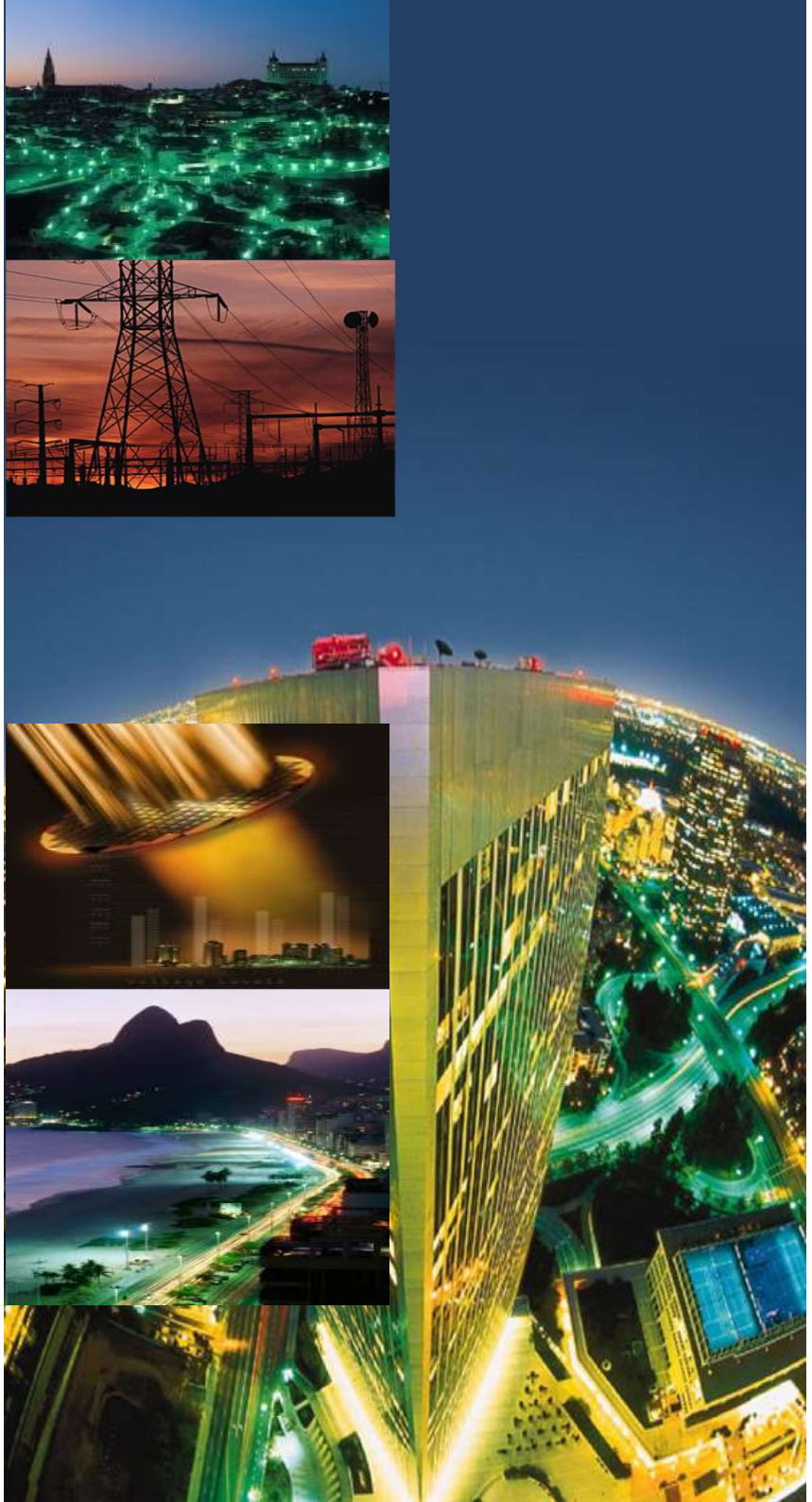


2022.10.7

제18회 서울국제전력시장 컨퍼런스(SICEM2022)

Issues of Energy and Power System for Energy Security

(에너지안보를 고려한 전원 믹스 구현 방안)

건국대학교 전기전자공학부
박종배 교수

Contents

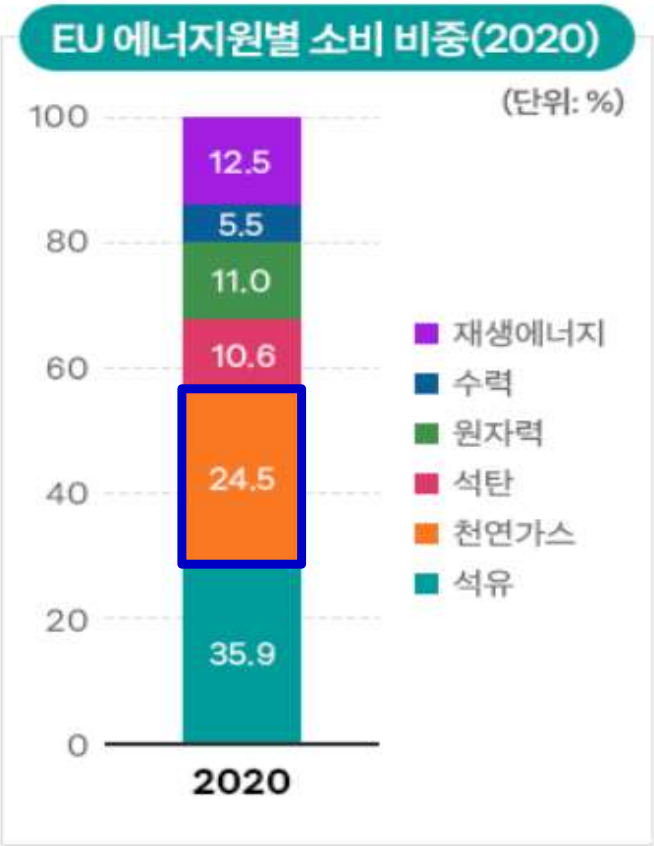
- **Global Energy Crisis and Energy Policy Principles**
  (글로벌 에너지 위기와 에너지 정책 원칙)

- **South Korea Situation and Major Issues**
  (우리나라 상황 및 에너지 안보 주요 이슈)

- **Suggestions and Discussions**
  (제언 및 토론)

Cause of Global Energy Crisis (글로벌 에너지 위기의 원인)

- **High Dependance on Russian Natural Gas in Final Consumption (최종에너지 소비에서 러시아 높은 천연가스 의존과 러시아에 의존)**



자료: Statista,
"Primary energy consumption in the EU by fuel 2019-2020"
(검색일: 2022.5.19)를 바탕으로 저자 작성.

EU의 대러시아 에너지 수입의존도(2020)

(단위: %)

석유	비중	석탄	비중	천연가스	비중
러시아	26.9	러시아	46.7	러시아	41.1
이라크	9.0	미국	17.7	노르웨이	16.2
나이지리아	7.9	호주	13.7	알제리	7.6
사우디아라비아	7.7	콜롬비아	8.2	카타르	5.2
기타	48.5	기타	13.7	기타	29.9

자료: Visual Capitalist,
"Visualizing the EU's Energy Dependency"
(검색일: 2022.5.19)를 바탕으로 저자 작성.

* 출처 : 대외정책연구원, GS Caltex (2022)

Global Economic Crisis (글로벌 경제 위기 전개)

- **From 'Energy Crisis' to 'Economic Crisis'** (유럽발 에너지 위기가 글로벌 경제 위기로 확대)

Global Fuel Price Surge
(글로벌 연료(LNG, 석탄) 가격 급등)

Global Economic Crisis
(요금/물가/환율 급등, 무역수지 악화)

Dependence on Russia and War
(EU 천연가스 러시아 의존과 러-우 전쟁)

Global Economic Crisis
(글로벌 경제 위기 전개)

- **Economic Impacts of 'Natural Gas Shock' from Europe**

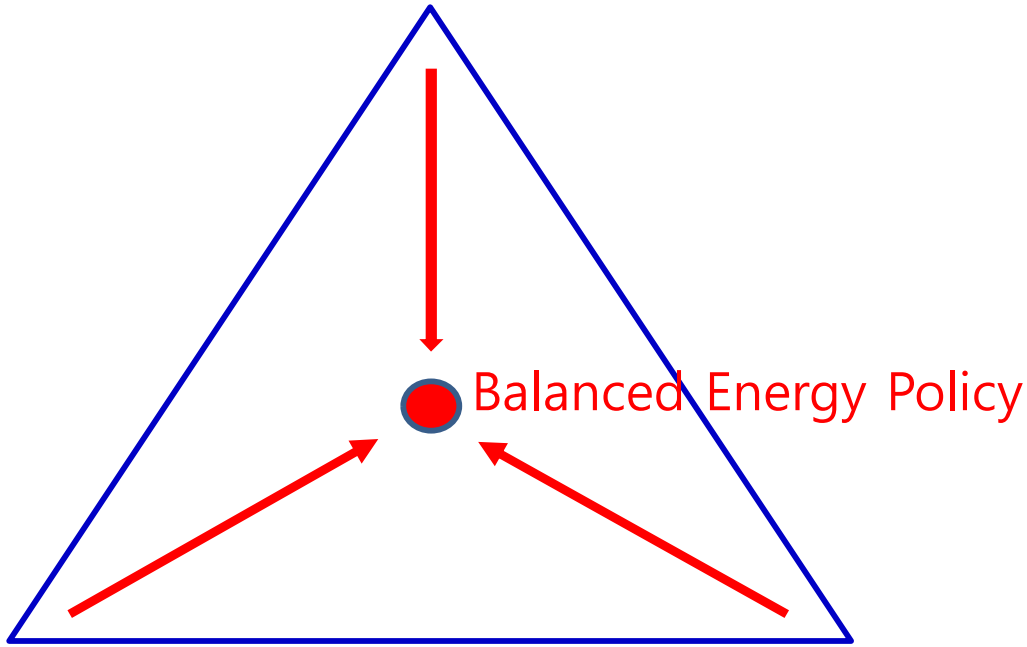
(현재의 위기는 유럽발 '천연가스 쇼크'이며, 경제 충격이 과거 중동발 '오일 쇼크'에 버금 갈 수 있음. 향후, 경제 충격 영향을 면밀하게 분석 필요)

Energy Trilemma & Energy Policy Principles

- **Energy Trilemma & Energy Policy** (에너지 정책의 기본 원칙)

Energy Affordability
(경제성, **경제위기**)

Emphasis placed on low cost fuel supply
(경제적 연료 공급)



Energy Security
(에너지안보, **에너지위기**)

Emphasis placed on reliable, stable, secure access to energy
(신뢰성 있고, 안정적이고, 안전한 에너지 수급)

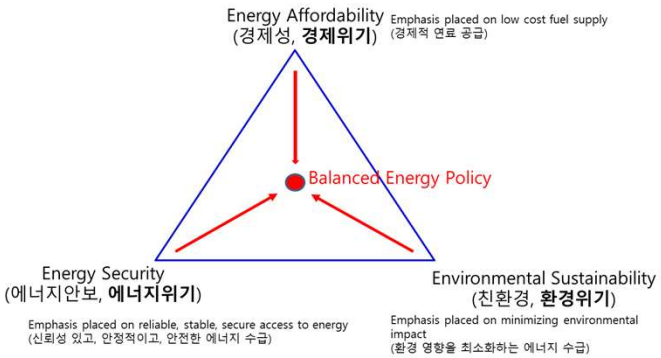
Environmental Sustainability
(친환경, **환경위기**)

Emphasis placed on minimizing environmental impact
(환경 영향을 최소화하는 에너지 수급)

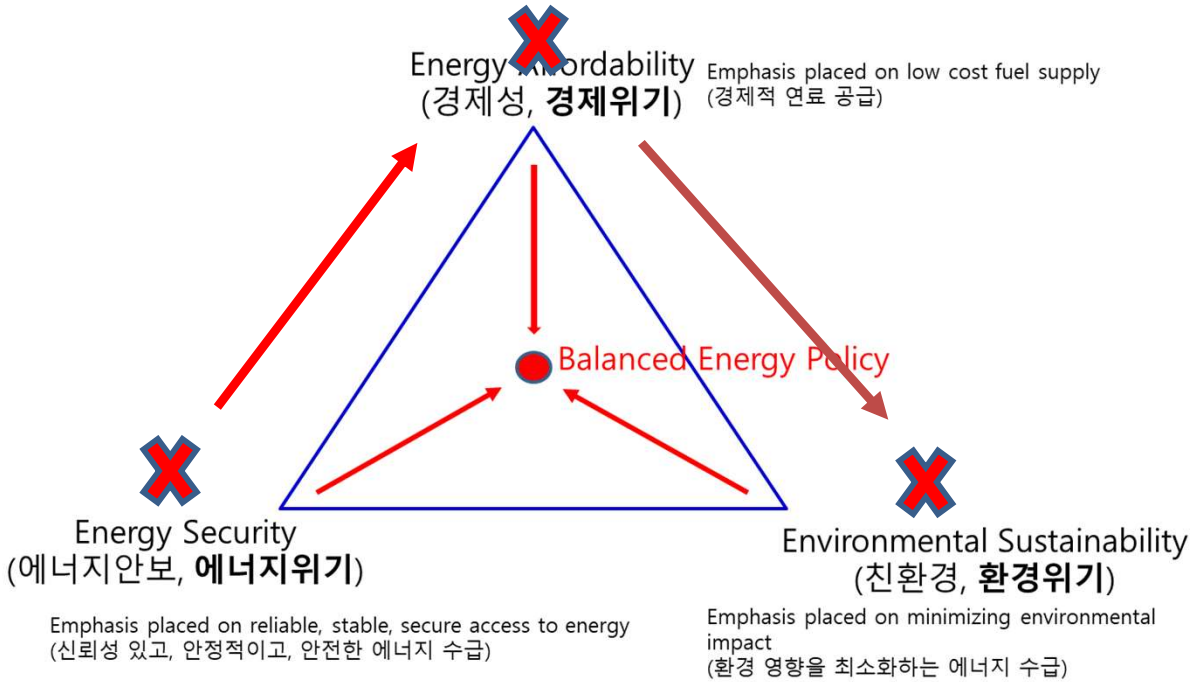
Global Energy Market Change (2020/2021 vs 2022)

- **Stable Energy Market (2020/2021) vs Energy Crisis (2022)**

(2020/2021)



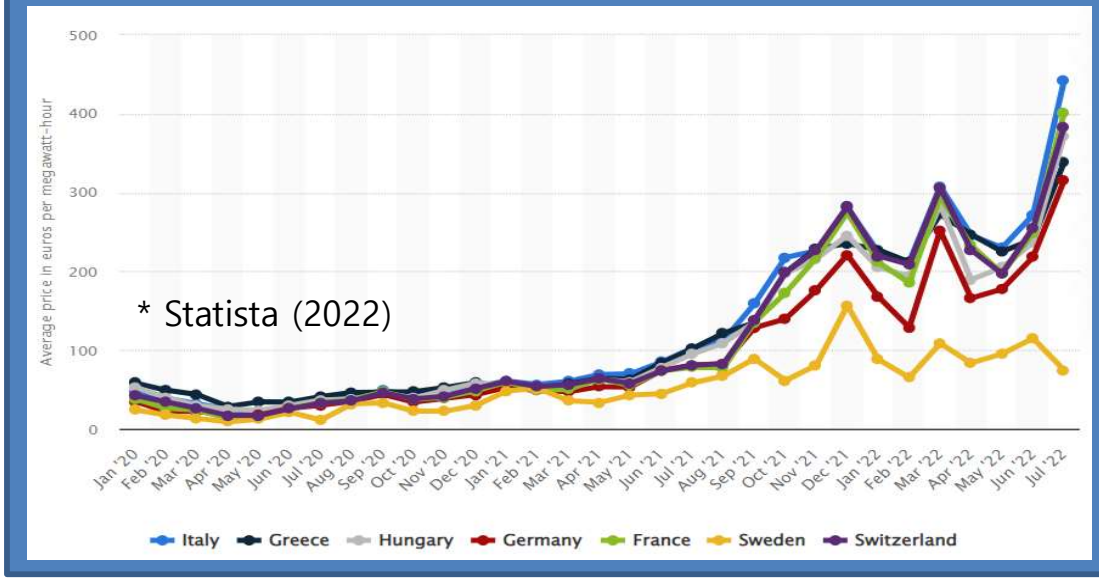
(2022)



- **2020/2021 Global Energy Market** (2020/2021 저렴하고 안정적인 에너지 공급으로 안보/경제/환경 거리가 멀지 않았음)
- **2022 Global Energy Market** (러-우 전쟁 발발로 인한 유럽발 천연가스 파동은 세계 경제 위기로 전개되고 있고, 경제 문제를 극복하기 위하여 석탄 재가동 등 환경이 오히려 악화되고 있음)

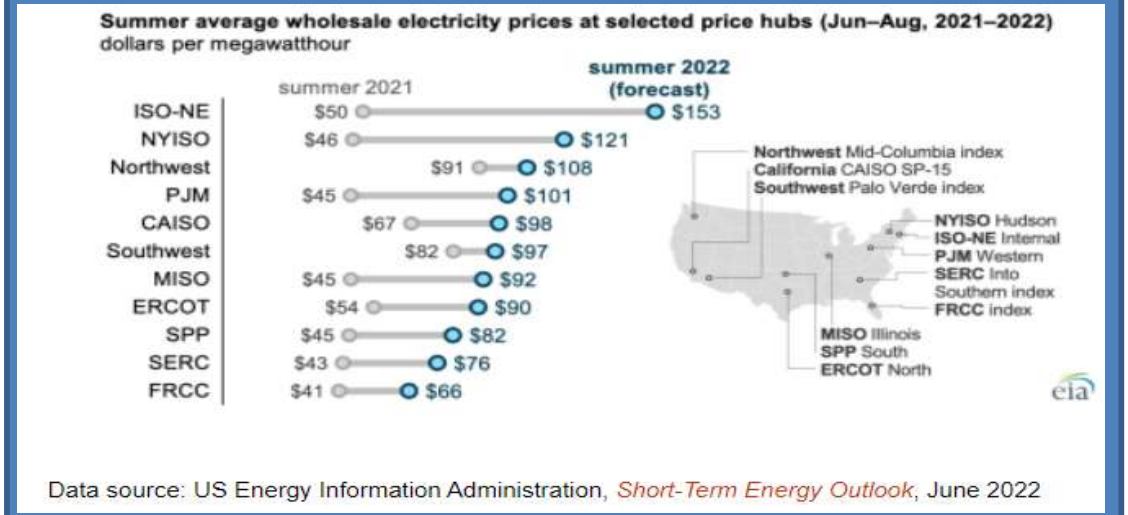
Global Power Market Crisis (EU/French/Germany/USA)

EU Day-ahead Market Prices (400€/MWh)

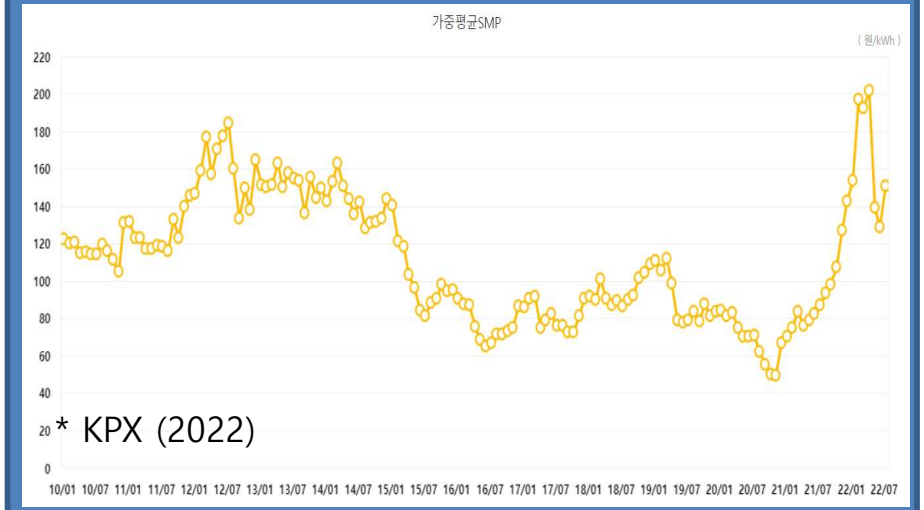


French/Germany Year-ahead Prices (1000€/MWh)

USA Summer Wholesale Prices (2021/2022) 100$/MWh



South Korea Day-ahead Prices (250₩/kWh)



Global Energy Crisis Examples (에너지위기 사례)

Renewables

European Power Jumps as Low Wind Is Exacerbating Energy Crisis

Wind turbines in Brandenburg, Germany. *Photographer: Krisztian Bocsi/Bloomberg*

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Market: This Ti

Markets
UK Market Sell
Piling Pressure

Markets
Wall Street Ban
Scenarios Over

Markets
Stocks, Comm

* Bloomberg (2022)

Nuclear

Explosion at Fukushima Daiichi Nuclear Power Plant March 2011

* Asia Pacific Journal (2013)

France's EDF under pressure to end all outages of nuclear reactors

State-controlled utility group has committed to restarting its 32 plants this winter, says energy minister

More than half of France's 56 nuclear reactors are offline for maintenance to address corrosion problems © Jean-Philippe Ksiazek/AFP via Getty Images

* The FT (2022)

Coal

Quixplained: Coal shortage and India's looming power crisis

Why is there a coal shortage? Which states are worst hit? What happens now? Take a look.

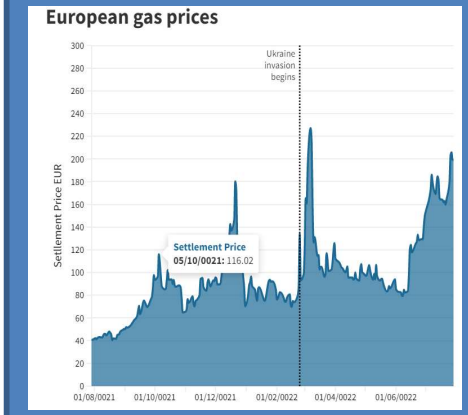
* The IndianExpress (2022)

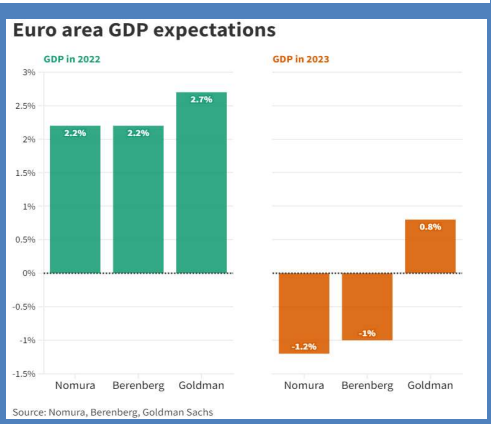
Column: China's widening electricity crisis caused by coal shortage

* Reutuer (2021)

Natural Gas

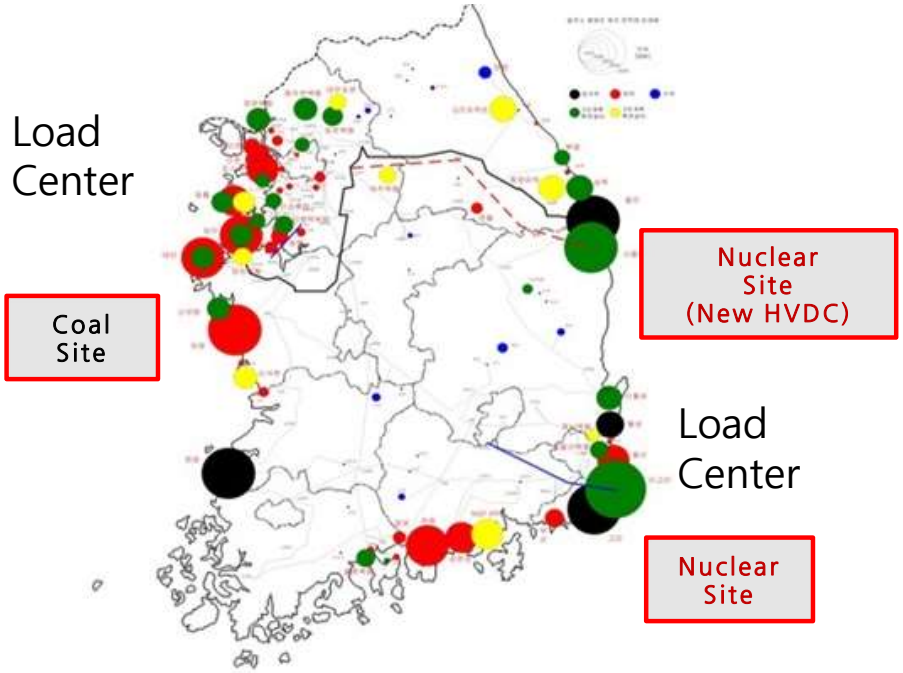
3 charts show Europe's unprecedented natural gas crisis





Power System Characteristics of South Korea

- **Centralized Bulk Power System (Generation, Transmission, Demand) – 대규모 생산-수송-소비**
- **Isolated Power System (고립 전력망)**



Energy Security Index Ranking of South Korea

- **WEC Energy Trilemma Index (2021)**

Energy Trilemma Index Full Report

The **World Energy Council**'s Energy Trilemma Index tool, produced in partnership with **Oliver Wyman**, ranks countries on their ability to provide sustainable energy through 3 dimensions: Energy security, Energy equity (accessibility and affordability), Environmental sustainability. The ranking measures overall performance in achieving a sustainable mix of policies and the balance grade highlights how well a country manages the trade-offs of the Trilemma with "A" being the best. Use this interactive Index to assess the sustainability of

2021 Country rankings

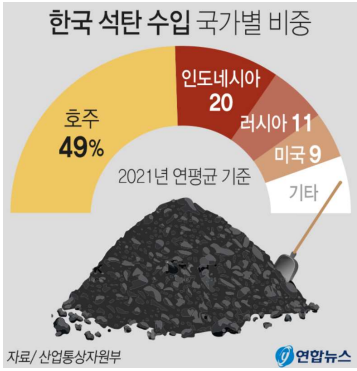
Index rank	Country name	Balance grade	Trilemma score	Energy security rank	Energy equity rank	Enviromental sustainability rank
1	Sweden	AAA	84.2	5	19	2
2	Switzerland	AAA	83.8	24	6	1
3	Denmark	AAA	83	11	10	7
4	Finland	AAA	81.7	2	21	19
4	United Kingdom	AAA	81.7	19	9	10
5	Austria	AAA	81	16	10	12
5	France	AAA	81.1	17	16	8
6	Canada	AAB	80.6	1	12	37
7	Germany	AAA	80.4	10	15	22
32	Korea (Rep.)	BBC	70.1	35	30	63

* WEC (2022)

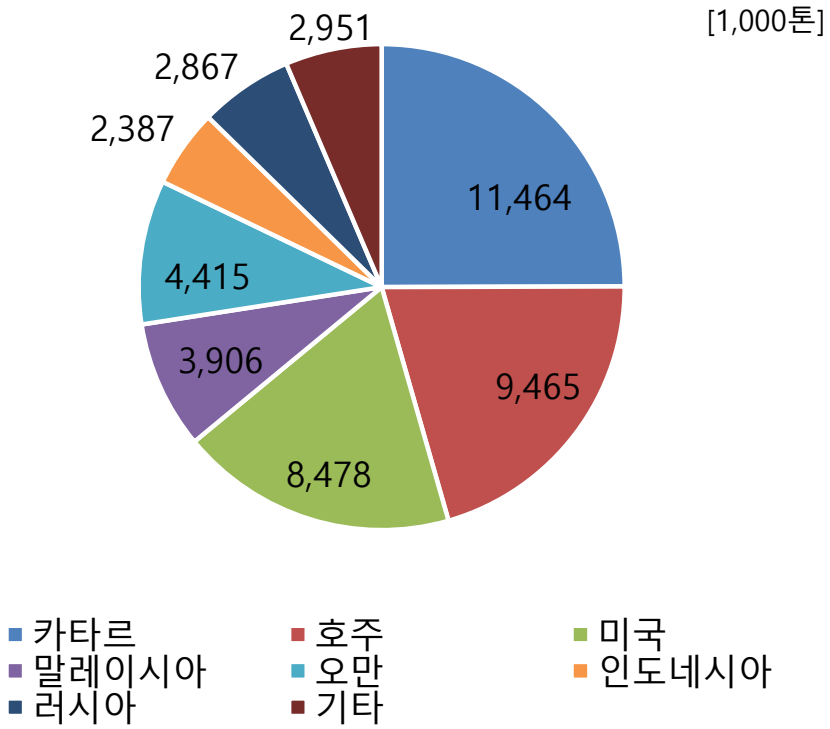
- **High Reliance of Fuel Import (연료 해외의존도 93%)**

Present Fuel Import Diversity in South Korea

- **Fuel Stocks**
  - Fuel Stocks for Power Supply : Nuclear (2 yrs), Coals (4 months), LNG (90% of Storages in Nov.)
  - Stable Electricity Supply
- **Diversity of LNG Import**
  - Long-term Contract (80%)
  - Qatar (25%), Australia (21%), USA (18%), Oman (10%), Russia (6%), Malaysia (5%), etc.
- **Diversity of Coal Import**
  - Australia (49%)
  - Indonesia (20%)
  - Russia (11%)
  - USA (9%), etc

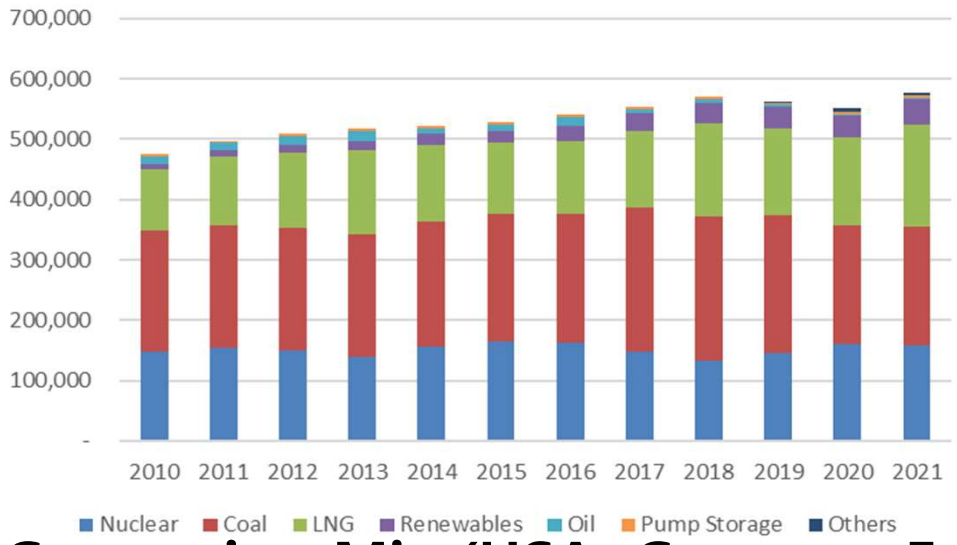


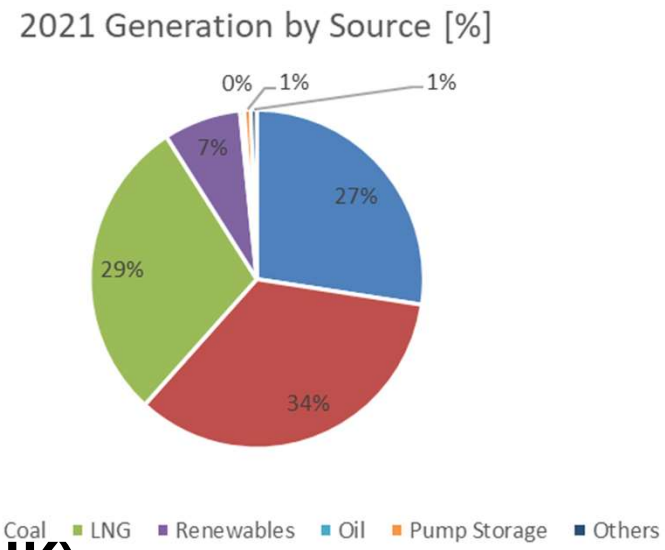
2021년 국가별 천연가스 수입비중



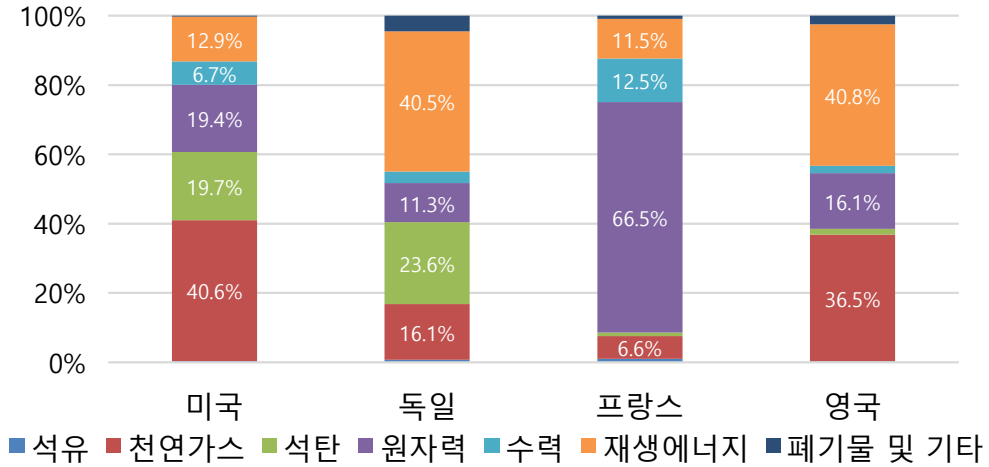
Generation Mix (South Korea, USA, EU)

- **Generation Mix Comparison in South Korea (2016, 2020)**
  - Coal (40% → 34%) > Nuclear (30% → 27%) > LNG (22% → 29%) > Renewables (4% → 7%)





- **Generation Mix (USA, Germany France, UK)**



Fuel Diversity & Generation Mix Security Index (사례)

- **Cohen G, Joutz F, Loungani P. "Measuring energy security : Trends in the diversification of oil and natural gas supplies," Energy Policy 2011.**
- **Grubb M, Butler L, Twomey P. "Diversity and security in UK electricity generation : The influence of low-carbon objectives," Energy Policy 2006.**
- **Index Examples**
  - Shannon-Wiener Index

    < 1: Unstable (연료 다양성의 부족으로 불안정한 공급)

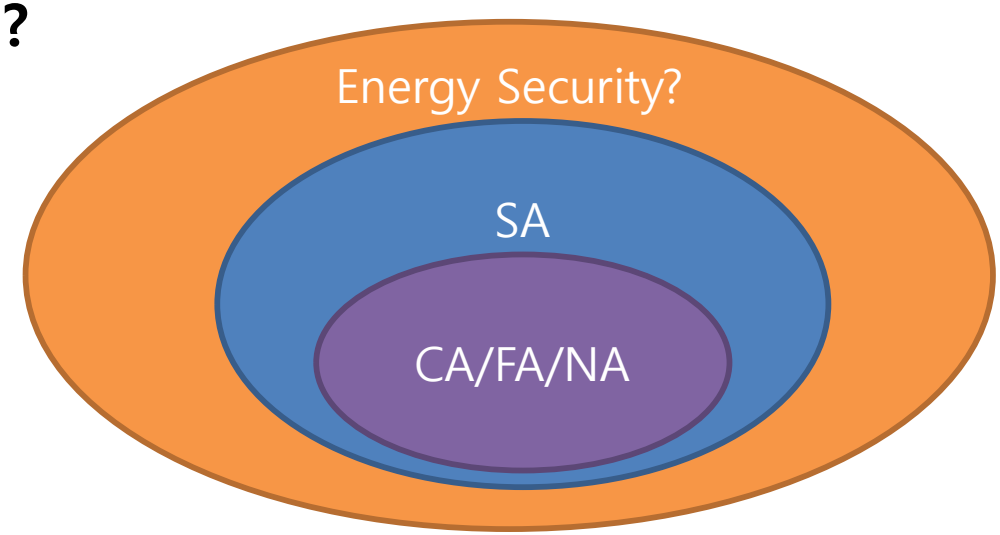
    > 2: Diverse and Stable (다양한 연료에 의존하는 안정적 공급)
  - Herfindahl-Hirschman Index (US Department of Justice)

    < 0.15: Competitive Market (경쟁적 시장)

    > 0.25: Concentrated Market (과다 집중된 시장)
- **Need to Develop Suitable Fuel Mix Diversity and Index for Korean Power System**

Evolution of National Power Plan in Security

- **Security Considerations in 9th & 10th National Power Plan**
  - Capacity Adequacy (설비 예비력) : LOLE 0.3 days/year, Reserve Margin : 22% ➔ 9th Plan
  - Flexibility Adequacy (유연 응동력) : CCGT, Pump Hydro, BESS ➔ 9th Plan
  - Network Adequacy (송전망 융통) : Resource Adequacy Considering Network Congestion
  - Stability Adequacy (주파수, 전압, 저장성) : System Inertia, Strength Index, Energy Storage ➔ 10th Plan
- **What is the Next Consideration for Energy Security in Power System?**



Government Plan & Energy Security (에너지안보 관련 정부계획)

● Government Plan & Energy Security

National Energy Plan (에너지기본계획) 에너지 안보 지수	National Power Plan (전력수급기본계획) 전력 안보 지수	National SG Plan (지능형전력망기본계획) 사이버 안보 지수
• Energy Security (에너지안보 정의와 기준) • Fuel Supply Chain (연료공급망 안정성) • Energy Security in Power Sector (전력부문 에너지안보 정의)	• (Regional) Resource Adequacy (LOLE/RM, Transmission) • Capacity, Fuel, Generation, Renewables, ESS Mix (전원/신재생/저장 구성) • Power System Security (전력계통 안전성) • Resilience (회복탄력성) ➔ 전력 안보의 기준 개발 ➔ 전력 안보를 고려한 전원 구성과 대응 방안 개발 (회복탄력성 정의와 대응 방안)	• Cyber Security (사이버 보안)

기존 정부 계획에 에너지 안보(전력 안보)와 관련한 추가 고려 사항, 반영 방안 등을 개발하고 정립할 필요가 있음 (특히, 전력안보지수와 대응 방안)

Energy Security Expansion and Power System

- **Traditional Power System Security ((N-1) Contingency)**

- **Flexibility Enhancement due to Renewables**

- **Fuel Diversity and Fuel Supply Stability**
  - Fuel and Generation Mix Diversity Definition
  - Fuel Supply Contingency Definition (ex. Largest Fuel Source Contingency: EU Case) & Back Up Cost by Other Fuels and Technologies)

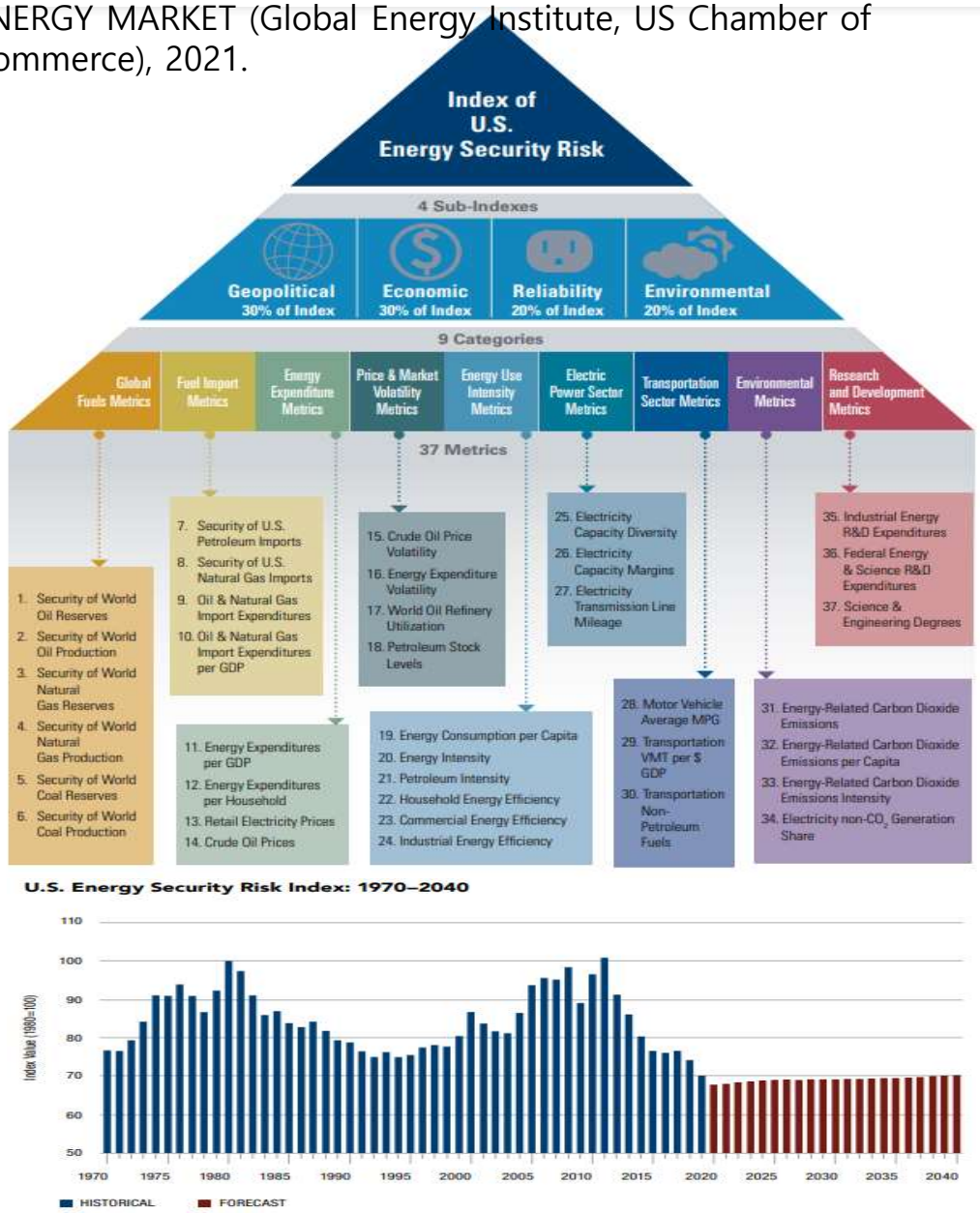
- **Additional Capacity Requirements by Energy Security Considerations**

Energy Security and Electricity Market

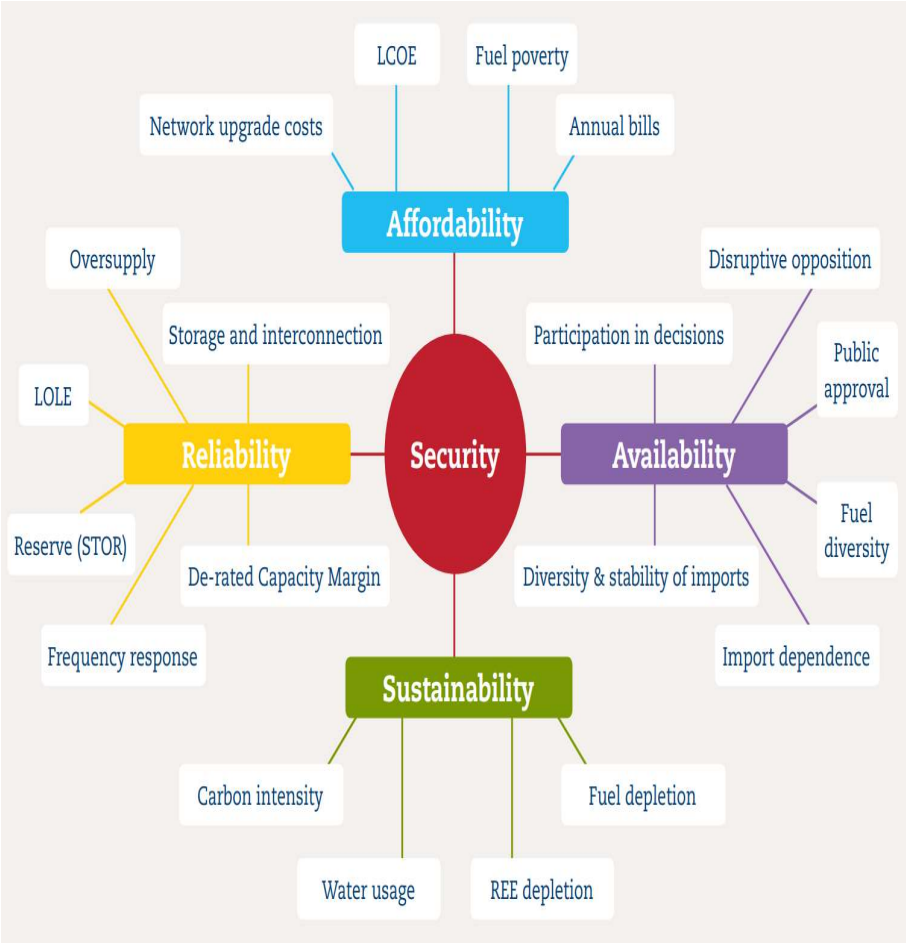
- **Electricity Market Evolution to Consider Energy Security in Capacity and Energy Market**
  - Capacity Mechanism
    - ✓ Traditional Capacity Market, Capacity Payment (기존 시장 통합)
    - ✓ Cold Reserve Market, Cold Reserve Contract (분리 시장 창설)
  - Energy Market
    - ✓ Marginal Costing Price Still Valid? (발전설비 진입/퇴출이 매우 제한적인 현재 한계비용 기반 도매시장 가격 체계가 유효한가?)
    - ✓ Uniform SMP Still Valid (송전설비 건설이 매우 제한적인 현재 지역 비차등 도매시장 가격 체계가 유효한가?)
    - ✓ Energy Market Split for Fuel Diversity? (에너지 안보 확보를 위하여 필요한 연료의 다양성을 유지하고 횡재이윤을 방지하기 위하여 에너지 시장은 원별로 분리되어야 하는가?)
- **Cost Increase by Energy Security Consideration (에너지 안보의 고려로 상승하는 비용은 어느 수준이며, 소비자의 수용은 가능한가?)**

Energy Security Evaluation Examples of USA and UK

INDEX OF U.S. ENERGY SECURITY RISK
ASSESSING AMERICA'S VULNERABILITIES IN A GLOBAL ENERGY MARKET (Global Energy Institute, US Chamber of Commerce), 2021.



UKERC(2018), The Security of UK Energy Futures



Suggestions and Discussions

- **Evaluation of Economic Impacts to Energy Industry and National Economy** (금번 에너지 위기에 따른 전력 산업의 비용 상승과 경제 충격을 면밀하게 정량화해야 함)
  - Energy Crisis Premium and EU Economic Impacts (에너지 위기 프리미엄의 출발점이 됨. 해외 특히 EU의 경제 충격 결과 분석자료 참조 필요)
- **Post Crisis Era Energy and Power Policy** (에너지 위기 이후의 에너지 정책과 전력 정책 방향에 대한 연구 시작)
  - Generation and Technology Mix in Post Energy Crisis (원자력 및 신재생 확대를 넘어 발전 및 기술 믹스를 체계적으로 정립)
- **National Energy and Power Risk Definition** (장기적으로 국가적 차원의 에너지와 전력 위험 정의, 기준과 지수 개발. 향후 에너지 기본계획, 전력수급 기본계획, 지능형전력망 기본계획 등에 체계적으로 반영 절차 마련)
  - Next National Power Plan Consideration (11차 전력수급계획에 반영할 내용은 단기적으로 준비)
- **Electricity Market Evolution (전력시장의 개선 방향 연구)**
  - Capacity Mechanism, Energy Market Mechanism, etc.

Thank you