Global Energy Perspectives: the Role of Nuclear Energy

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International Institute for Applied Systems Analysis (IIASA)

- International, independent, interdisciplinary science
- Research & big-data on major global problems
- Solution & policy oriented, integrated systems analysis

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www.IIASA.ac.at

2016 #2
Global CO2 Emissions

- IPCC Category I
- RCP 2.6
- GEA (SE4ALL)

Global CO2 emissions (GtCO2)

- Peak by 2020
- reductions of 35-75% by 2050
- almost zero or negative in the long term

Source: GEA, 2012; IPCC, 2014
Global CO2 Emissions

Source: Rogelj et. al, 2015
The Key Energy Challenges

Energy Access

Climate Change

Energy Security

Air Pollution
Health Impacts

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Multiple Benefits of Integrated Policies

Total Global Policy Costs (2010-2030)

- Only Energy Security
- Only Air Pollution and Health
- Only Climate Change
- All Three Objectives

Source: McCollum et. al, 2012; IPCC, 2014
The World in 2050 (TWI2050)

- How to achieve global development within a safe and just operating space
- “Safe space” of interaction among SDGs: sustainability narratives and integrated models
- Sustainable Development Pathway based on existing literature e.g. SSP1, GEA, DDPP
- Multiple-benefits and tradeoffs of transformation toward the “safe space” and how to achieve sustainable futures
Sustainability Transformation

“Doing More with Less” within Planetary Boundaries

→ Growing number of actors of change:
  • green businesses
  • cities
  • civil society
  • science
  • IGOs (UN etc.)

→ Increasing problem perception

→ Values and norms

→ Policy regimes

Vision: Sustainable Future

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Source: WBGU, 2011

2016 #11
Asia-Pacific Primary Energy
A Transformational Pathway (I)

Energy savings (efficiency, conservation, and behavior)
~40% improvement by 2030
~30% renewables by 2030

Savings
Other renewables
Nuclear
Gas
Oil
Coal
Biomass

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www.GlobalEnergyAssessment.org
Somewhat larger nuclear role than worldwide
Asia-Pacific Primary Energy
A Transformational Pathway (III)

Even larger nuclear role

Even larger nuclear role

Savings
Other renewables
Nuclear
Gas
Oil
Coal
Biomass

Renewables
Nuclear
Gas
Oil
Coal
Biomass

www.GlobalEnergyAssessment.org
Global Water Withdrawals
A Pathway with Full Portfolio

Source: Fricko et al, 2014
Nuclear in GEA pathway

- IPCC range
- IPCC median
- GEA-Supply
- GEA-Mix
- GEA-Efficiency
- NEA/IEA high (2008)
- IEA/NEA Blue (2010)
- IEA/NEA Blue H (2010)
- NEA/IEA low (2008)
- IAEA (2010)

GWe

1990 2000 2010 2020 2030 2040 2050
# Four stages of nuclear development

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<td>2011-</td>
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Source: Rogner, 2016
Nuclear power before Fukushima

- Dramatic improvement in operating performance between 1990 and 2005
- Higher capacity factors
- Power up-rates
- Licence extensions
- Market in “used” reactors
- “Money printing” machines
- Previous “hopes/fears” that NPPs would be victims of electricity liberalization have not materialized!
- Market liberalization proved difficult for new NPPs
Global electricity and the nuclear share share

Source: Rogner, 2016
Global nuclear power generating capacity (as 31 December 2015)

Source: Adapted from IAEA-PRIS
Regional nuclear generating capacities

- **North America**
- **Western Europe**
- **Eastern Europe & CIS**
- **Asia**

As per 31 December 2015
Source: Adapted from IAEA - PRIS

Source: Rogner, 2016, adopted from IEA-PRIS

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2016  #27
Load factor: Global fleet of nuclear reactors

1990 – 2000: Performance improvements correspond to a virtual construction of 34 NPPs of 1,000 MW each

Without 40 GW laid off in Japan

Source: Rogner, 2016
Construction starts 1950 to 2015

As per 31 December 2015
Source: Adapted from IAEA - PRIS

No. of construction starts

Total installed capacity, GW

Source: Rogner, 2016

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Age structure of nuclear power plants

Note: Age of reactor is determined by its first grid connection. Reactors connected in current year are assigned with the age 0 years.

Source: Rogner, 2016
Status global nuclear power

Units in Operation: 442
384.2 GWe

Units under construction: 66
65.0 GWe

Source: Rogner, 2016
Naval Reactors

- U.S. ~130 reactors used as primary propulsion and electric power generation in submarines, aircraft carriers, a cruiser and a destroyer.

- Has safely accumulated over 5400 reactor-years of operation

- Uses more enriched fuel than commercial reactors

- Russia ~100; France ~20; UK ~20; and China ~ 6 reactors used as primary propulsion.

- Source of trained personnel in reactor operation.
IAEA – Low global nuclear scenarios

Capacity in 2030: 385 GW versus 546 GW in 2010 projection

Nuclear generation share in 2030: 8.6% versus 13.8% in 2010 projection

GW(e)

Year of projection:
- 2005
- 2006
- 2007
- 2008
- 2009
- 2010
- 2011
- 2012
- 2013
- 2014
- 2015

Source: Rogner, 2016

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Source: Rogner, 2016

IAEA – High global nuclear scenarios

Capacity in 2030: 632 GW versus 803 GW in 2010 projection

Nuclear generation share in 2030: 11.3% versus 16.6% in 2010 projection

Year of projection:
- 2005
- 2006
- 2007
- 2008
- 2009
- 2010
- 2011
- 2012
- 2013
- 2014
- 2015

Source: Rogner, 2016
Drivers of the renaissance in interest

- Continued growth in global energy demand
- Energy security
- Fossil fuel price volatility
- Need for low-cost base load electricity
- Environment protection and climate change
- Nuclear power: Improved operations, good economics and safety record starting in the early 1990s

In spite of economic crisis:
- Prospects better than ever since the mid 1990s

Source: Rogner, 2016
R&D is needed for innovative solutions

- Safety, economics, storage, non-proliferation
- Advance modular, standard-design plants
- Easy and cheap $^{235}$U reserves limited
- Once-through fuel cycle wastes 95% of energy
- Closed fuel cycle renders nuclear energy practically unlimited (for 10,000 years) with a considerable reduction of high-level radioactive wastes
- Radically new designs including nuclear fusion
Fabrication of nuclear fuel

URANIUM

DEPLETED

STORAGE

ENRICHMENT

CONVERSION

CONCENTRATION

EXTRACTION OF URANIUM

UO₂

ENRICHED

MOX

DEPLETED

NEW FUEL

MOX

SPENT FUEL UO₂

PLUTONIUM

REPROCESSED

REPROCESSING PLANT

FINAL STORAGE

FINAL WASTES

NATURAL URANIUM

REACTOR

NEW FUEL UO₂
ITER Design is Final

May 2001

Size: 3 times JET,
Plasma current: 15 MA
Plasma volume 837 m³
Plasma surface 678 m²
B = 5.3 T @ 6.2m
500 MW, 500 s, Q > 10
R = 6.2 m
Final scientific demonstration
French Nuclear Reactors

- 58 reactors with 63 GWnet (66 GWgross)
- ~50 GW within 10 years (1980-1990)
- High degree of standardization:
  - 925 MW PWR Westinghouse license
  - 1350 MW PWR upscaled with maximized French equipment
  - 1550 MW PWR N4, precursor to 1650 EPR (lack of standardization)

Source: Grubler, 2009
French Nuclear Plants: Total Costs
1970-2000 = 1.5 $10^{12}$ FF(1998) = ~$250 billion

Source: Grubler, 2009
Anatomy of a Scale-up “Success”

- 80% nuclear electricity
- Load management and modulation
- No major accidents
- Little public opposition
- Stable regulatory environment (technocratic “grandes ecoles” elite)
- Continued development (scale-up) of technology
- Full-scale industry developed (incl. fuel cycle)

Source: Grubler, 2009
Construction Time
(construction start to grid connection)

Data Source: IAEA PRIS, 2009
Beyond French Power Plants

- Similar pattern in the U.S. (albeit moderated)
- “Negative” learning: Cost escalation due to regulatory environment rather than intrinsic to technology
- Diseconomies of scale with increasing number and fewer plants being built
- Advantages of “granularity” (small unit-scale) and standard design

Source: Grubler, 2009
Nuclear Power Plants US & France: “Negative” Learning by Doing

Source: Grubler, 2009
Drastic cost escalation even for most successful OECD nuclear scale-up program

Reasons for cost escalation:
- Scaling-up in reactor size (negative economies)
- Domestic production (low knowledge spillovers)
- Departure from standardized design (N4/pre-EPR: CEA decides not EDF)
- Scale-back of expansion program (vs. exuberant forecasts and lengthened construction time)

Lessons for the future – lack of cost certainty
- Challenge for learning-by-doing paradigm
- Need for granularity (standard, modular design)

Source: Adapted from Grubler, 2009
Supply Technologies Cost Trends

Source: Grubler et al, 2012
Investment Portfolios
World

No Sustainability Policies
(2558 bill.)

Today (941 bill.)

2005-2010

2050

Source: Riahi et al, 2012
Investment Portfolios
World

No Sustainability Policies
(2558 bill.)

GEA-Efficiency
(2849 bill.)

Source: Riahi et al, 2012
Investment Portfolios
Asia-Pacific

No Sustainability Policies
(516 bill.)

Today
(275 bill.)

2005-2010

2050

GEA-Efficiency
(579 bill.)

Source: Riahi et al, 2012
**Investment Portfolios Asia-Pacific**

**No Sustainability Policies**
(516 bill.)

**Today**
(275 bill.)

**2005-2010**

**2050**

**GEA-Efficiency**
(579 bill.)

Source: Riahi et al, 2012

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Statement: Energy services are central for further development and a transformation toward sustainable future. It is important to increase RD&D and investments and establish stable regulatory mechanisms to achieve these development goals.
THANK YOU

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