Topic: Smart Grid Optimization with AI

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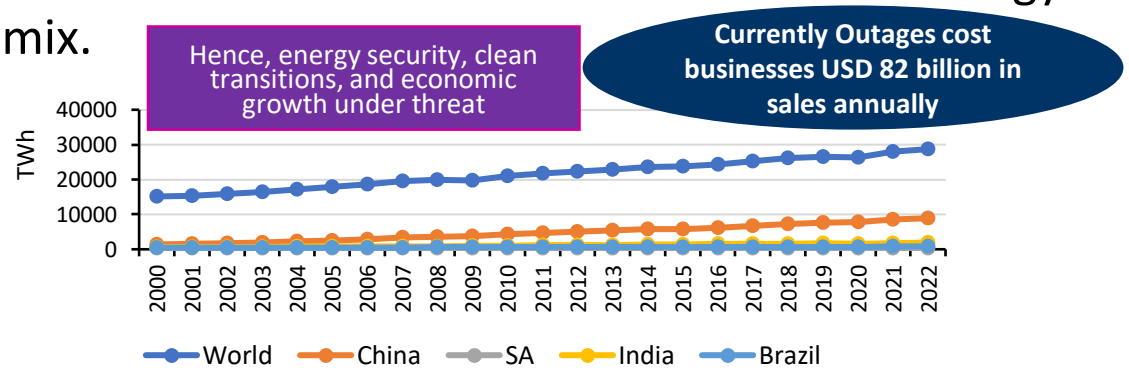
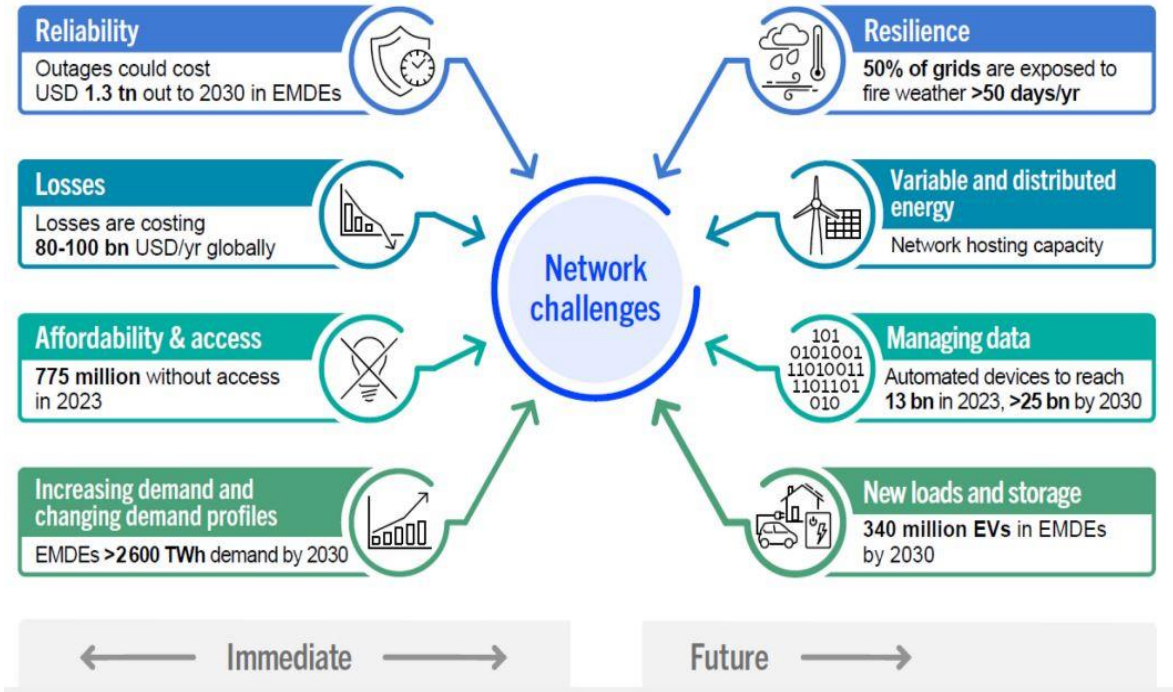
Study Motivation

- The continuous rise in urbanization, living standards, and technological advancement has increased the demand for energy(IEA, 2023a).
- Electricity share of global final energy consumption has risen from 16% in 2000 to 21% in 2021, making it the second-largest energy source after oil(IEA, 2023a, OurWorldInData.org, 2024).
- At the same time, about 10% of the global population still lacks access to electricity and a 20% faster increase in global electricity use over the next decade is required to meet various countries' national energy and climate goals (Net zero emissions by 2050) (IEA, 2023a).

However, the aging power grid infrastructure and traditional controlled system of many economies struggles to meet current energy demands with scarce resources and a balanced available energy mix.

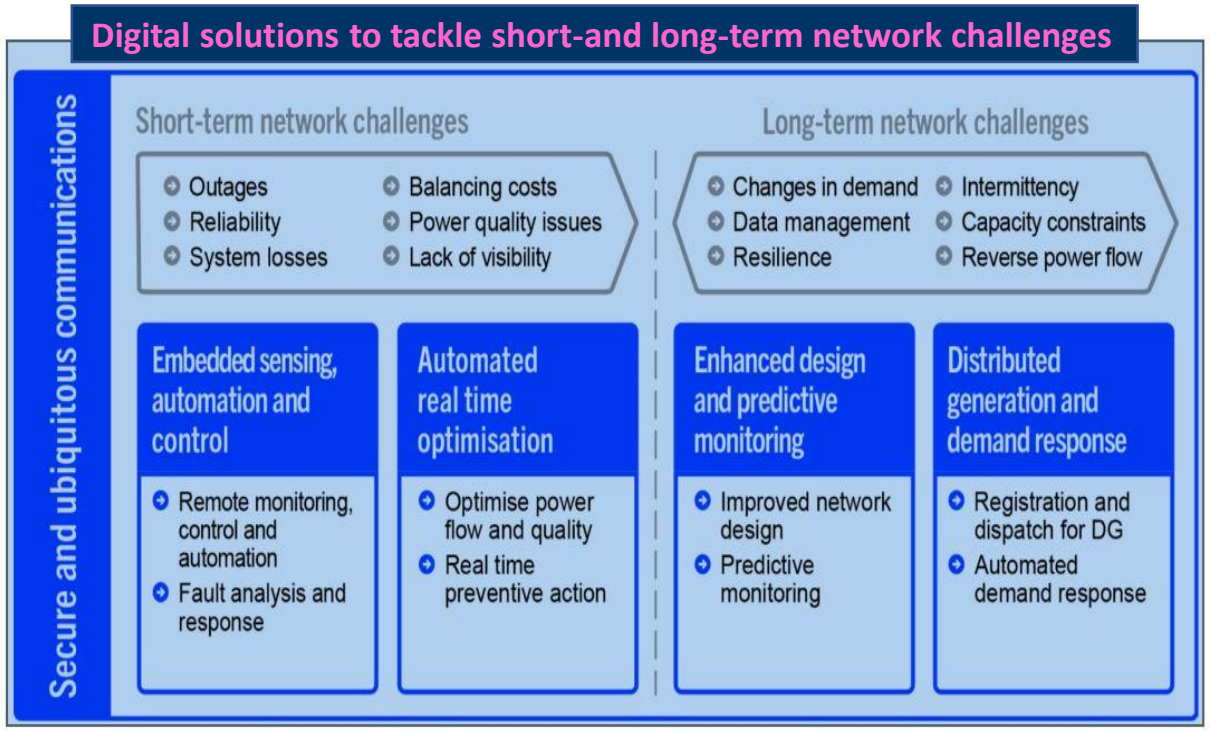


Electricity consumption- World and selected EMDEs, (Ourworldindata, 2024)



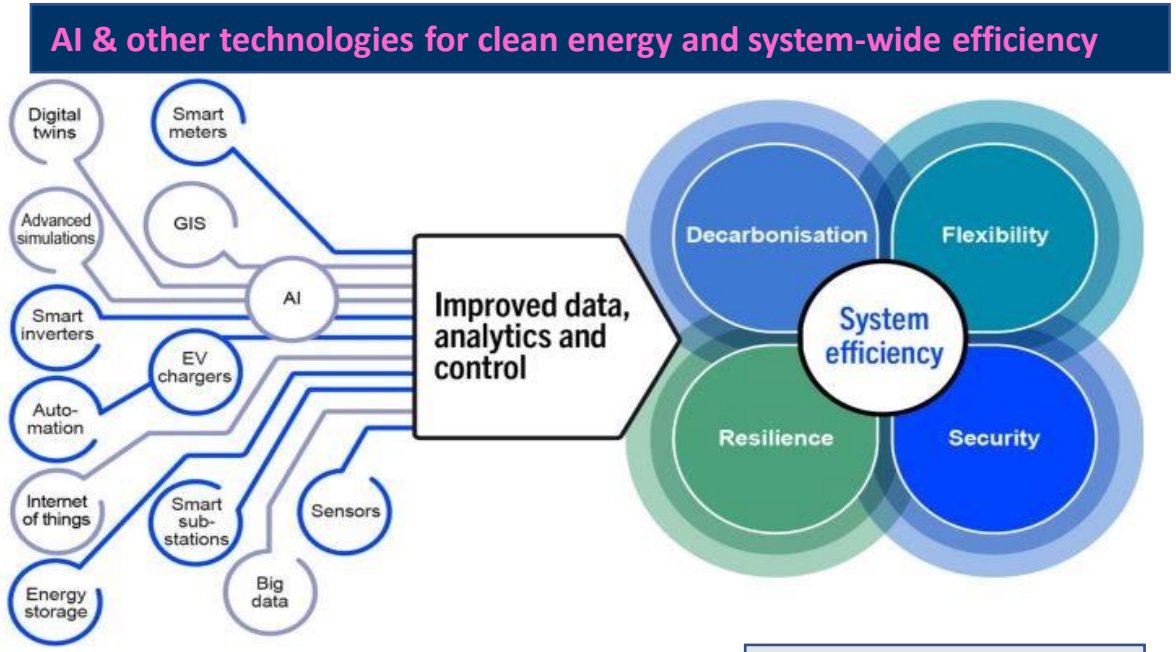
Study Motivation

- Smart grid technology offers a solution for improving the generation, transmission, and distribution of electric power.
- Smart grids leverage advanced sensors, communication, and control technologies to enhance the generation, distribution, and consumption of electricity.



Source: World Economic Forum, Accelerating Smart Grid Investments and(IEA, 2023c)

- Artificial Intelligence serves as the intelligent agent driving smart grids, assessing the environment and taking actions to optimize specific objectives.



Source: (IEA, 2023c)

Study Objectives

- To explore an overview of AI's impact on Smart Grid optimization
- To utilize China as a case study to assess the outcome of digitalizing power grids

While artificial intelligence has become increasingly important in addressing energy challenges, research on how AI optimizes energy activities is still in its nascent stages (Zheng et al., 2024).

Main Contributions

- Theoretical contributions involve enhancing understanding of AI's ability to optimize smart grid operations, improve energy efficiency, and enable the integration of renewable energy sources.
- The article offers a comprehensive evaluation of the practical implementation of AI in smart grid operations, taking China as a Case

Source: (IEA, 2023c)

Smart grid concept and definition

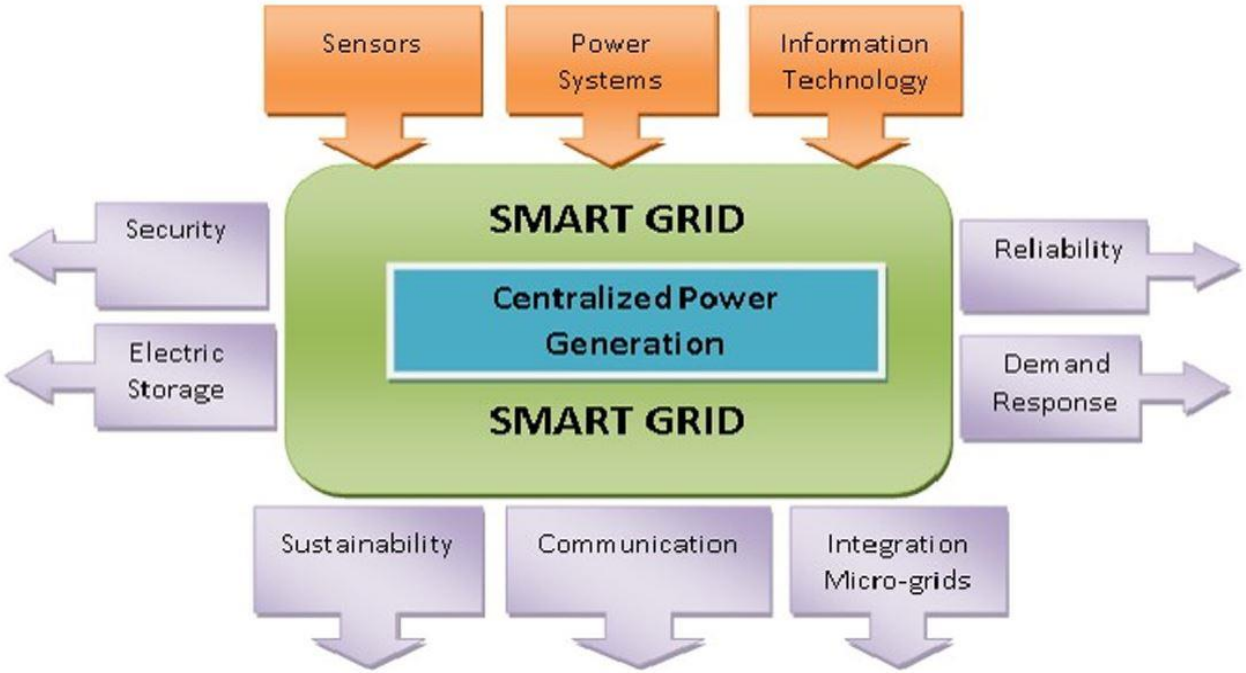
- A grid is a network of electrical conductors that distributes power to consumers.
- Smart grids are conventional grids enhanced with automated features for increased reliability and sustainability

Smart and Conventional Grid

Smart Grid	Conventional Grid
Two-way real-time communication	One-way communication
Distributed system of power generation	Centralized for power generation
Interconnected Network	Radial Network
A large number of sensors are involved	A small quantity of basic sensors are used
Digital Operation	Mechanical Operation
Automatic Control and Monitor	Manual Control and Monitor
Wide range of control	Limited control
Security and privacy concerns	No security or privacy concern

Source: (Majeed et al., 2021)

Smart grid architecture (Majeed et al., 2021)



Drivers of Grid development

Economic growth and electrification, Distributed energy resources, Electric vehicles effects, Rising Climate Change Impact, Improving electricity access is essentials etc,

Smart Grids Optimization and AI

AI optimizes smart grids through various mechanisms:

- ❑Renewable Energy Integration
- ❑Grid Management and Operation
- ❑Energy Storage Optimization
- ❑Demand Response
- ❑Asset Management
- ❑Cybersecurity

Sources;(IEA, 2023a, Ayub Khan et al., 2023)

Renewables Perspective

Decentralized energy resources (DERs) primarily utilize renewable energy sources and flexibility services from DERs can be integrated into grid planning to meet long-term needs more affordably. AI software can enable DERs to feed surplus electricity into the grid, aiding the integration of renewable energy sources (RES) into smart grids.

Perspective of Energy supply and demand

- In traditional grids, consumers lack awareness of their energy usage efficiency and lack incentives to change their consumption habits
- To balance energy supply and demand, Demand response is utilized-modifying electricity usage in response to price changes to enhance energy efficiency, which remain complex
- AI can predict energy consumption patterns accurately, helps utilities adjust supply in real-time, ensuring a balance between supply and demand

Future Global grid projections

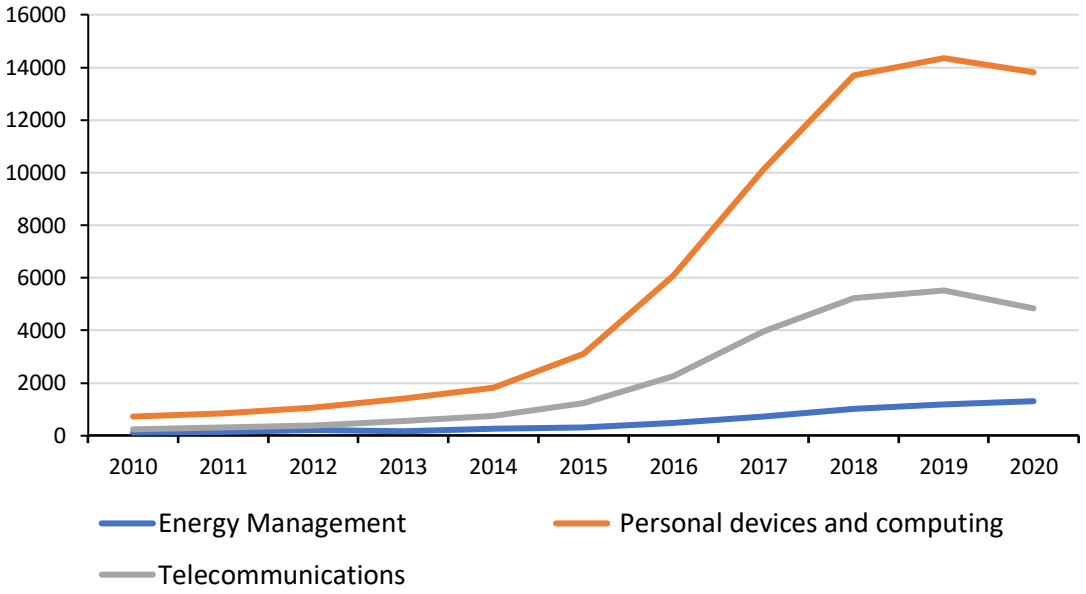
	Transmission			Distribution			Total	
	2021	2030	2050	2021	2030	2050	2021	2030
United States	0.5	0.6	1	11.1	11.5	15.2	11.6	12.1
European Union	0.5	0.6	0.9	10.3	11	14	10.8	11.7
Japan	0.04	0.04	0.05	1.3	1.3	1.7	1.4	1.4
Other advanced economies	0.5	0.6	1	6.9	8	13.7	7.4	8.5
Southeast Asia	0.2	0.3	0.8	4.7	6.3	11.9	4.9	6.6
India	0.5	0.7	1.7	11.3	14	25.6	11.8	14.7
Africa	0.3	0.4	1.1	3.9	5	14	4.2	5.3
China	1.6	2.4	3.7	7.8	12.3	27.6	9.4	14.8
Other EMDEs	1.2	1.5	2.5	14.4	16.8	30	15.6	18.3
World	5.3	7.2	12.7	71.7	86.1	153.7	77.1	93.4

Installed line length, transmission and distribution, by region in the Announced Pledges Scenario (million km)(Source; IEA, 2023a)

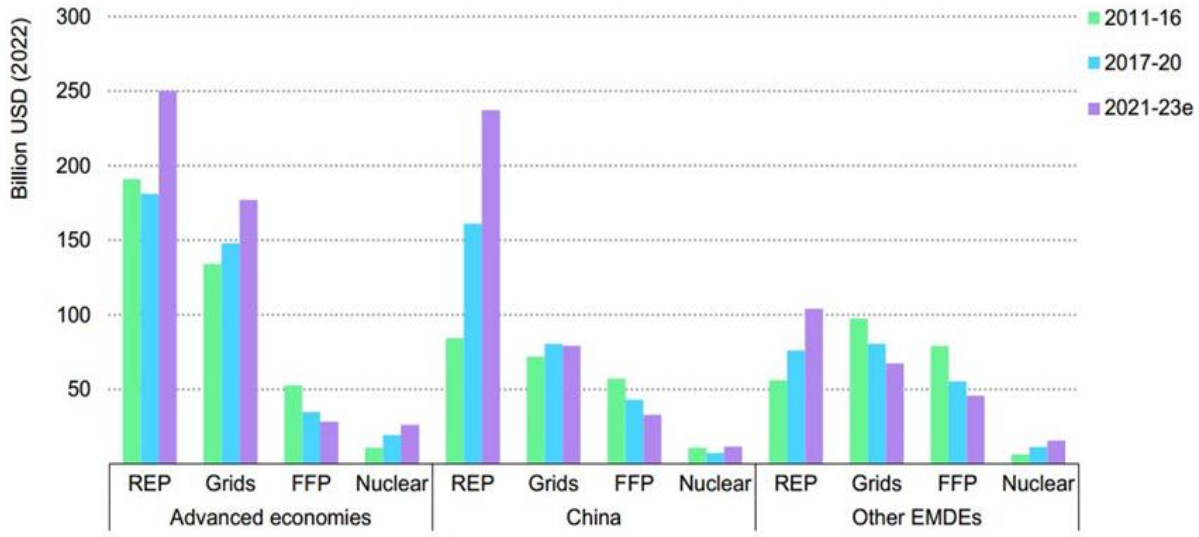
Grid development delay

- Can add 58 gigatons more of CO2 emissions
- Energy importing countries to spend over USD 500 billion more on fossil fuel imports from 2031 to 2050
- 10% lower of global solar PV by 2030 (IEA, 2023a)

Investment in smart grid



AI Patent applications granted in Energy Management (OurWorldInData.org, 2024)



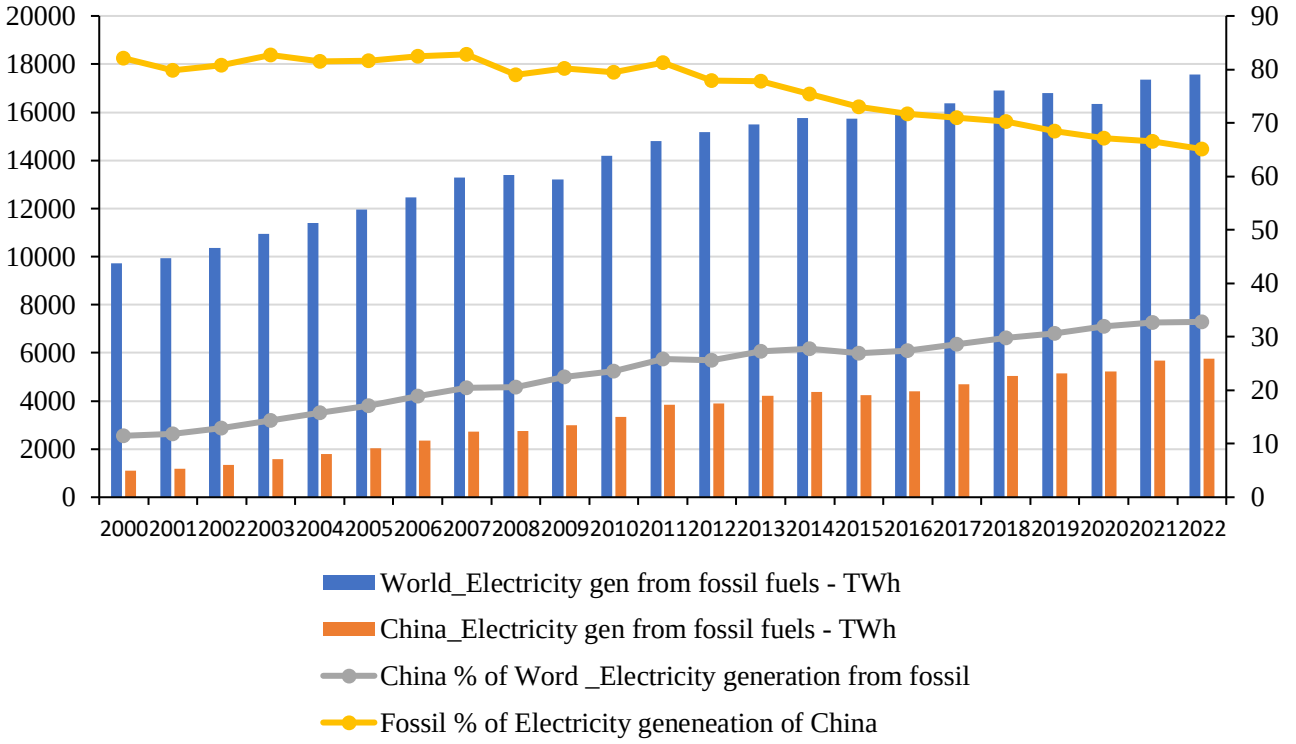
Average annual investment in the power sector by geography and category, 2011-2023 (estimate)((IEA, 2023c)

Lower number of patents granted in AI for energy management compared to other sectors

Investment have not keep pace, Cost is a major limitation in developing and implementing smart grids. Ratio of GDP to Smart Grid cost is as high as 27% in some economies (Young, 2017).

Case study-Smart Grid development in China

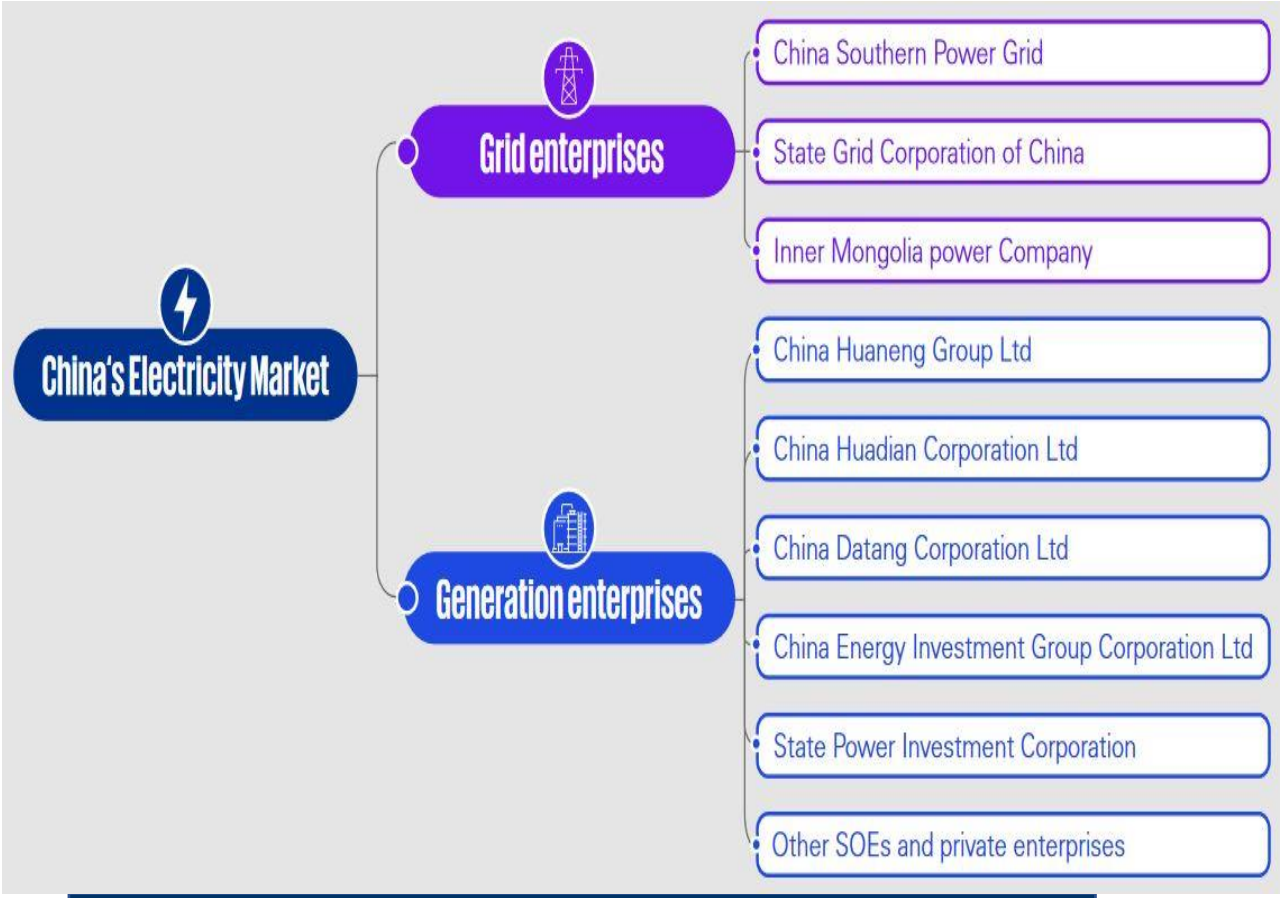
- China aims to reach peak emissions by 2030 and achieve carbon neutrality by 2060.
- To achieve these goals, the country has set policy objectives to reduce the consumption of fossil fuels and increase renewable usage
- In this regard, China has implemented smart grid technology extensively throughout the country
- Notable project is the database power system established by China Southern Power Grid (CSG)



Electricity generation from fossil fuels in the World and China

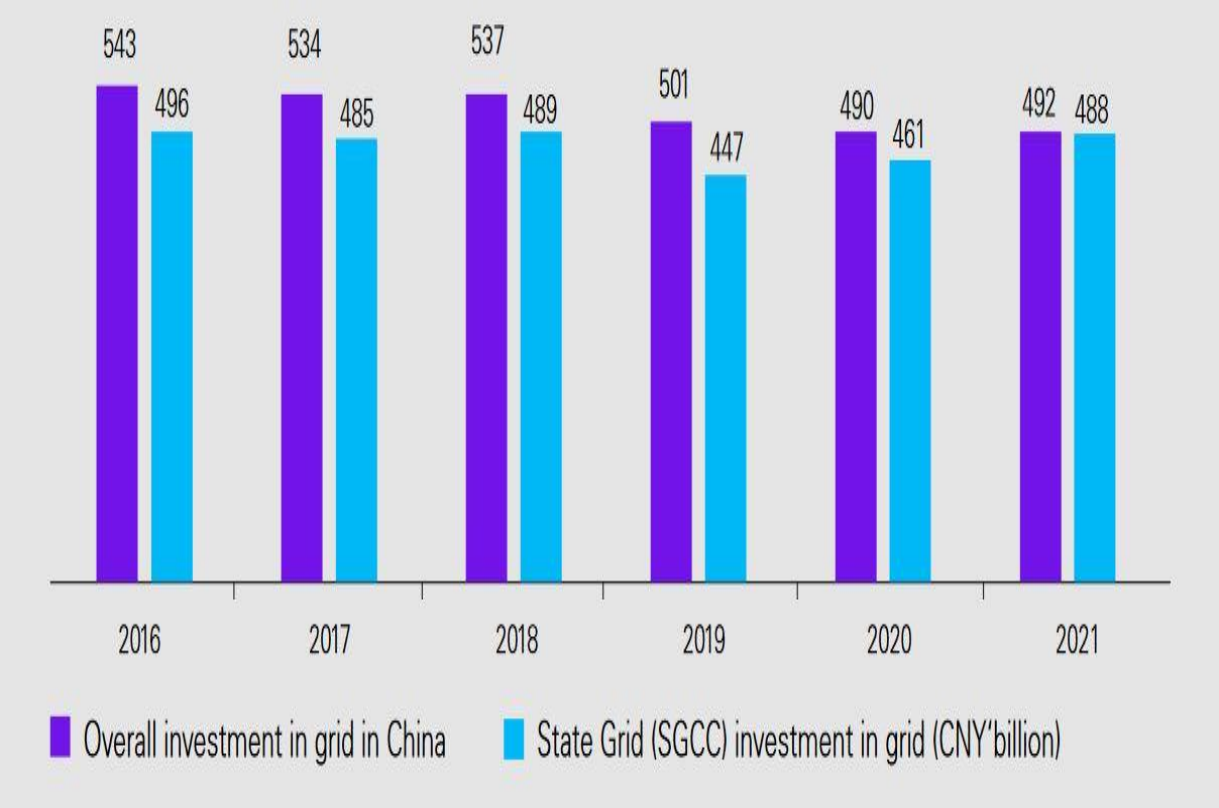
Policy on strong smart grid in China

- China's 12th 5-year plan highlights the importance of building a robust smart grid
- smart grid in China is primarily led by the State Grid Corporation of China (SGCC) and the China Southern Power Grid (CSG)
- Smart grid in China is planned in three phases(Phase I (2009-2010) , Phase II (2011-2015), Phase III (2016-2020).
- The smart grid systems aim to be strong, reliable, efficient, economical, clean, user-friendly, transparent, open, and environment-friendly(Deng, 2015)

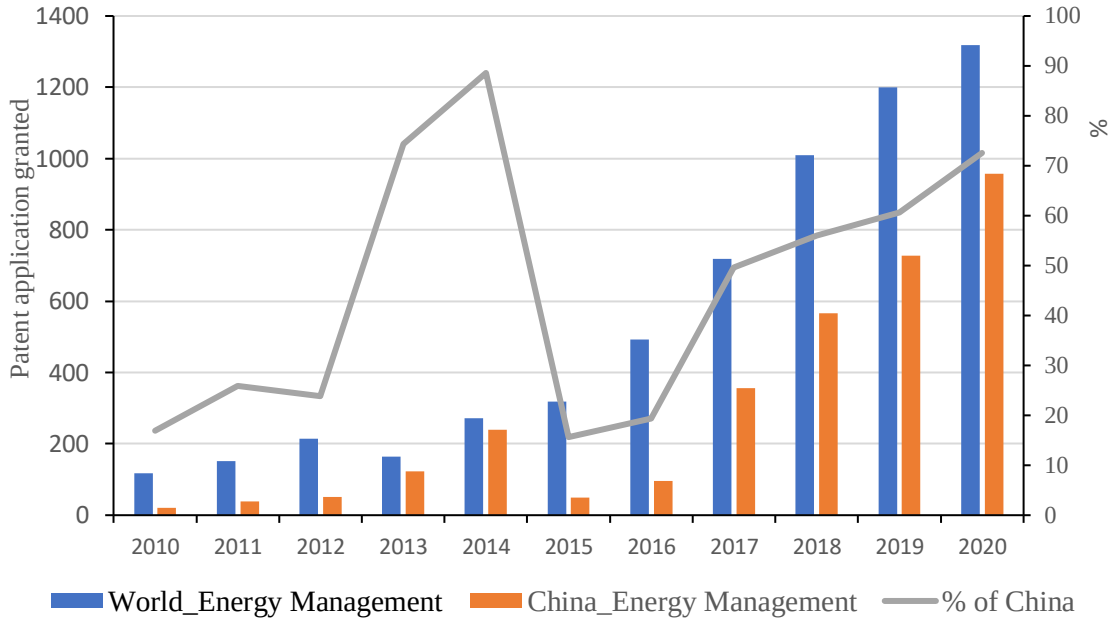


Electricity generation from fossil fuels in the World and China

Investment-China



China's investment in grid (Source: KPMG-China, 2023)



AI Patent applications granted in Energy Management (OurWorldInData.org, 2024)

Smart Grid benefits in China

- low-carbon benefits of smart grids in China are projected to reach 224.57 billion yuan(FuLiwen, ZhaoHuiru, 2012)
- Smart grids could conserve 4850 TWh of electricity, saving customers 2790 billion RMB
- Smart grid could increase renewable energy installation by 25–30 GW
- Smart grids reduce the operation costs –power sys can save 32 million tonnes of coal equivalent (Mtce) annually

Sources: (Yuan et al., 2014), (Deng, 2015),

Challenges-strong smart grid in China

- Government pricing that hinders efficient resource allocation, asymmetric information leading to higher integration costs, and a lack of transparency in cost-related information, absence of an efficient pricing mechanism , the monopolization of the integrated network

Conclusion

- Smart grids have offered customers added value by saving them money, reducing the operation costs of the power system, avoiding the need for significant investment in the power sector, and contributing to environmental benefits.
- AI has the potential to revolutionize energy management in smart grids, improving their responsiveness, efficiency, and sustainability.
- AI algorithms play a crucial role in optimizing the integration of renewable energy sources (RES) into the grid and are effective in balancing energy supply and demand.
- Patent applications in AI for energy management are behind other sectors and cost of investing in smart grid remain high in developing economies
- Future Global grid projections show that Insufficient grid infrastructure development could hinder clean energy transitions in several ways
- China has made significant progress in developing smart grids and AI, developing economies can benefit from the lessons learned from China's approach to smart grid optimization with AI.

Recommendation

- Government should prioritize and boost investments in grid infrastructure upgrades and AI technology implementation
- Promote patenting and innovation in AI for smart grid optimization
- Develop financial mechanisms and policies to reduce the cost of investing in smart grid technologies
- Allocate funding for research and development of AI applications in smart grids
- At Utility level, Implement effective data management practices to leverage AI capabilities for grid optimization

The End