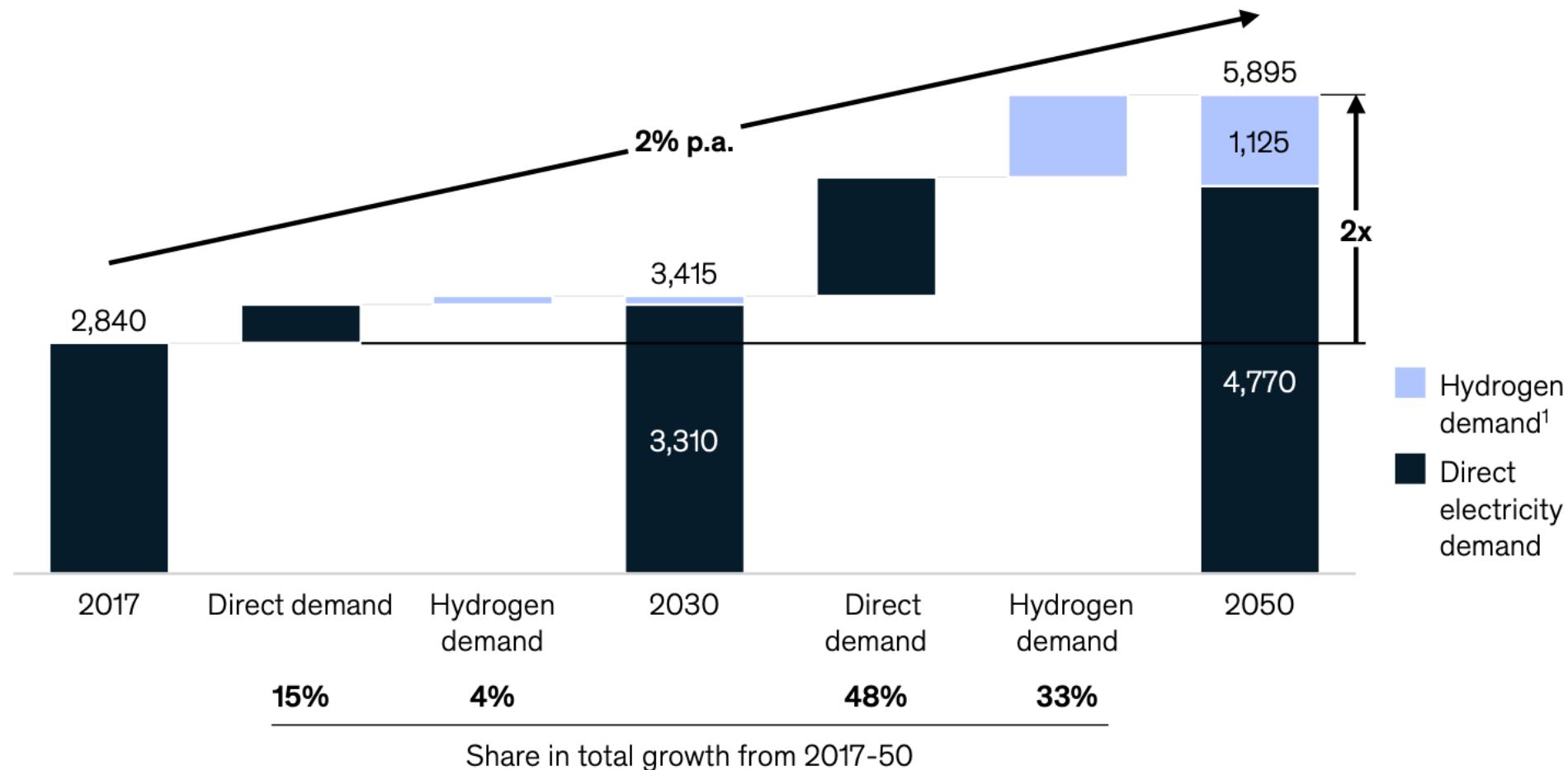
Renewable generation share
(incl. wind, solar, hydro & biomass)



전력 생산은 두배로 늘려야

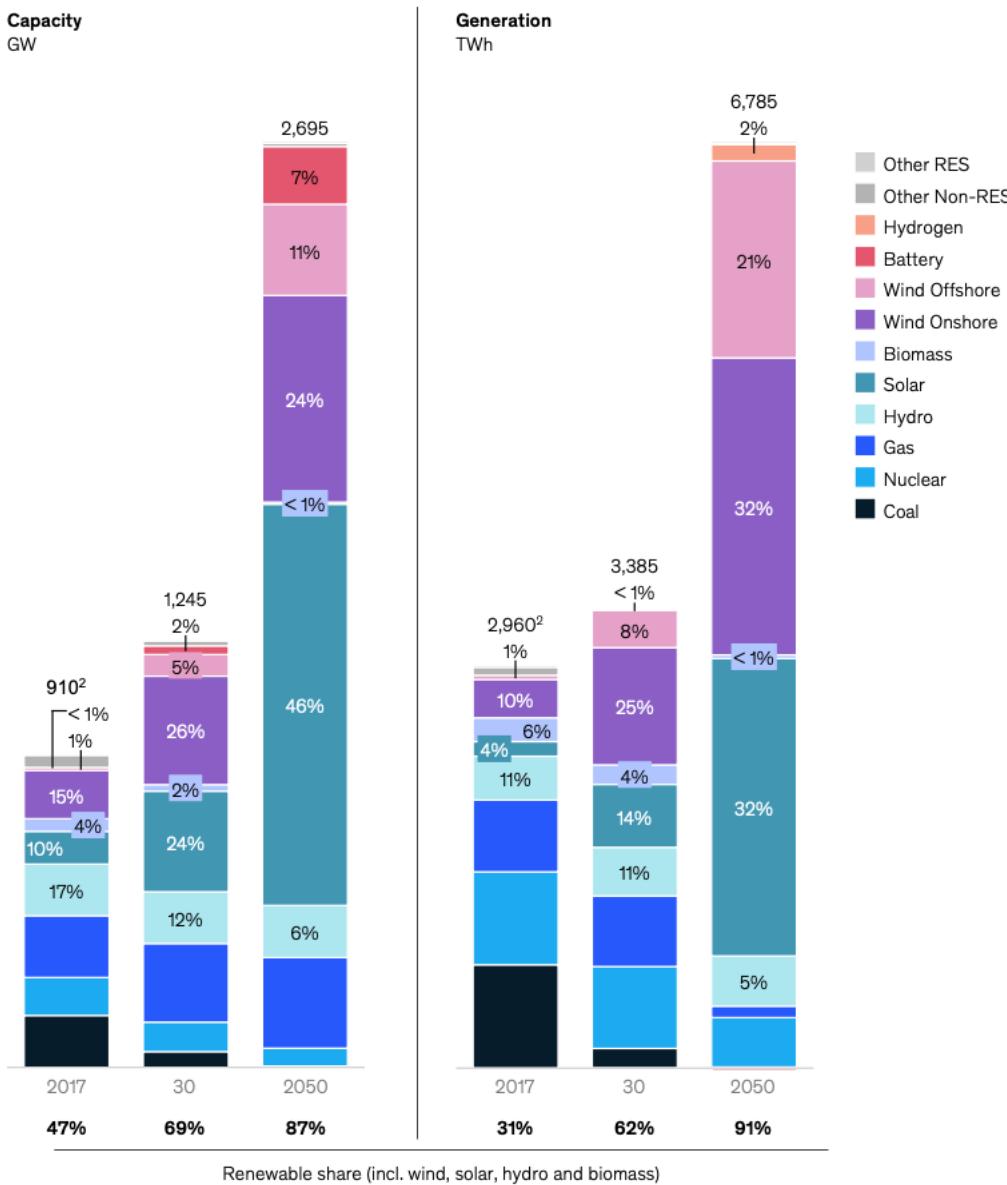
Electric power demand

Net electricity demand in EU-27 (excluding grid loss and own consumption), 2017-50, TWh



태양광, 풍력이 메인으로

Capacity and generation mix in EU-27, 2017-50

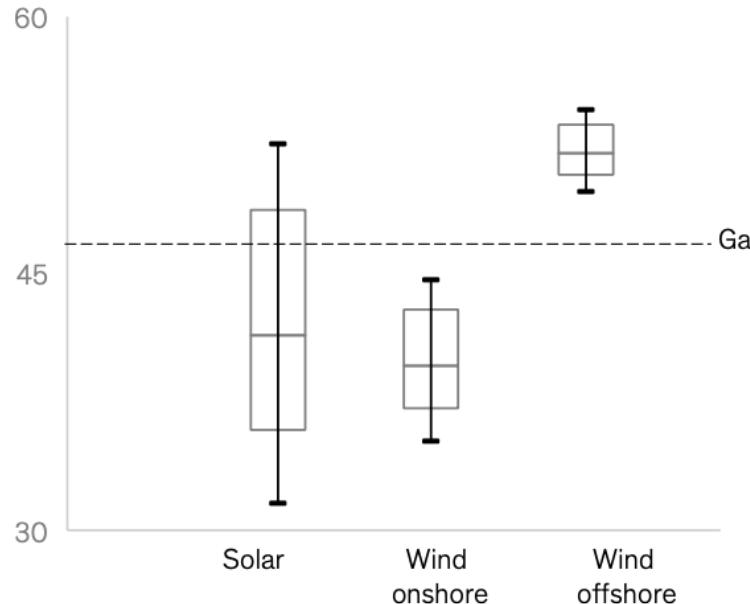


비용은 이미 낮지만 더욱 낮아질 것

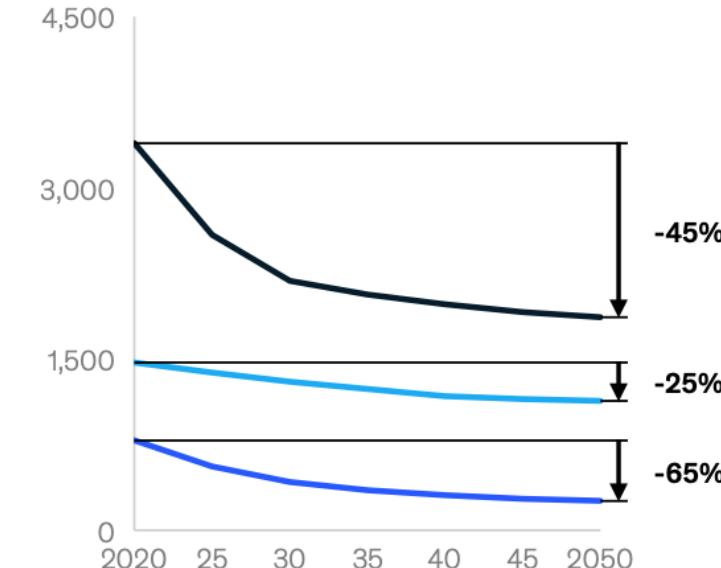
Exhibit 33

Capital expenditure costs for renewable power systems may drop dramatically by 2050.

LCOEs¹ of renewable new builds vs. SRMC² of existing gas plants
EUR/MWh, 2020



Renewable capex
EUR/kW



Max
3rd quartile
Median
2nd quartile
Min

Wind onshore Solar PV (utility scale)
Wind offshore

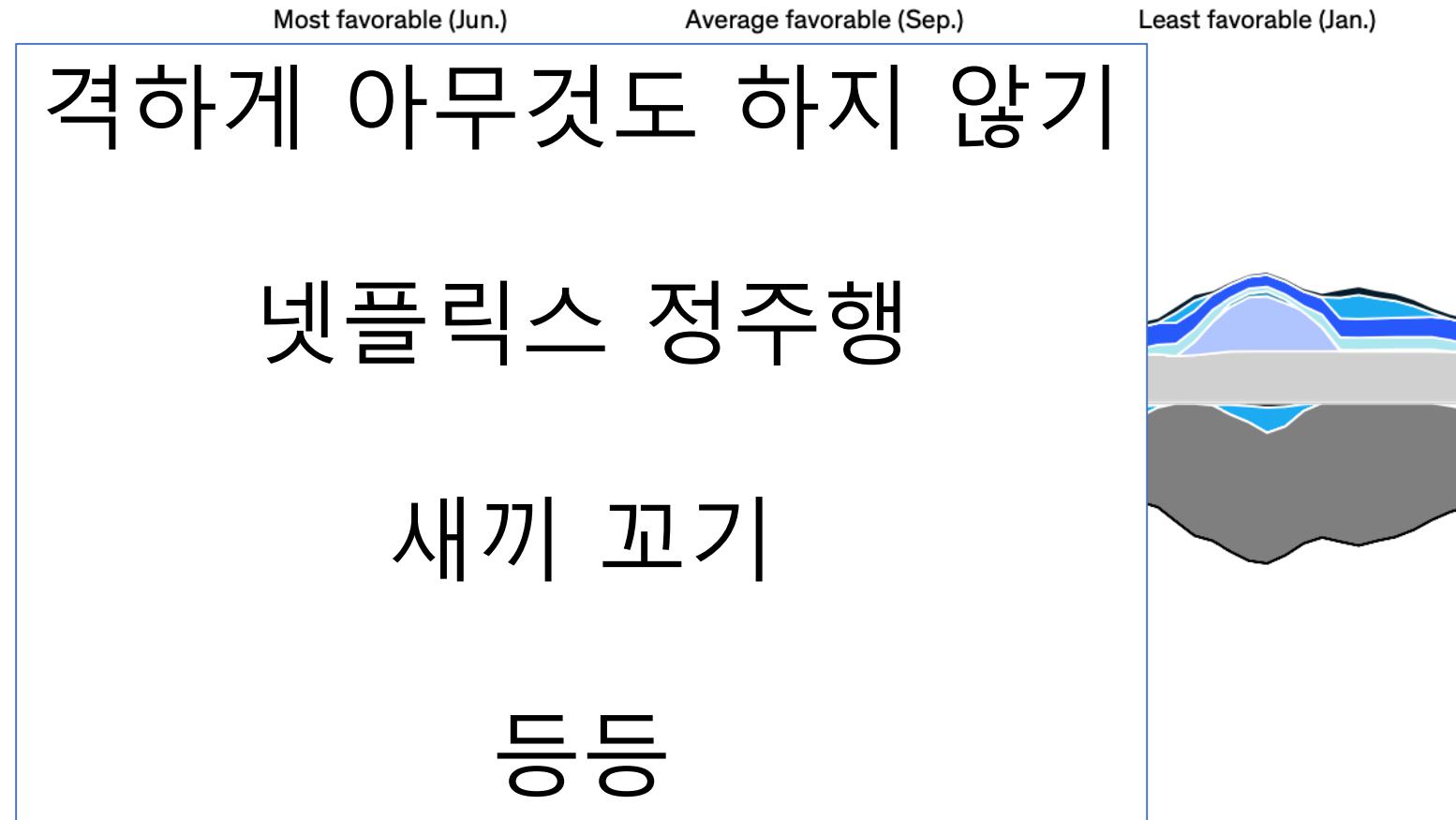
겨울 전기 생산/수요 맞추는게 만만치 않음

Exhibit 34

As they become more dependent on renewables, power systems will need to become more flexible to cope with surpluses and deficits.

Three representative daily generation and load profiles, Southern European country, 2050

Renewable conditions



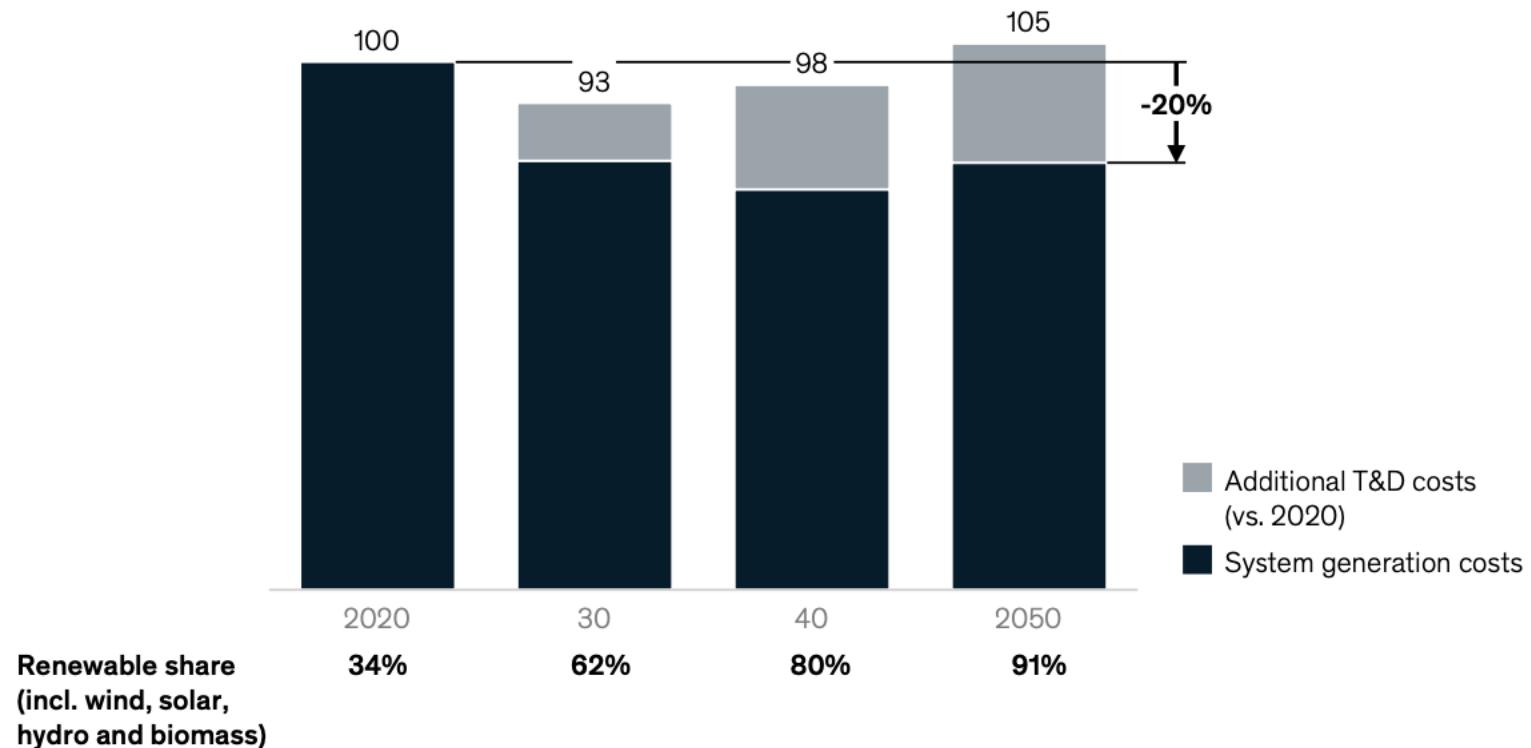
■ DSR¹ ■ Gas ■ Net transmission flow ■ Wind Onshore ■ Bulk load
■ Battery ■ Hydro ■ Solar ■ Fuel creation

전기 생산은 싸게 가능 – 부가 장치가 좀 돈이 들어감

Exhibit 35

By 2050, power generation costs could fall nearly 20 percent, but higher transmission and distribution costs may offset these savings.

Electricity costs, EUR/MWh, EU-27, indexed to 2020 = 100

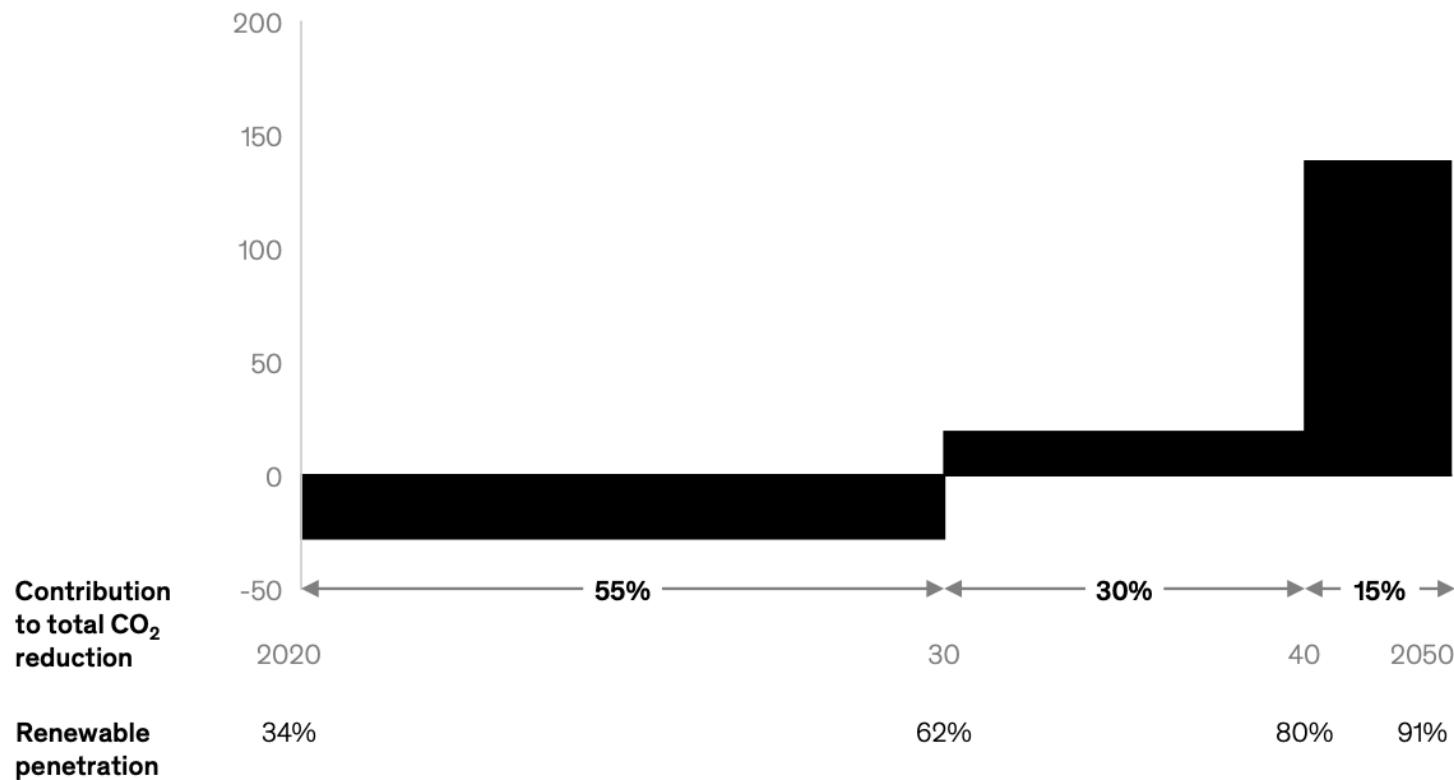


2040년 이후 부가 장치 (배터리 등) 투자비 많이 들어

Exhibit 36

Savings should exceed decarbonization costs for 85 percent of the EU's power sector emissions, but eliminating the last 15 percent would be expensive.

Average abatement costs, EUR/ton CO₂ abated , EU-27



Source: McKinsey

자동차는 전기차 100% – 수소차도 일부 역할 할 수도

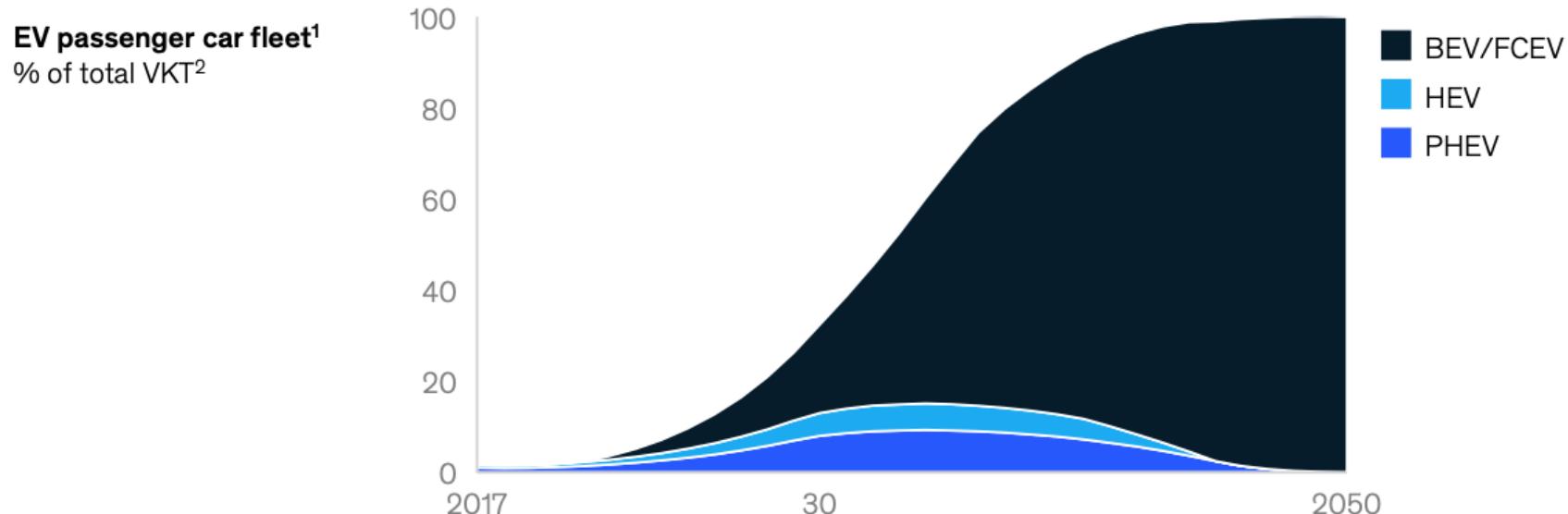
Exhibit 37

Transportation pathway in brief

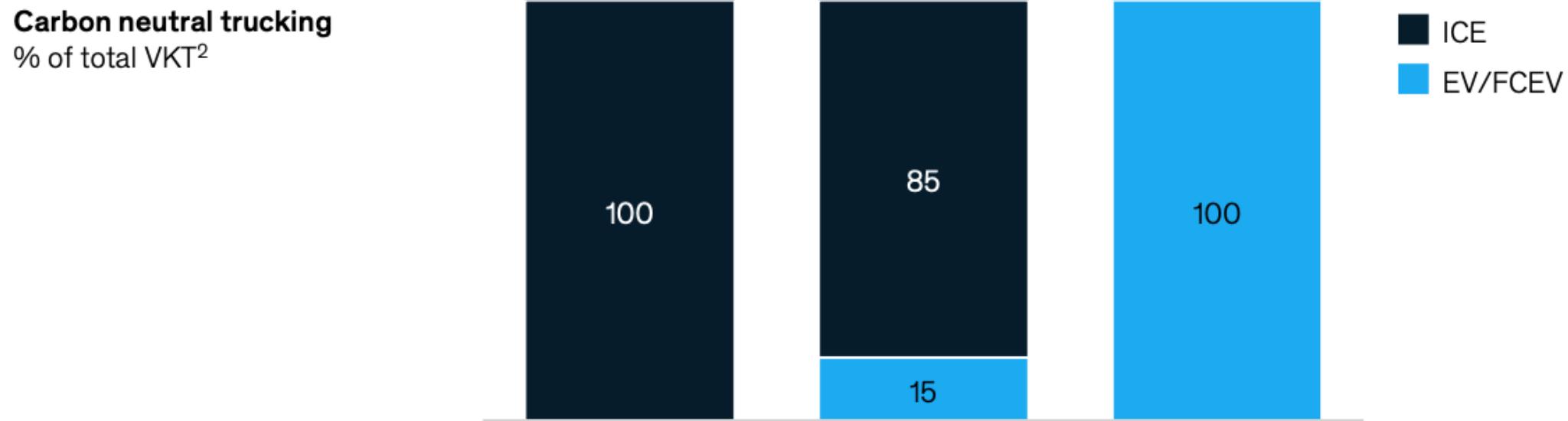
The low-cost pathway in the transportation sector depends on EV passenger car sales, carbon-neutral trucking, and greater adoption of biofuels and synfuels.



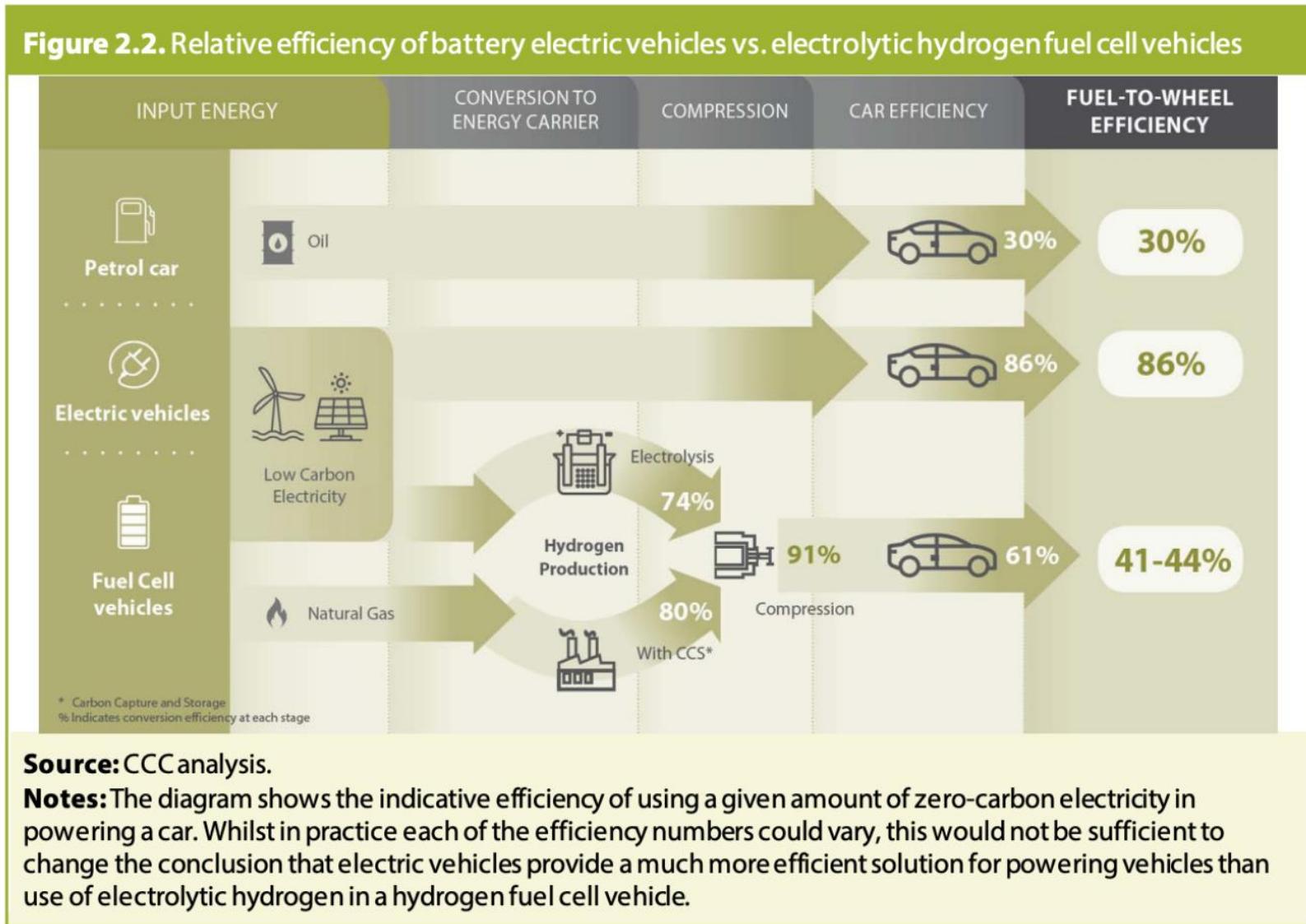
EV passenger car sales ¹	2017	2030	2050
% of total			
HEV/PHEV	3	20	0
BEV/FCEV	1	>60	100



트럭도 전기 아니면 수소



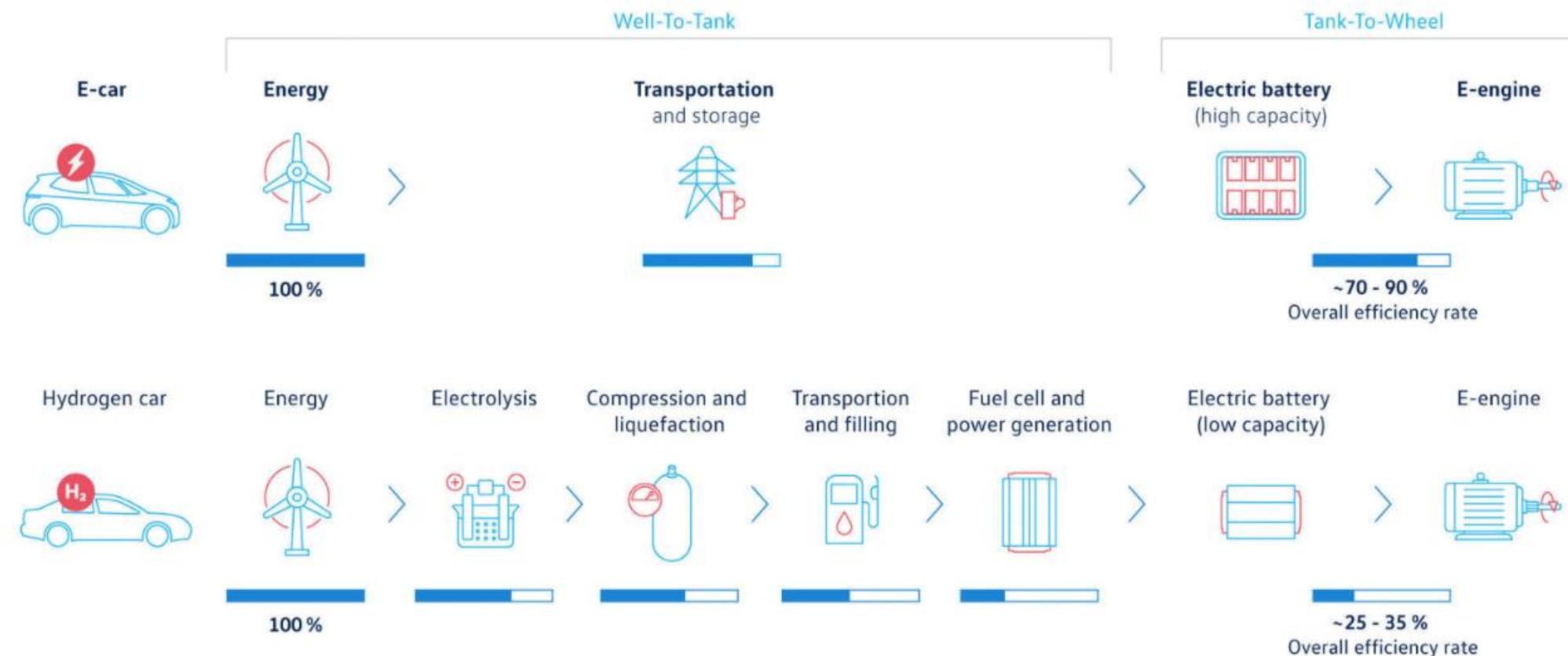
에너지 효율: 전기차 86% - 수소차 41~44%



에너지 효율: 전기차 70~90% - 수소차 25~35%

Hydrogen and electric drive

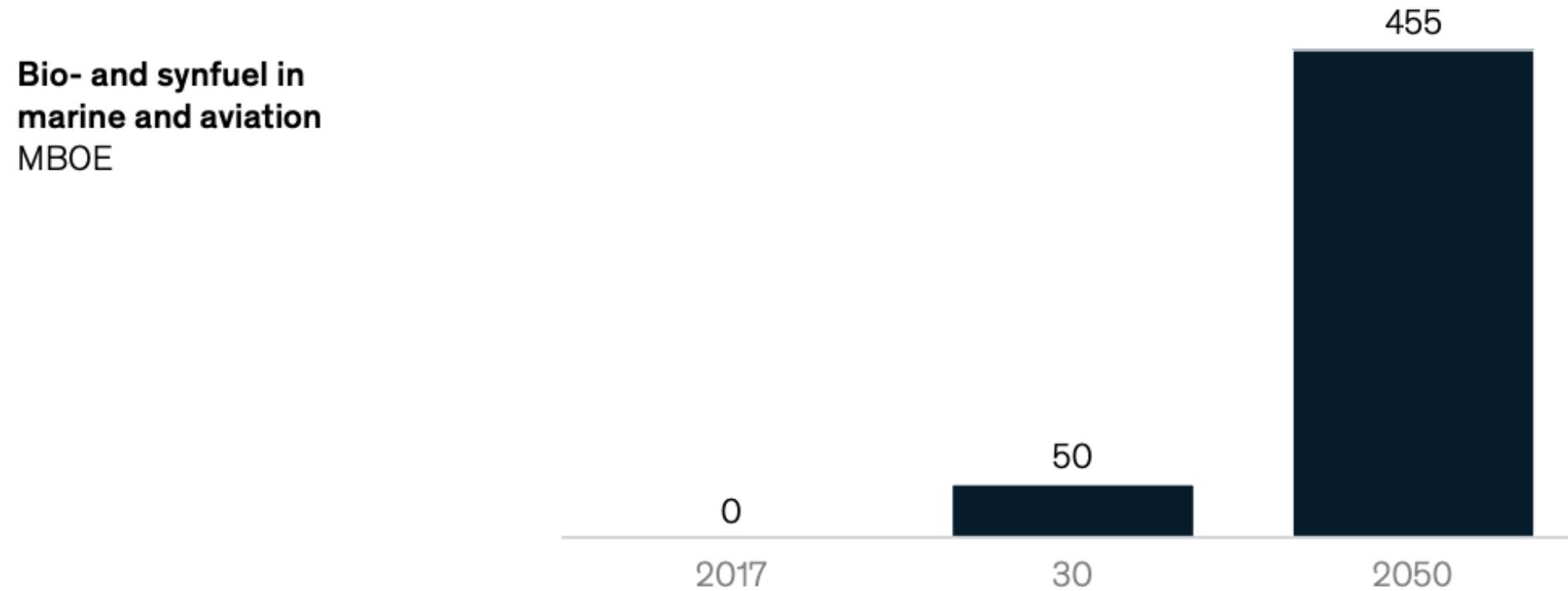
Efficiency rates in comparison using eco-friendly energy



Source Volkswagen

<https://www.volkswagenag.com/en/news/stories/2019/08/hydrogen-or-battery--that-is-the-question.html>

비행기는 바이오 연료 또는 합성연료 가능할 듯 (비쌈)



전기차가 주도

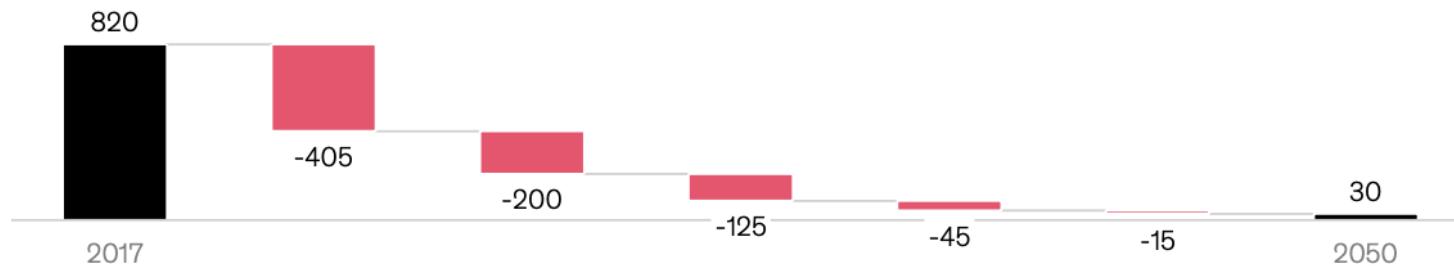
Exhibit 39

Electrification and hybridization account for half of the emissions abatement in transportation.

Domestic transportation emissions for EU-27, MtCO₂e

Domestic transportation base case emission reduction 2017-50

MtCO₂e



Key levers	Electrification & Hybridization	Energy efficiency	Hydrogen	Demand reduction	Alternative fuels ¹
Description	Electrification of cars, urban/regional trucks and city buses	Improved energy efficiency through vehicle design (e.g., engine efficiency) and operational efficiency (e.g., speed reduction, higher utilization)	Fuel cell vehicles, predominantly in long-haul truck and bus applications	Demand reduction and behavioral shift driven by e.g., ICE bans, congestion charging and smart parking solutions	Alternative fuel (bio- and synthetic) use in aviation and marine
Share of emission reduction	51%	25%	16%	6%	2%

Levers can be combined in multiple ways and the most cost-optimal reduction path is uncertain.

1. Includes domestic marine and aviation transportation

산업 온실가스 감축 경로

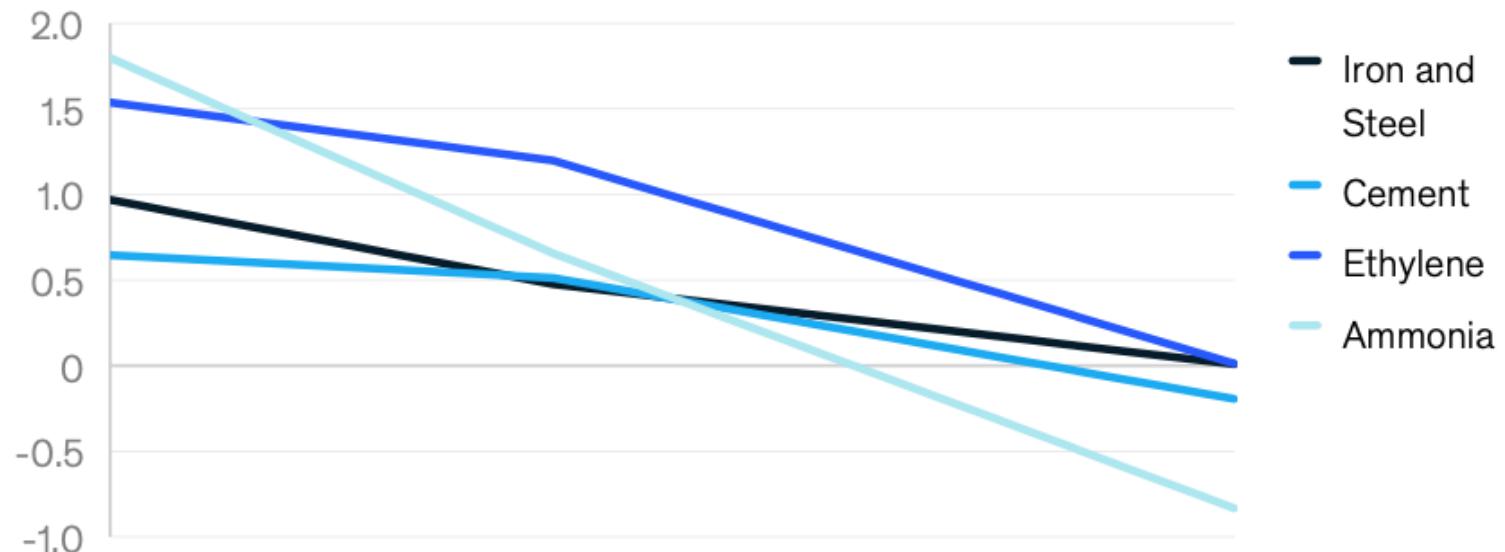
Exhibit 40

Industry pathway in brief

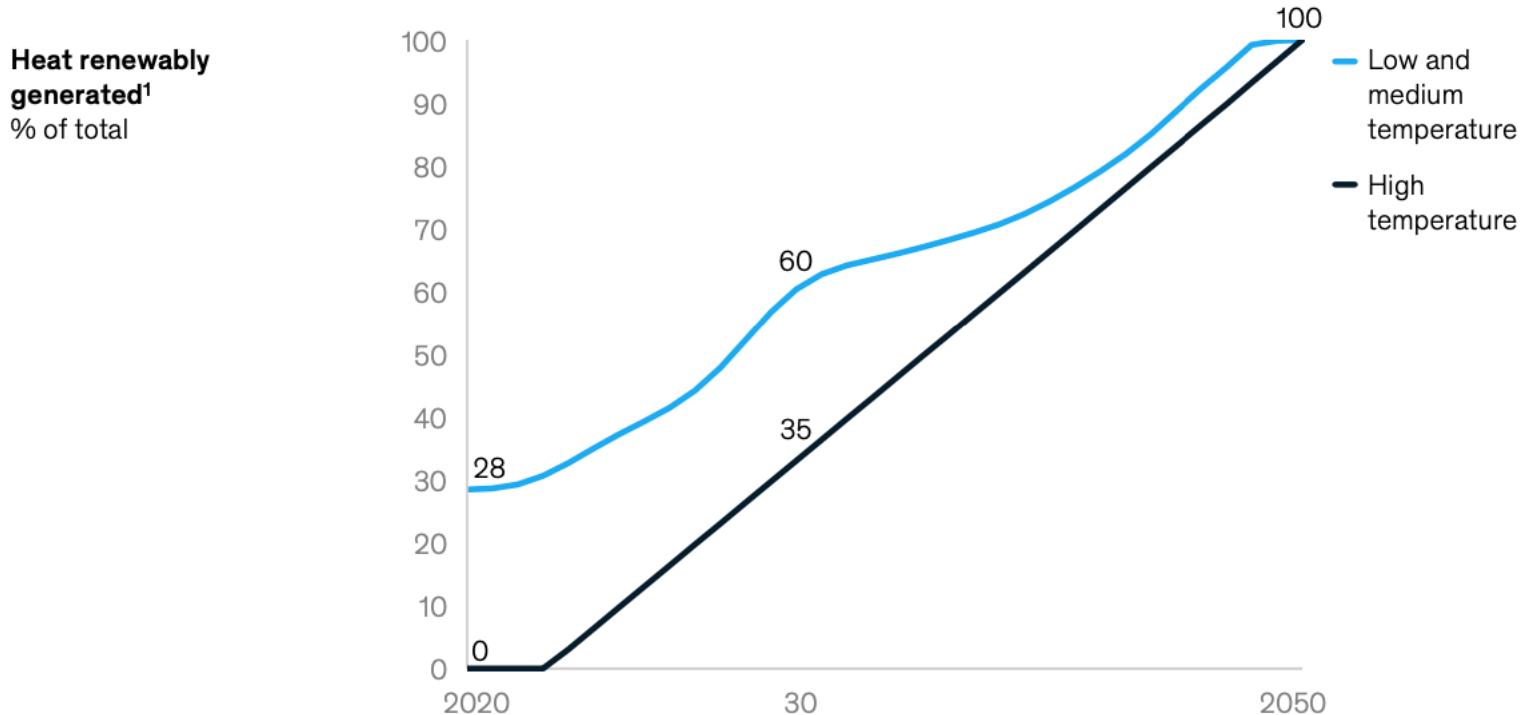
Renewable heat generation and carbon capture could help EU industry cut emissions 96 percent by 2050



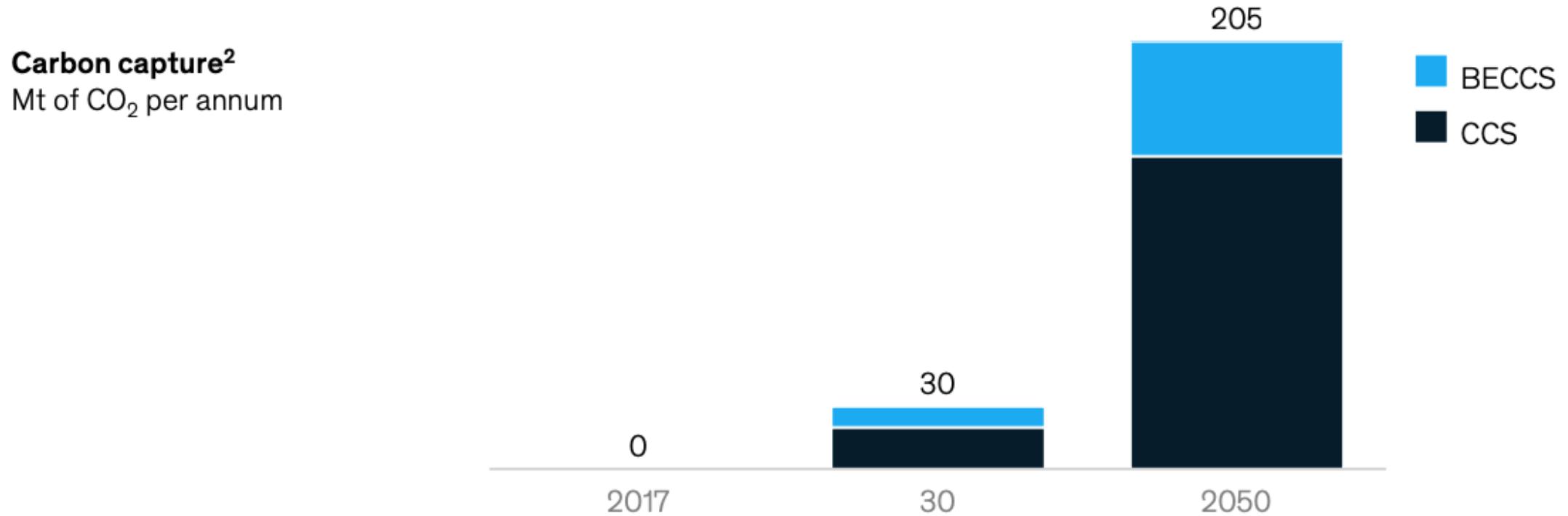
Average carbon intensity
Ton CO₂e emitted by ton
product produced



재생 열 (바이오 메스)



탄소 포집 저장



건물

3.4 Buildings



재생 열 보급 늘리는게 관건

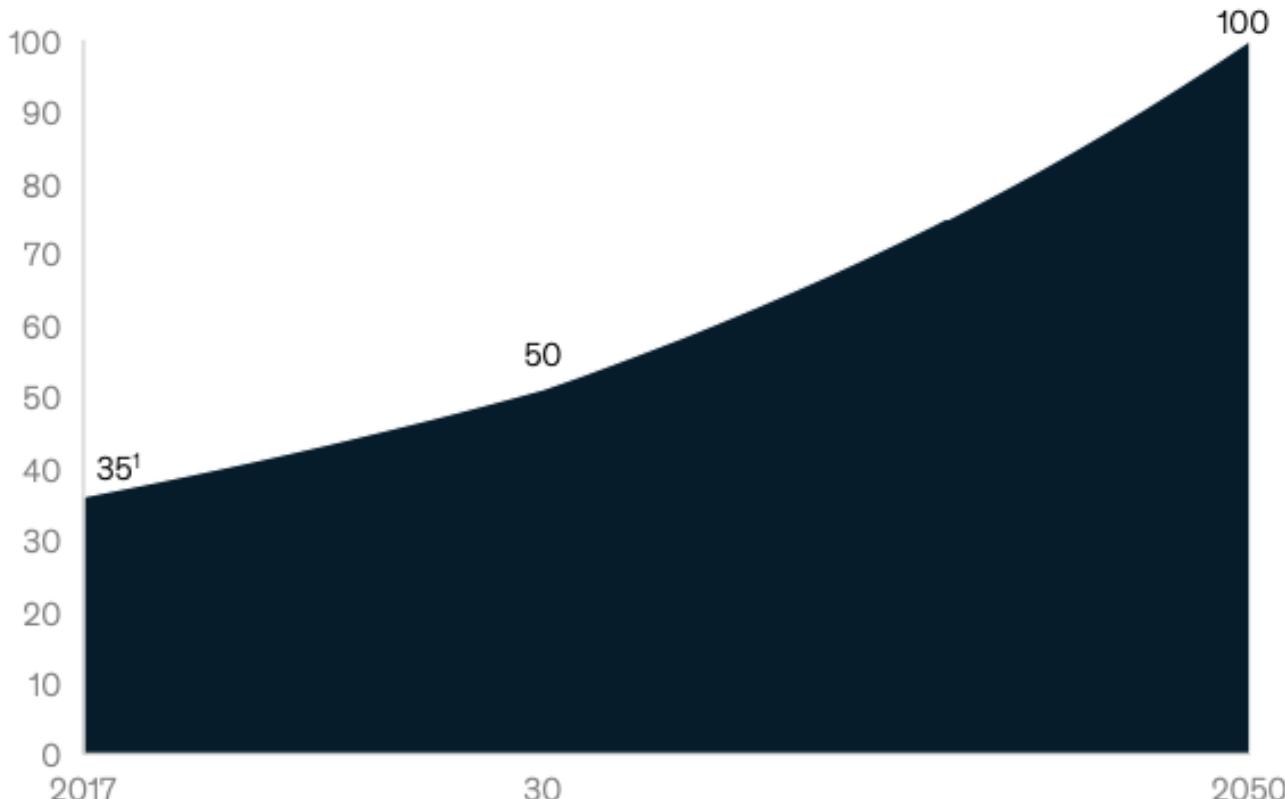
Exhibit 46

Buildings pathway in brief

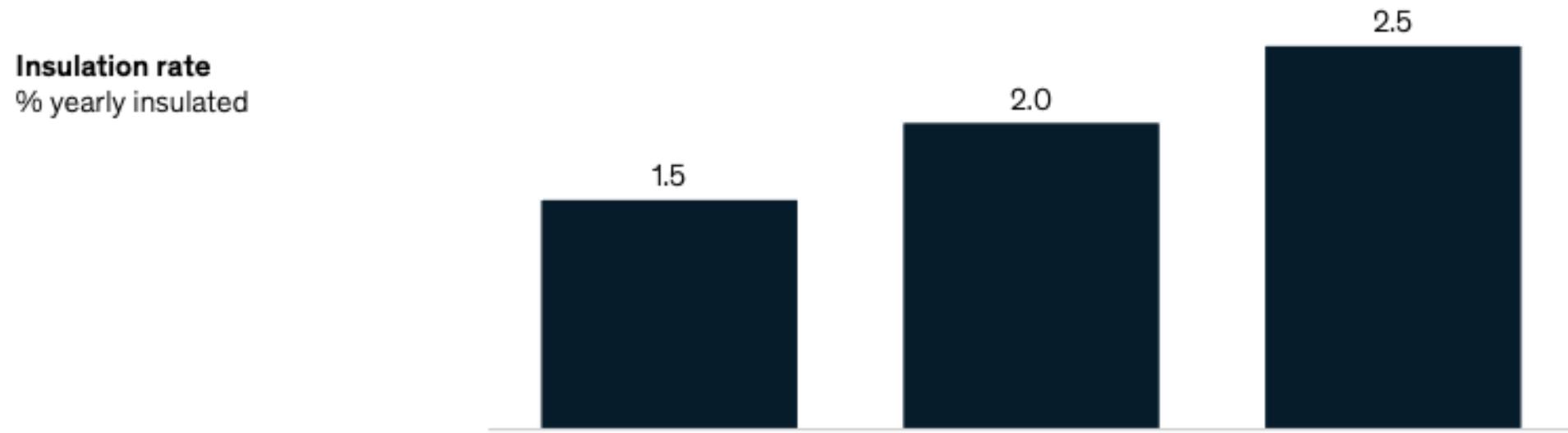
The building sector could reach net-zero cost by improving building insulation and switching to renewable heating technologies.



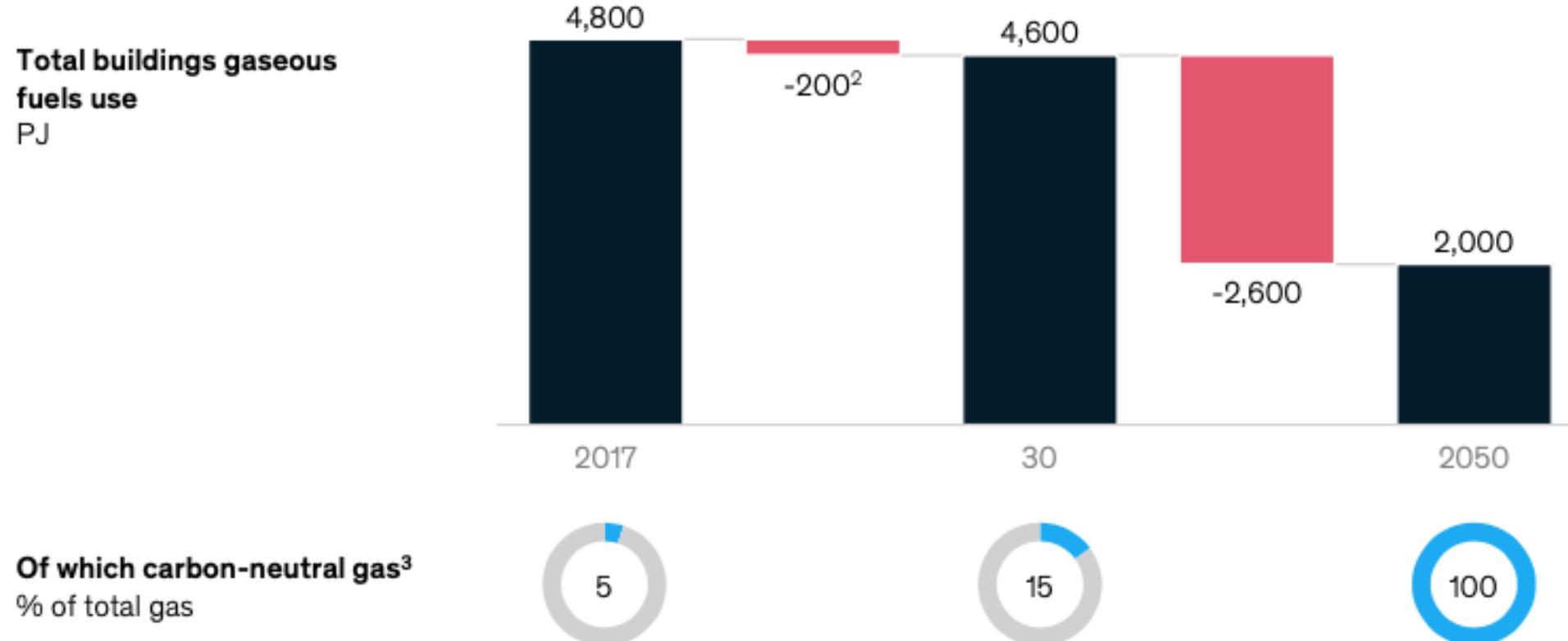
Dwellings on renewable heating
% of total dwellings



단열 개선



탄소중립 가스 보급 100% 달성 필요 (수소?)



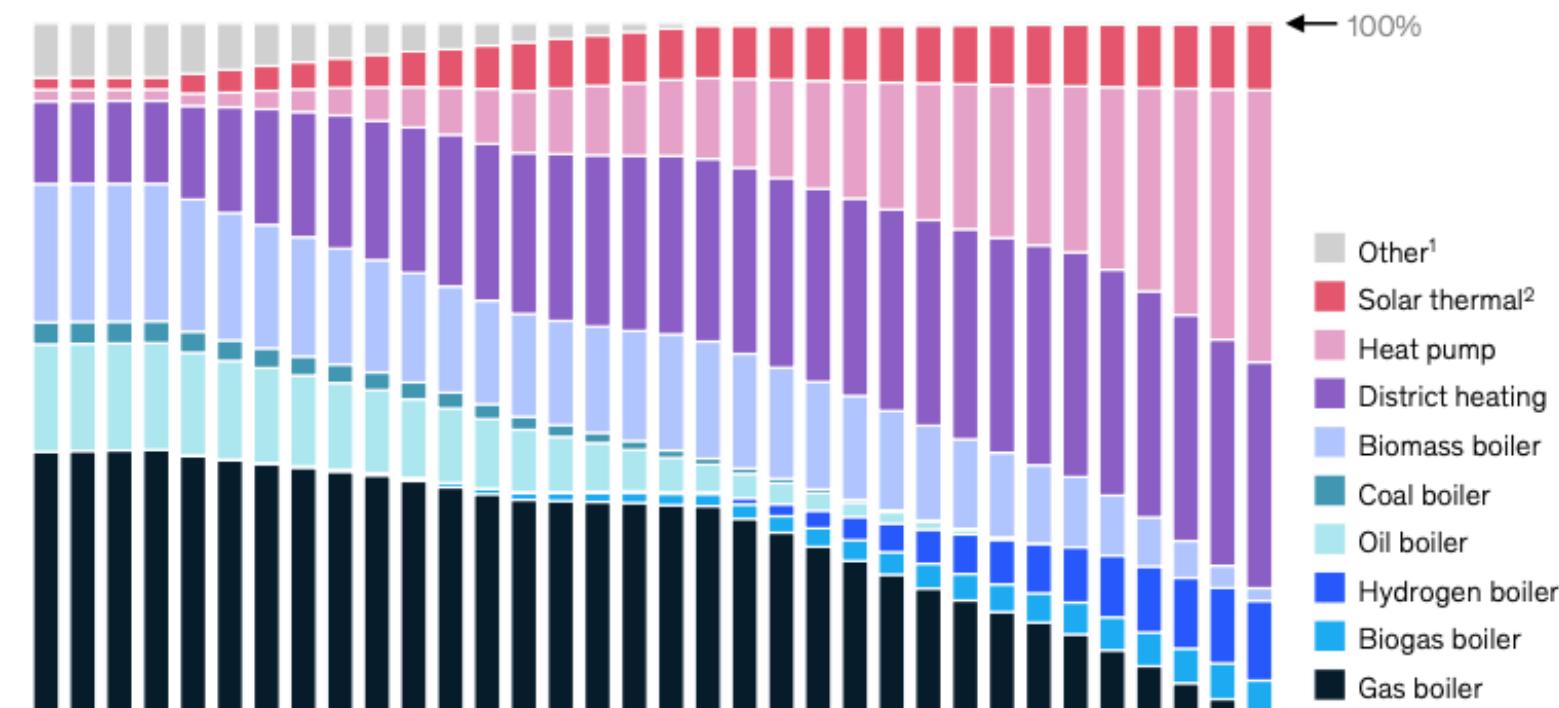
히트 펌프 역할 중요 - 석유/가스 보일러는 퇴출

Exhibit 48

Heat pumps could play a vital role in the decarbonization of the EU building sector.

Space and water heating technology mix

Penetration level in %



농업 - 농기계 탄소 중립 (전동화 등)

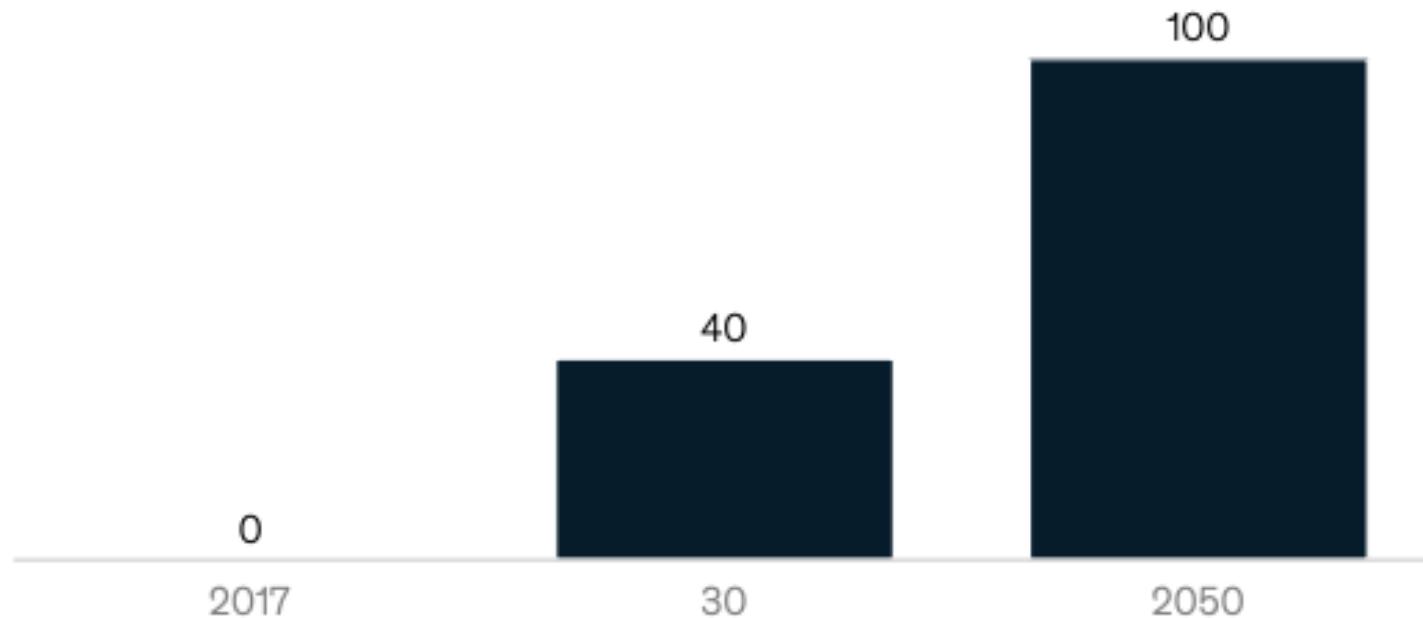
Exhibit 49

Agriculture pathway in brief

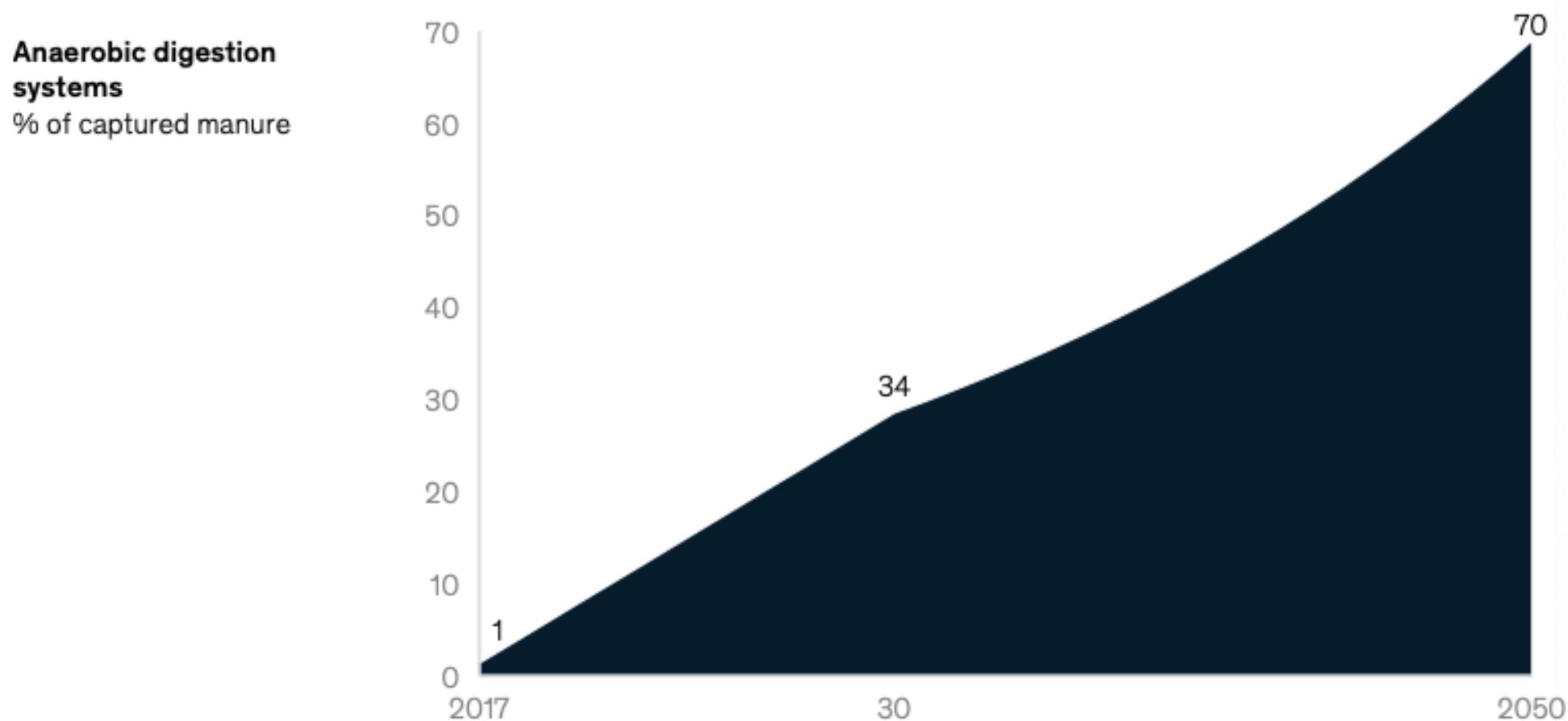


The agriculture sector can decarbonize by electrifying farm machinery, turning manure into biogas, and breeding animals that produce fewer GHG emissions.

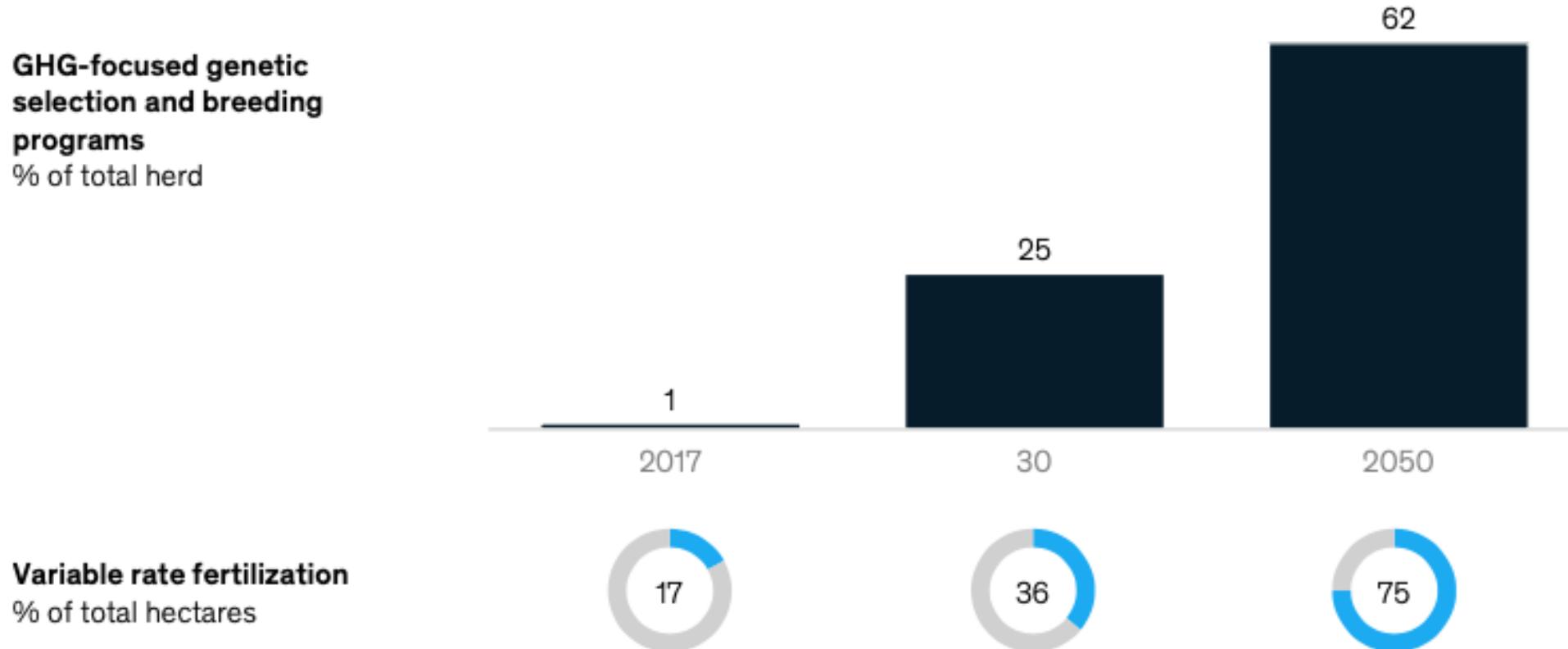
Carbon neutral energy in equipment
% of total



분뇨 - 가스화 처리



온실가스 배출 관리에 중심을 둔 축산

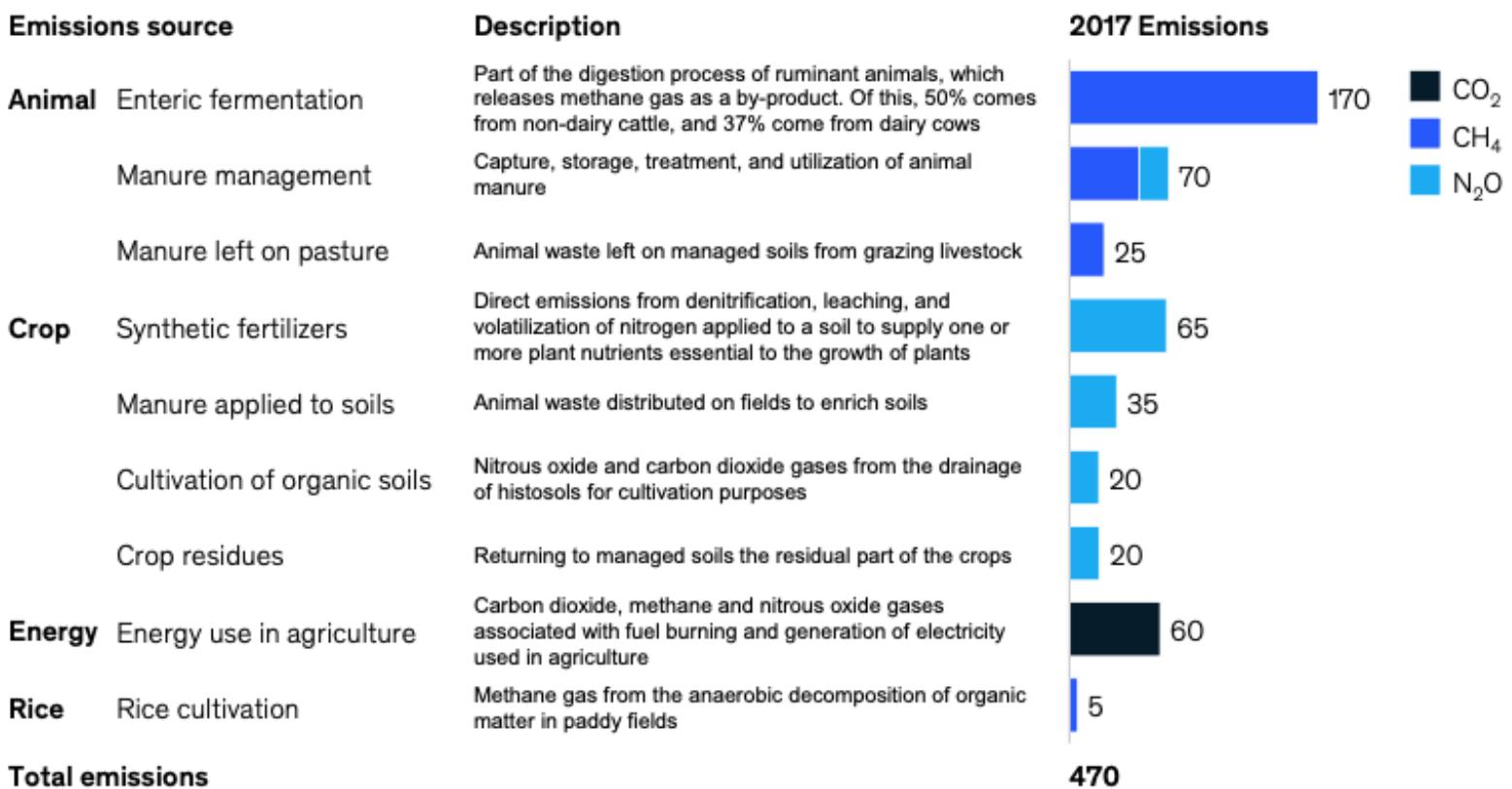


동물 사육이 가장 큰 문제

Exhibit 50

Animal digestion processes and manure are responsible for most agricultural GHG emissions across the EU-27.

MtCO₂e, EU-27



감사합니다.