Jadrová energetika a skleníkový efekt
Nuclear energy and greenhouse effect

Jozef Misak

Valné zhromaždenie SNUS
17.5.2022
Energoland JE Mochovce

CONTENTS OF THE PRESENTATION

NUCLEAR RESEARCH INSTITUTE

- Energy and greenhouse gases
- Sustainability of variable renewable energy (VRE) sources
- Contribution of VRE sources to reduction of greenhouse gas emissions
- VRE sources and environment
- Economical competitiveness of VRE sources
- Sustainability, flexibility and multipurpose use of nuclear power
- Safety of nuclear power (risk of radiation exposure)
- Conclusions

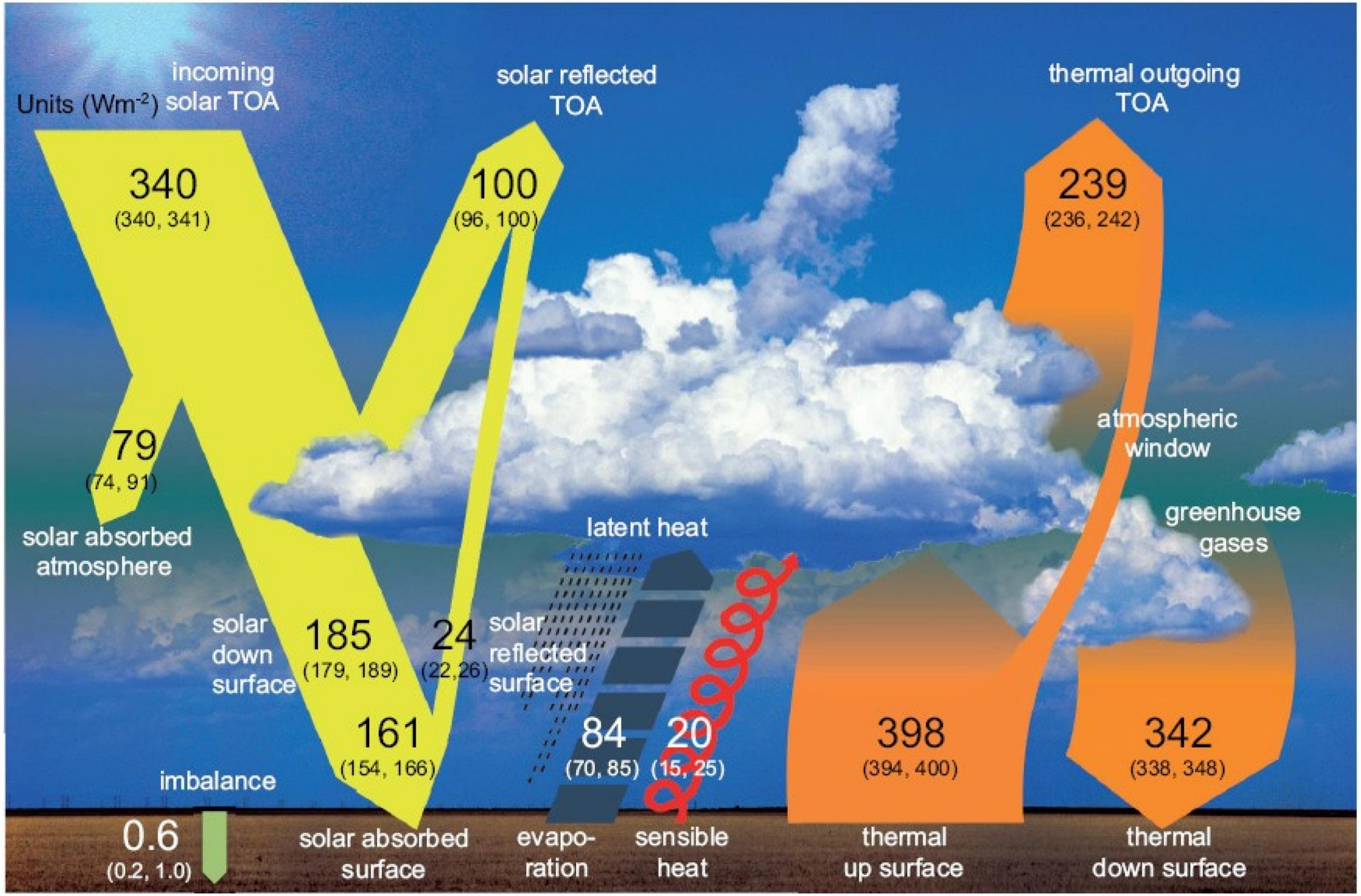
Acknowledgment: This presentation has been prepared from numerous inputs and several publications by a group of authors Barry W. Brook /[a], Agustin Alonso /[b]; Daniel A. Meneley /[c]; Jozef Misak /[d]; Tom Blees /[e]; Jan B. van Erp /[f]

/[a] Professor, Environmental Sustainability, Univ. of Tasmania, Australia; /[b] Prof. Emeritus, Univ. Politechnica de Madrid, Spain; /[c] Prof. Univ. of Ontario, Inst. of Technology, Canada ; /[d] Vicepresident for Strategy, NRI, Rez, Czech Republic; /[e] President, Science Council for Global Initiatives, USA; /[f] Consultant, Chicago, USA;

UJV Group
PEOPLE | INNOVATION | TECHNOLOGY

ENERGY AND GREENHOUSE GASES

GLOBAL ANNUAL MEAN ENERGY BUDGET OF THE EARTH

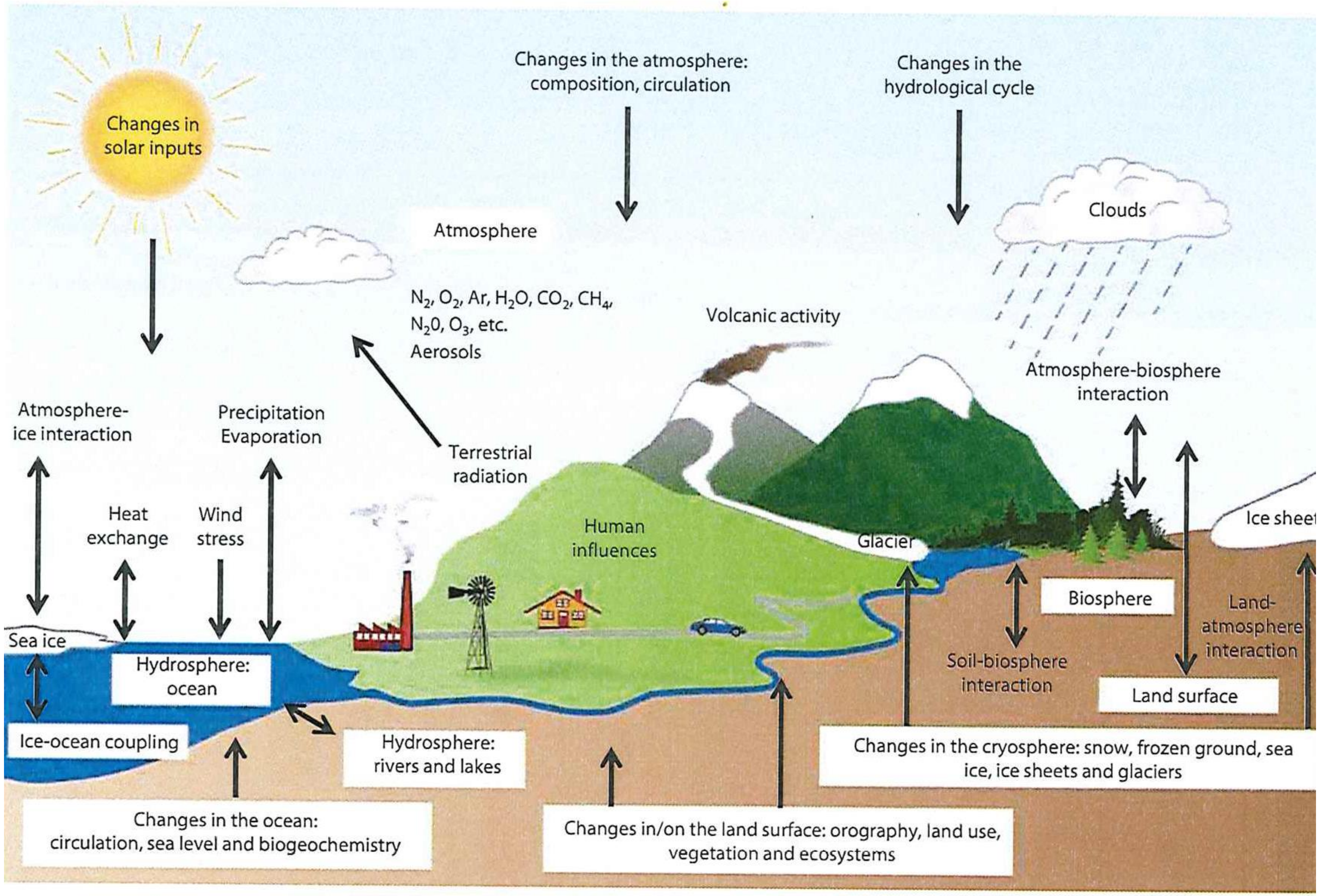


Global mean energy budget under present-day climate conditions. Numbers state magnitudes of the individual energy fluxes in W m–2, adjusted within their uncertainty ranges to close the energy budgets. Numbers in parentheses attached to the energy fluxes cover the range of values in line with observational constraints.

NUCLEAR RESEARCH INSTITUTE

Source: Climate Change Assessment of the Vulnerability of Nuclear Power Plants and Approaches for their Adaptation, OECD 2021, NEA No. 7207

CLIMATE SUBSYSTEMS, THEIR INTERACTIONS AND PROCESSES



Source: IPCC, 2007.

Source: Climate Change Assessment of the Vulnerability of Nuclear Power Plants and Approaches for their Adaptation, OECD 2021, NEA No. 7207

WORLD EMISSIONS BY POLLUTANT (2017)

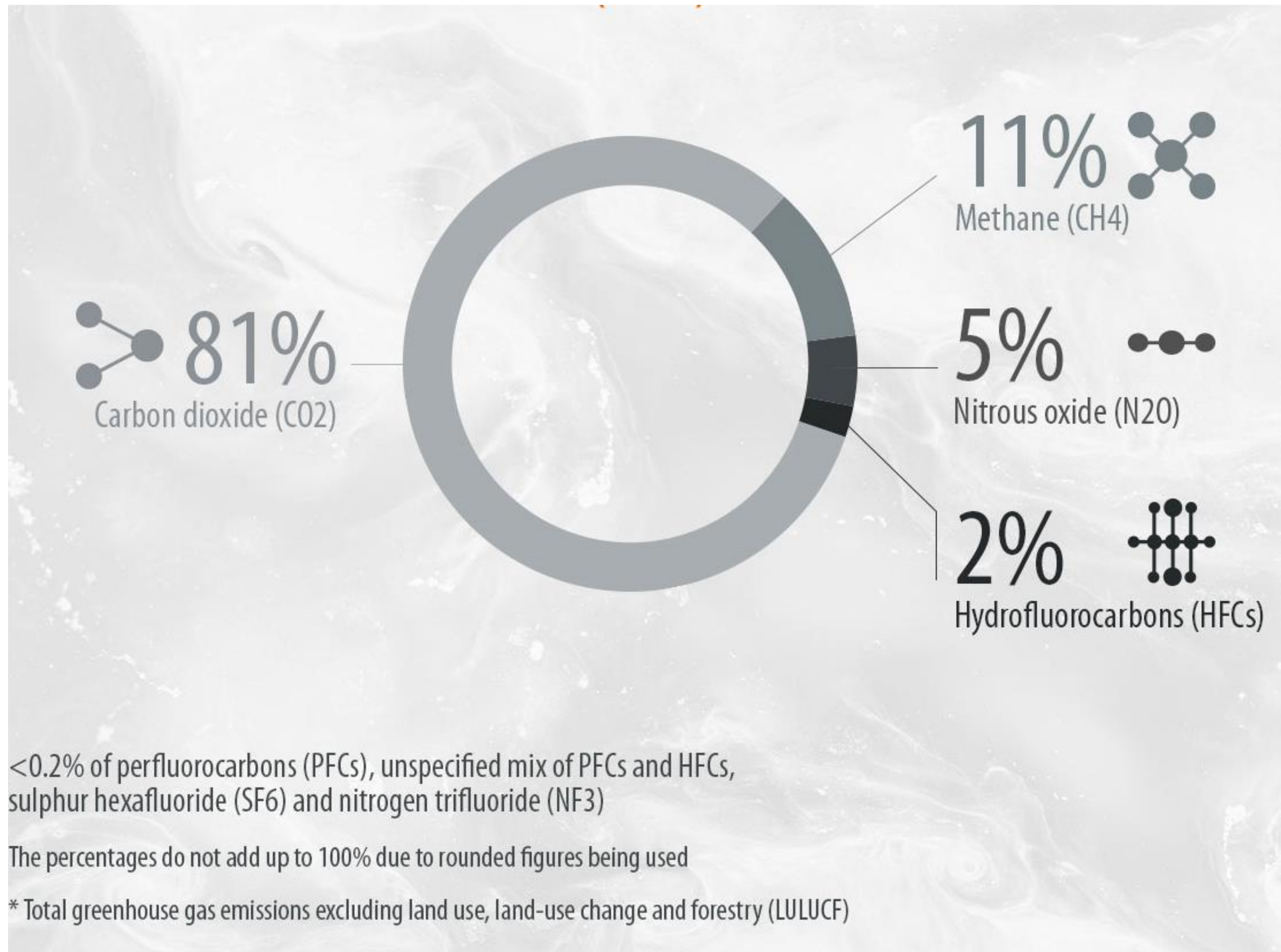
(SOURCE: UNFCCC DATA INTERFACE)

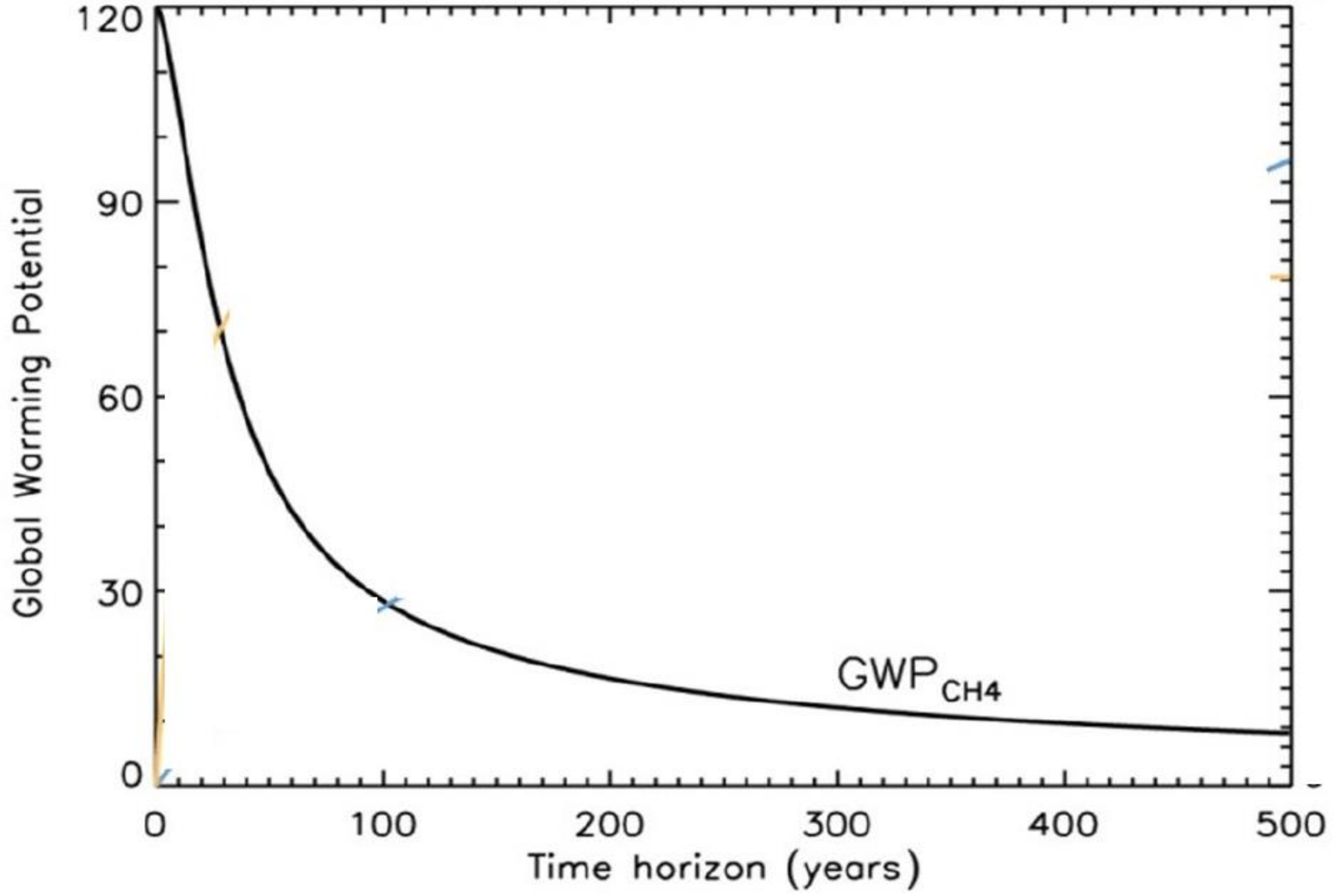
NUCLEAR RESEARCH INSTITUTE

CO2 is the greenhouse gas that is emitted the most. It is commonly produced by human activities. Other greenhouse gases are emitted in smaller quantities, but they **trap heat far more effectively than CO_2**, and in some cases are thousands of times stronger.

CO_2 equivalent means the number of metric tons of CO2 emissions with the same global warming potential as one metric ton of another greenhouse gas. The **three main greenhouse gases** and their **100-year global warming potential (GWP) compared to carbon dioxide** are:

1 x – carbon dioxide (CO_2)
25 x – methane (CH_4) – but 86 x in first 20 years (for pulse release)
298 x – nitrous oxide (N_2O)



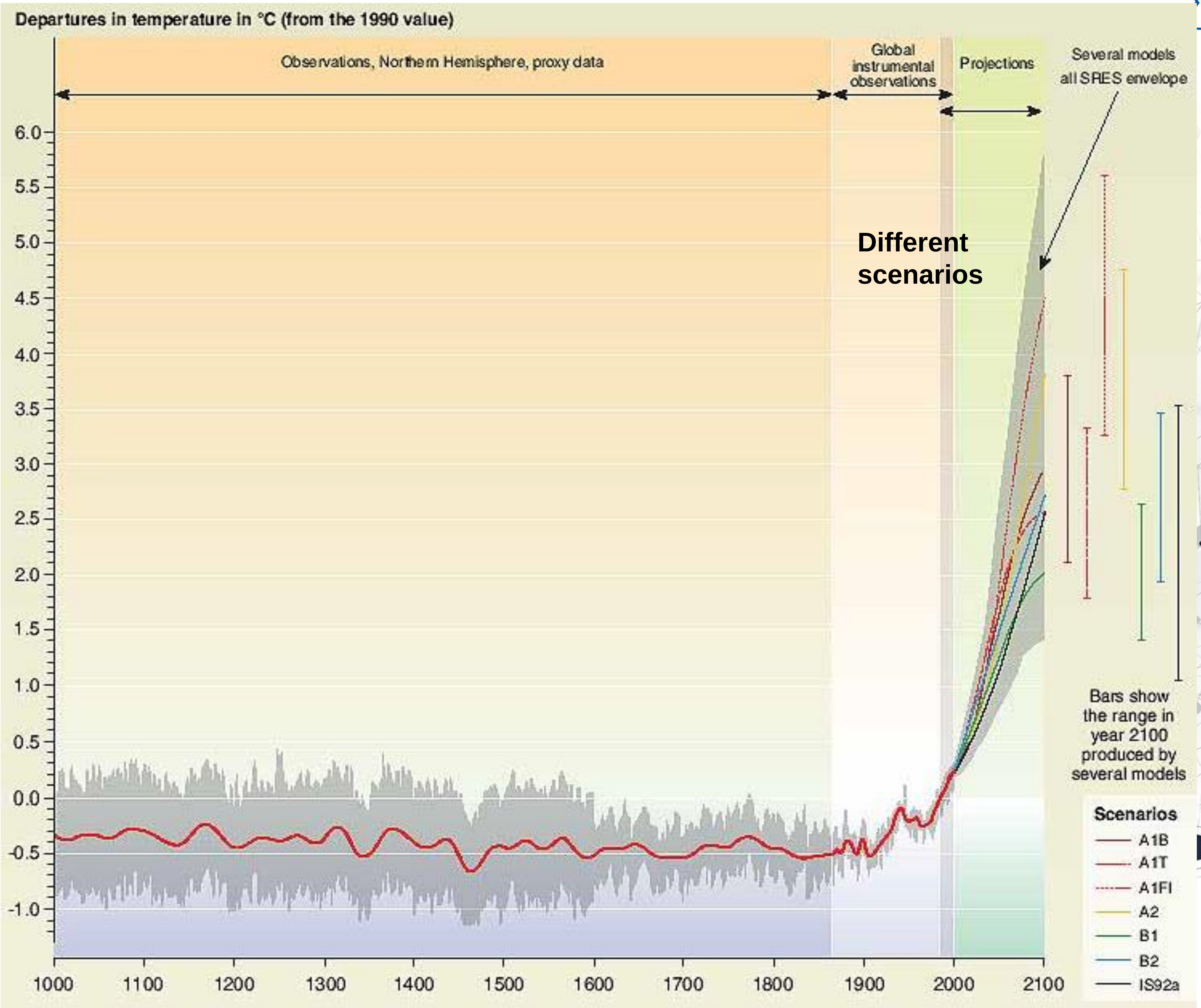


UJV Group
PEOPLE | INNOVATION | TECHNOLOGY

VARIATION OF TEMPERATURE FROM 1000 TO 2100

NUCLEAR RESEARCH INSTITUTE

- Climate change represents an urgent and potentially irreversible threat to human societies and the planet
- Increased temperature also means higher energy in the atmosphere, which may lead to higher intensity of storms, tornados, precipitations
- Renewable energy sources are often presented as the only solution to control global warming
- Solar and wind plants are considered as a key part of the solution



UJV Group
PEOPLE | INNOVATION | TECHNOLOGY

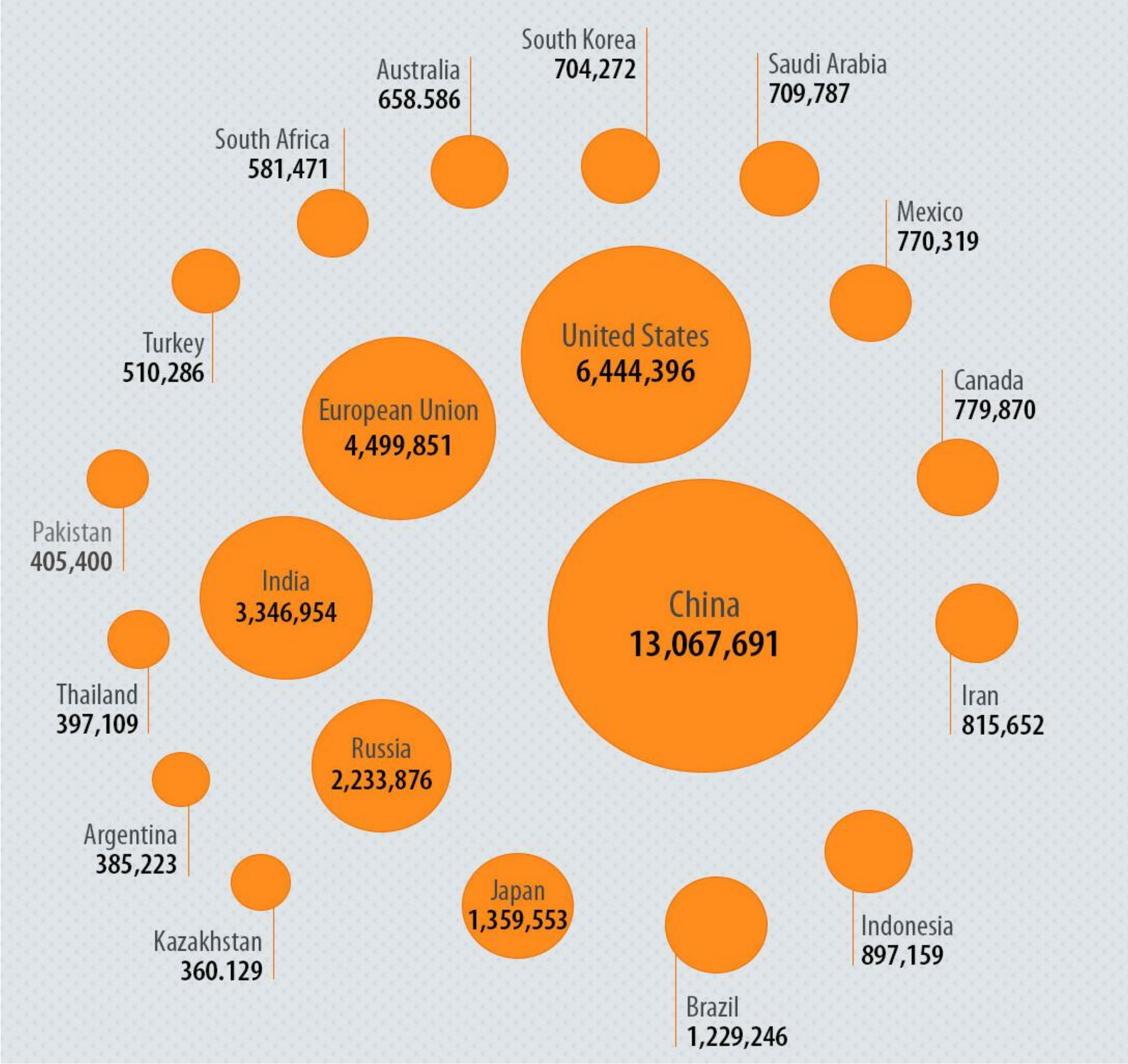
TOP GREENHOUSE GASES EMITTERS IN THE WORLD IN 2015 (KT OF CO2 EQUIVALENT)

NUCLEAR RESEARCH INSTITUTE

The infographic shows the world's top total greenhouse gas emitters in 2015. The **EU is the third biggest emitter** behind China and the United States and followed by India and Russia.

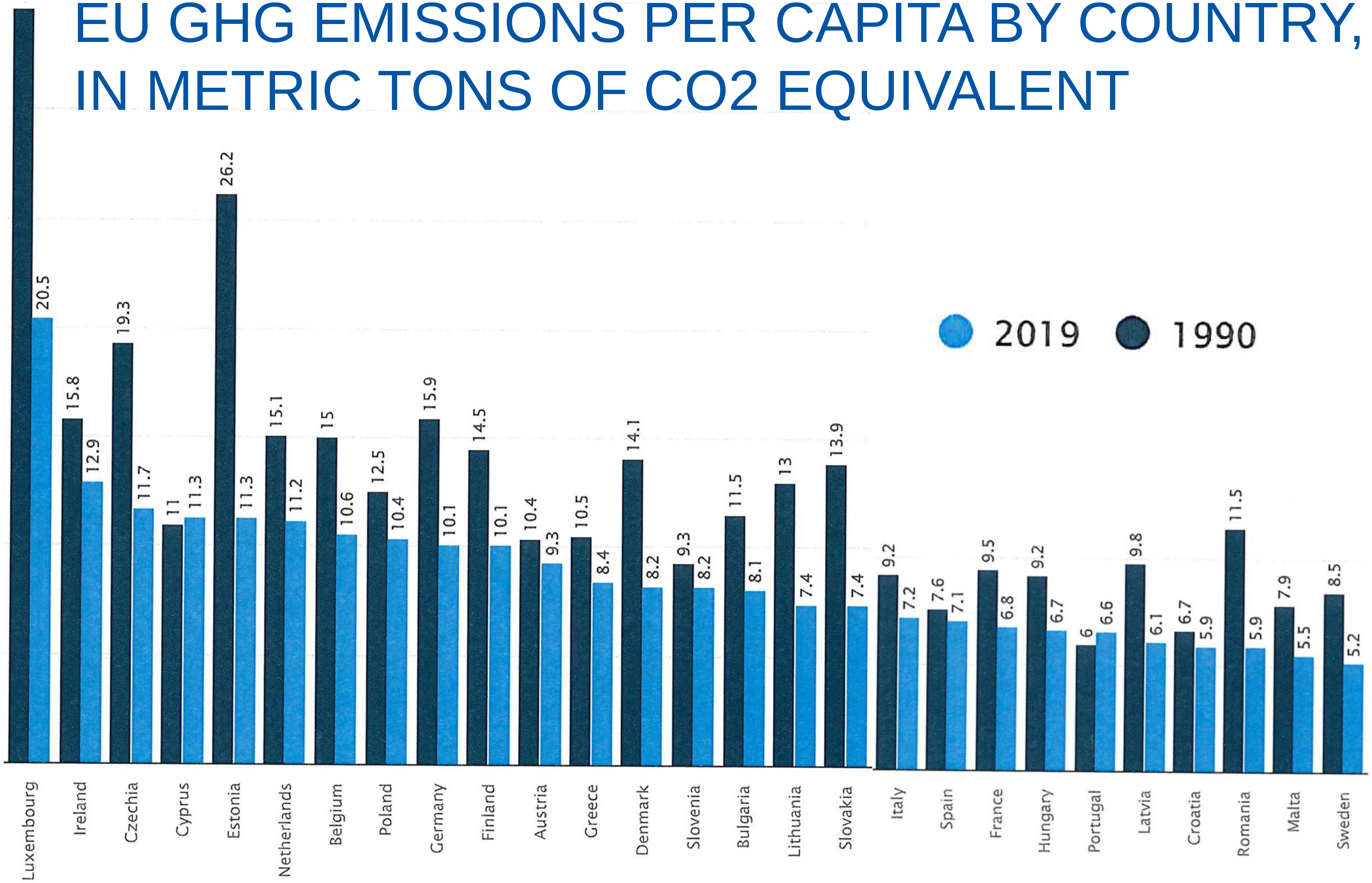
Greenhouse gases remain in the atmosphere for periods ranging from a few years to thousands of years. As such, they have a worldwide impact, no matter where they were first emitted.

Source: europarl.eu, JRC report on fossil CO2 and GHG emissions in all world countries (2019)



UJV Group
PEOPLE | INNOVATION | TECHNOLOGY

EU GHG EMISSIONS PER CAPITA BY COUNTRY, 2019 IN METRIC TONS OF CO2 EQUIVALENT

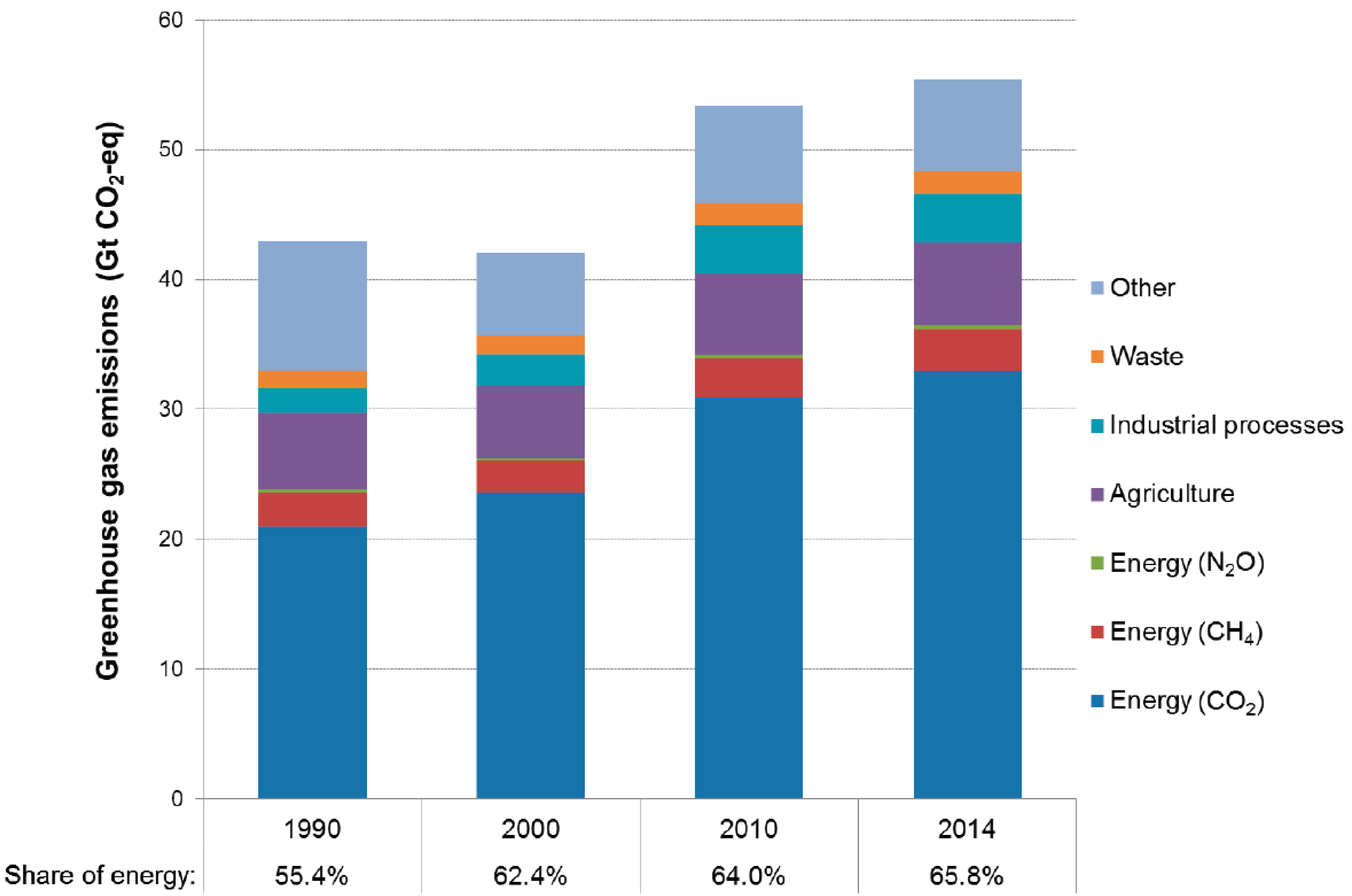


NUCLEAR RESEARCH INSTITUTE

UJV Group PEOPLE | INNOVATION | TECHNOLOGY

THE ROLE OF ENERGY IN CLIMATE CHANGE

The production and use of energy accounts for almost two thirds of total GHG emissions



Source: Climate Change and Nuclear power, IAEA 2018

SUMMARY ON ENERGY AND GREENHOUSE GASES

NUCLEAR RESEARCH INSTITUTE

- Climate change represents an urgent and potentially irreversible threat to human societies and the planet
- The three main greenhouse gases and their 100-year global warming potential (GWP) compared to carbon dioxide are: 1 x – carbon dioxide (CO_2), 25 x – methane (CH_4) – but 86 x in first 20 years and 298 x – nitrous oxide (N_2O)
- Greenhouse gases remain in the atmosphere for periods ranging from a few years to thousands of years, they have a worldwide impact, no matter where they were first emitted
- The EU is the third biggest emitter behind China and the United States
- The production and use of energy accounts for almost two thirds of total GHG emissions
- Scope of utilization of nuclear power makes significant difference in GHG emission by the country
- Reduction of GHG emissions in energy sector is important and urgent task

UJV Group
PEOPLE | INNOVATION | TECHNOLOGY

SUSTAINABILITY OF VARIABLE RENEWABLE ENERGY SOURCES

SUSTAINABILITY AND LIMITATIONS OF VRE

NUCLEAR RESEARCH INSTITUTE

Sustainability: The ability to provide energy on a very large-civilization-spanning-time scale without depriving future generations and in a way that is environmentally friendly, economically viable, safe and reliable'

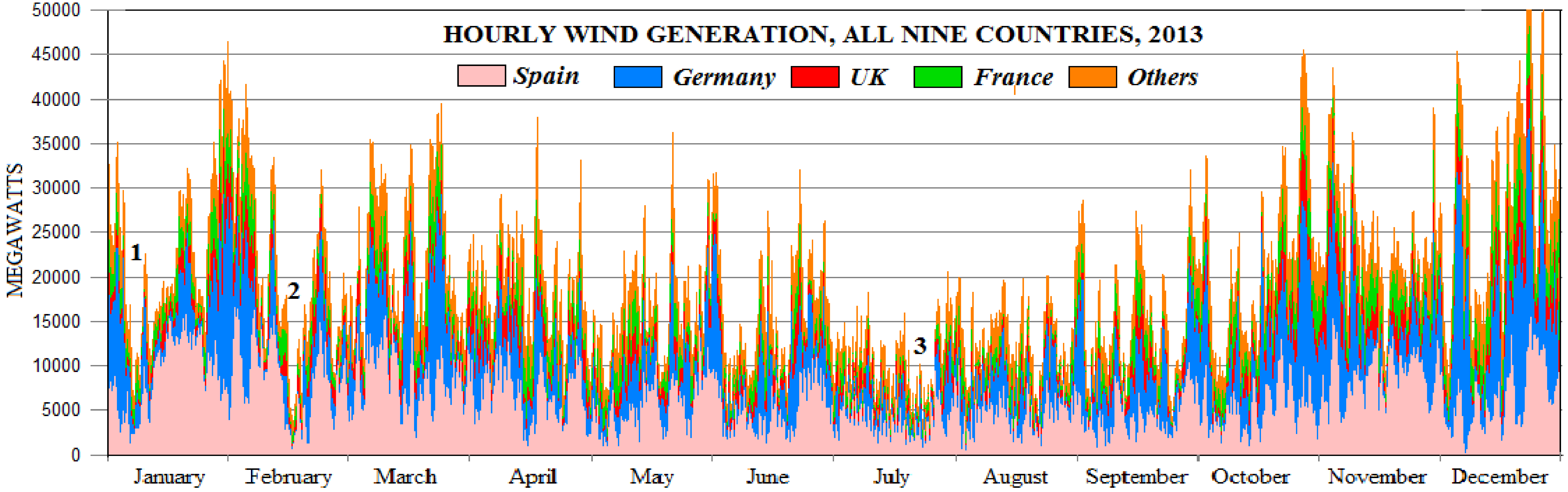
Main issues of intermittent renewable resources (with many implications):

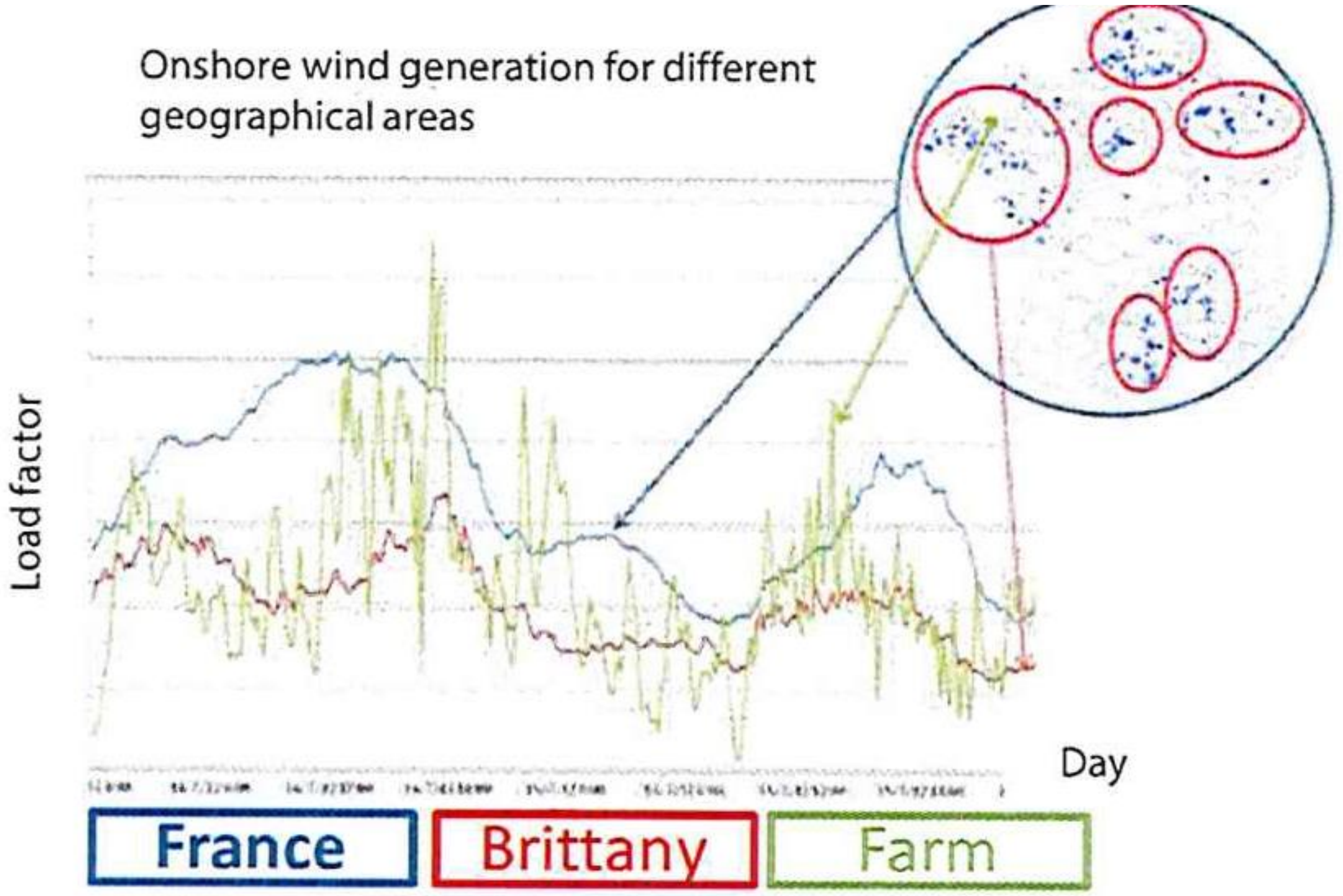
- transmission
- **intermittency**
- footprint (low density)
- environmental impact
- system cost
- Quality

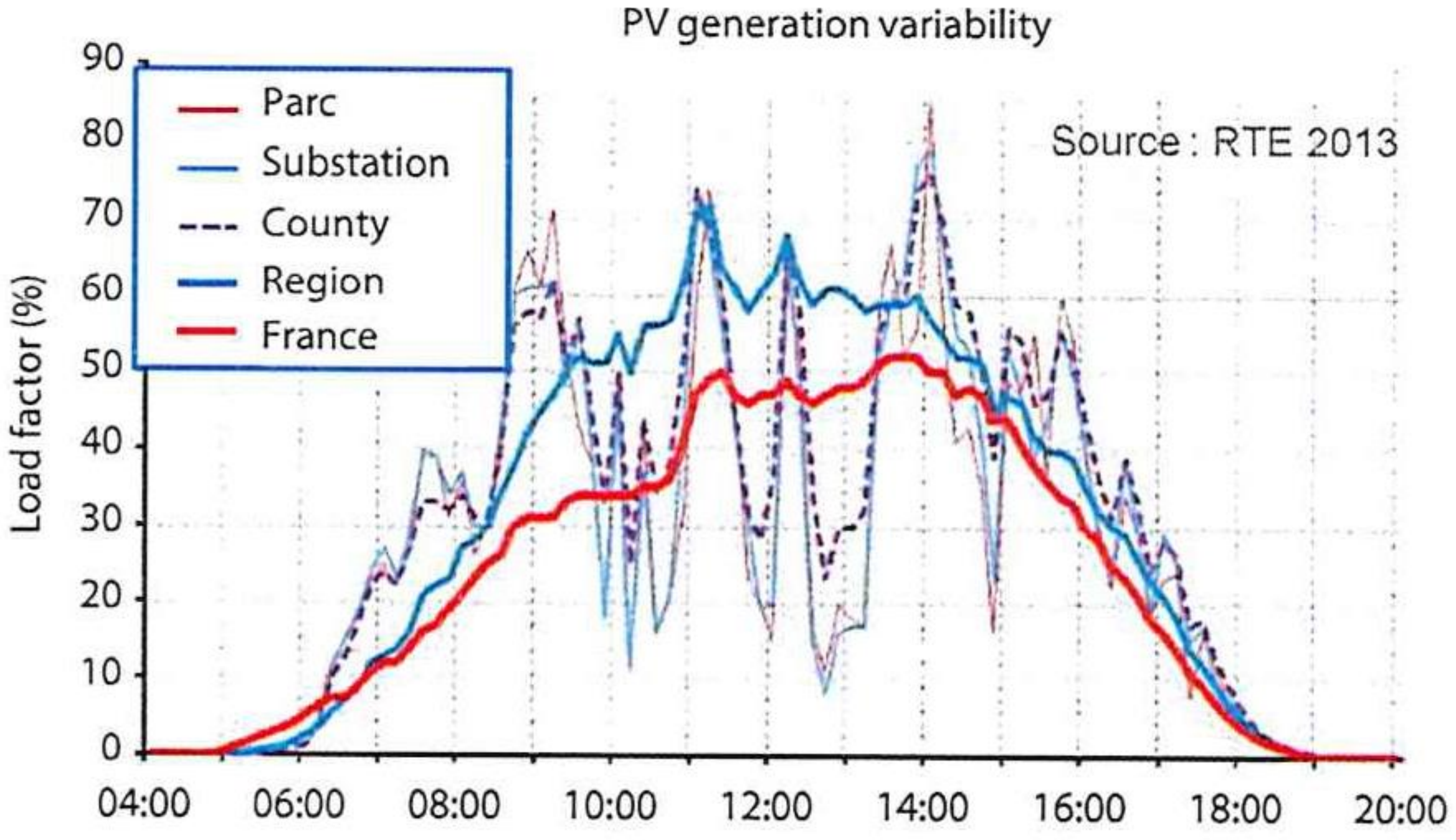
Questions:

- Is it possible to replace all or most fossil energy with renewables and, if so, would this be sustainable?
- Is nuclear energy sustainable and what should its role in the energy mix be?

PROBLEM OF INTERMITTENCY – VARIABILITY, NO CONTROL







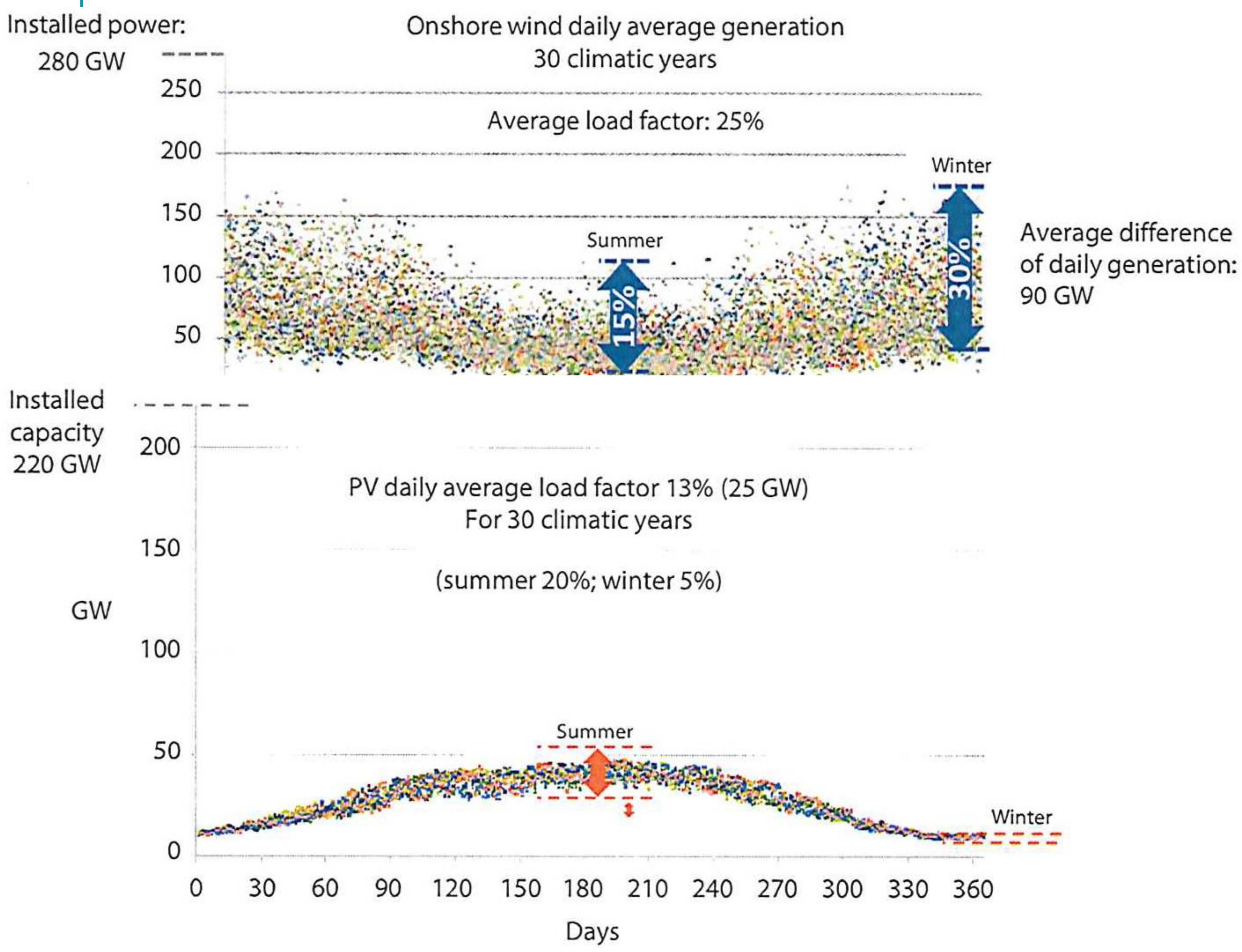
Source: EDF, 2015.

Wind and solar PV daily generation profile when aggregated at different levels

Source: The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables, OECD/ NEA No. 7299, 2019

SIMULATED WIND AND SOLAR PV GENERATION IN EUROPE OVER 30 DIFFERENT YEARS

NUCLEAR RESEARCH INSTITUTE



Source: The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables, OECD/ NEA No. 7299, 2019

Capacity factors

- Coal 50 – 70 %
- Nuclear 80 – 90 %
- Solar photovoltaic (PV) 5 – 20 %
- Solar concentrated solar power (CSP) 30 – 40 %
- Wind 15 – 40 %
- Hydro 40 – 50 %

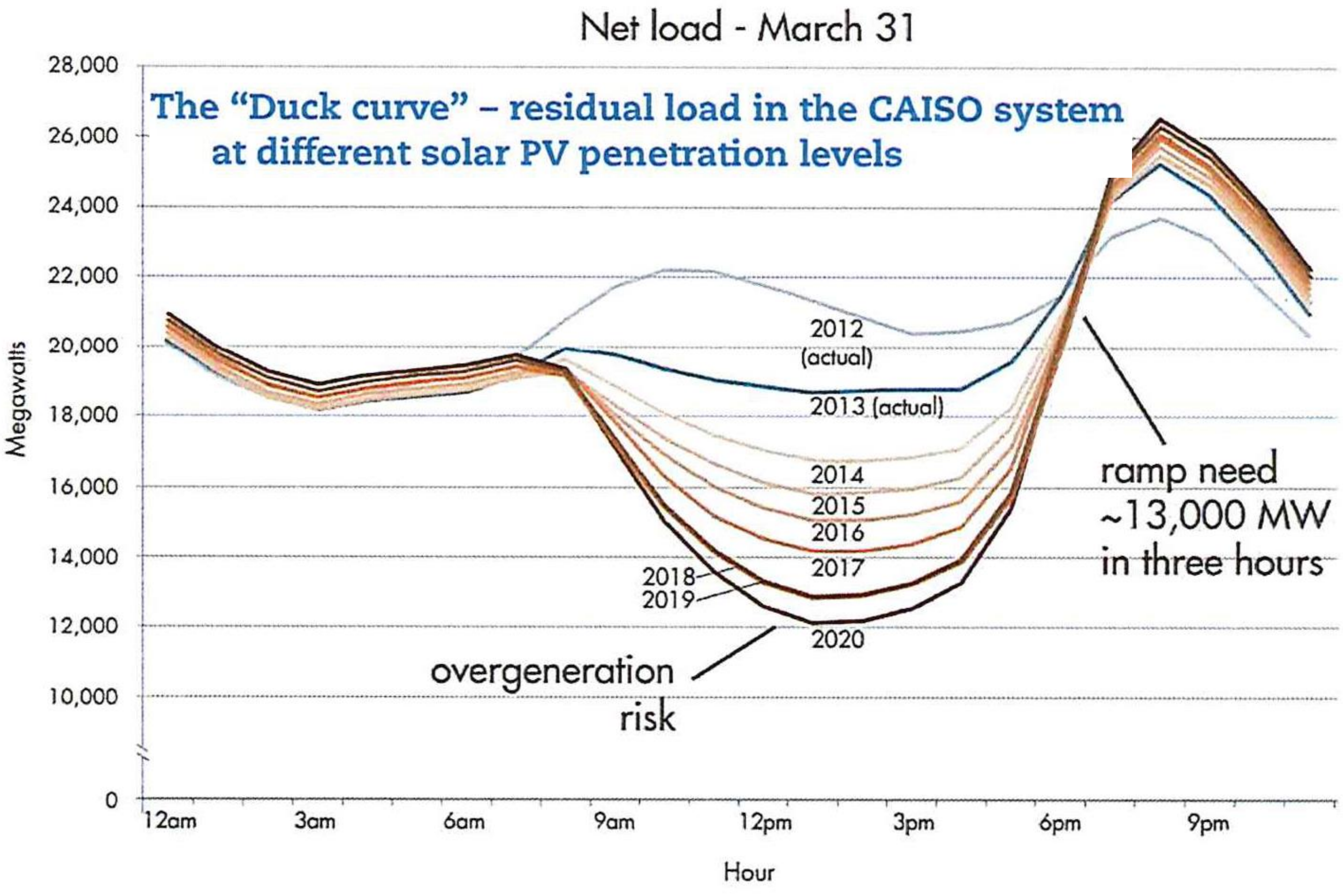
Plant lifetime

- Nuclear 60 – 80 years
- Wind 20 – 30 years
- Solar PV 20 – 30 years

Source: Climate Gamble – Is Anti-Nuclear Activism Endangering Our Future?, ISBN 978-952-7139-04-2 ebook, data mainly from USA

UJV Group
PEOPLE | INNOVATION | TECHNOLOGY

PROBLEM OF INTERMITTENCY – THE NEED OF RESIDUAL (BACK-UP) POWER



Source: CAISO, 2013.

Note: Licensed with permission from the California ISO. Any statements, conclusions, summaries or other commentaries expressed herein do not reflect the opinions or endorsement of the California ISO.

Condition for stability of the grid:

Production = Consumption

What is the quality of intermittent power?

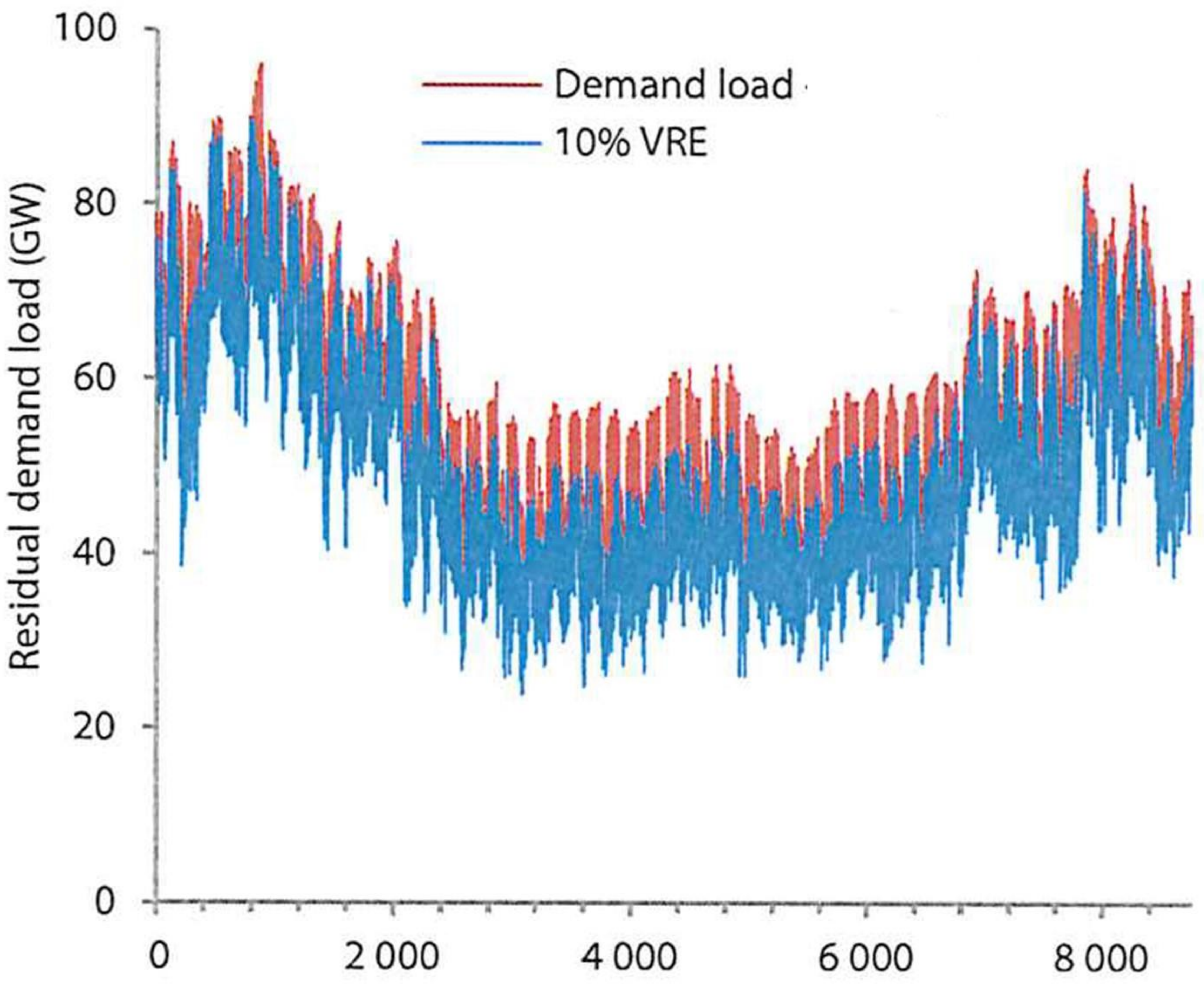
Who should provide back-up power?

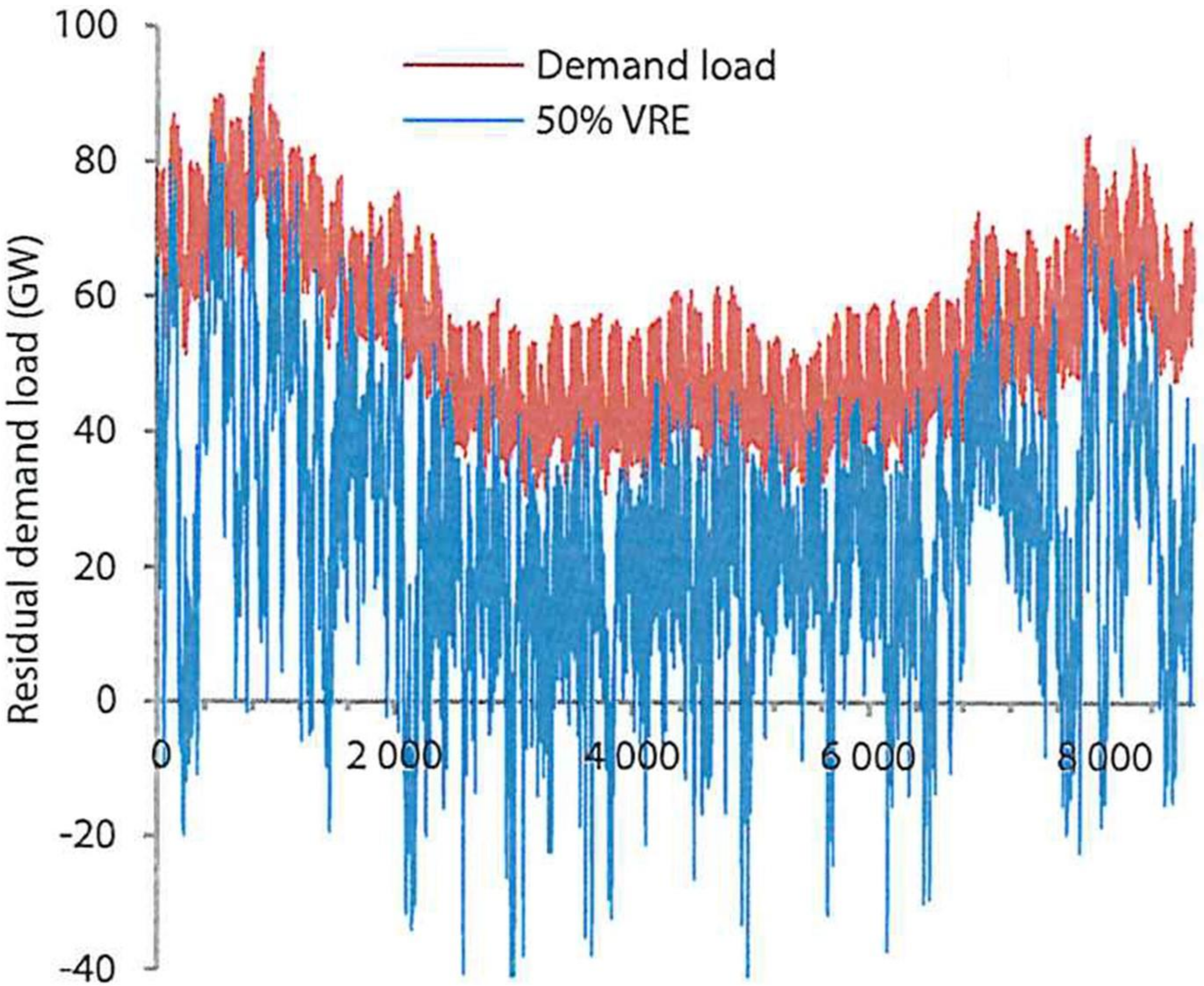
Who should be responsible for maintaining the frequency in the grid?

Figure copied from: The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables, OECD/ NEA No. 7299, 2019

PROBLEM OF INTERMITTENCY – THE NEED OF RESIDUAL (BACK-UP) POWER (EXAMPLE)

NUCLEAR RESEARCH INSTITUTE





Source: The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables, OECD/ NEA No. 7299, 2019

UJV Group
PEOPLE | INNOVATION | TECHNOLOGY

SOLUTIONS TO INTERMITTENCY
(FOR A LARGE SUPPLY OF ELECTRICITY)

NUCLEAR RESEARCH INSTITUTE

- Connect renewable generators to «intelligent» grids:
  - Technology not yet developed for large scale applications
  - Intelligent grids are very costly
  - Intermittency only partially addressed, as illustrated above
- Create a balanced renewable energy generation-electricity storing-distribution system:
  - Reversible pumped-hydro power stations have siting, technical and economic limitations
  - Even hydro stations can store energy for hours, but not for days
  - Batteries with sufficiently large capacity not available and can hardly be available
- Provide back-up to renewable generators by gas-fired stations
  - Large environmental impact due to production of carbon dioxide and methane releases as discussed further

ENERGY STORAGE TECHNOLOGIES

(V. WAGNER, OENERGETICE.CZ, 11.09.2018)

There are many physical options for storing energy, but most of them have limited large scale utilization

- Rechargeable accumulator batteries (300 kWh/m3)
- Flow or liquid batteries
- Superconducting induction accumulators
- Mechanical energy storage
- Storage plants using compressed air
- Production of synthetic fuels
- Production of hydrogen
- Heat storage

Problems: limited capacity (mostly tens of MW, for few hours), high consumption of materials, efficiency of conversion- energy loss (60-70%), space requirements, necessary research and development

NUCLEAR RESEARCH INSTITUTE

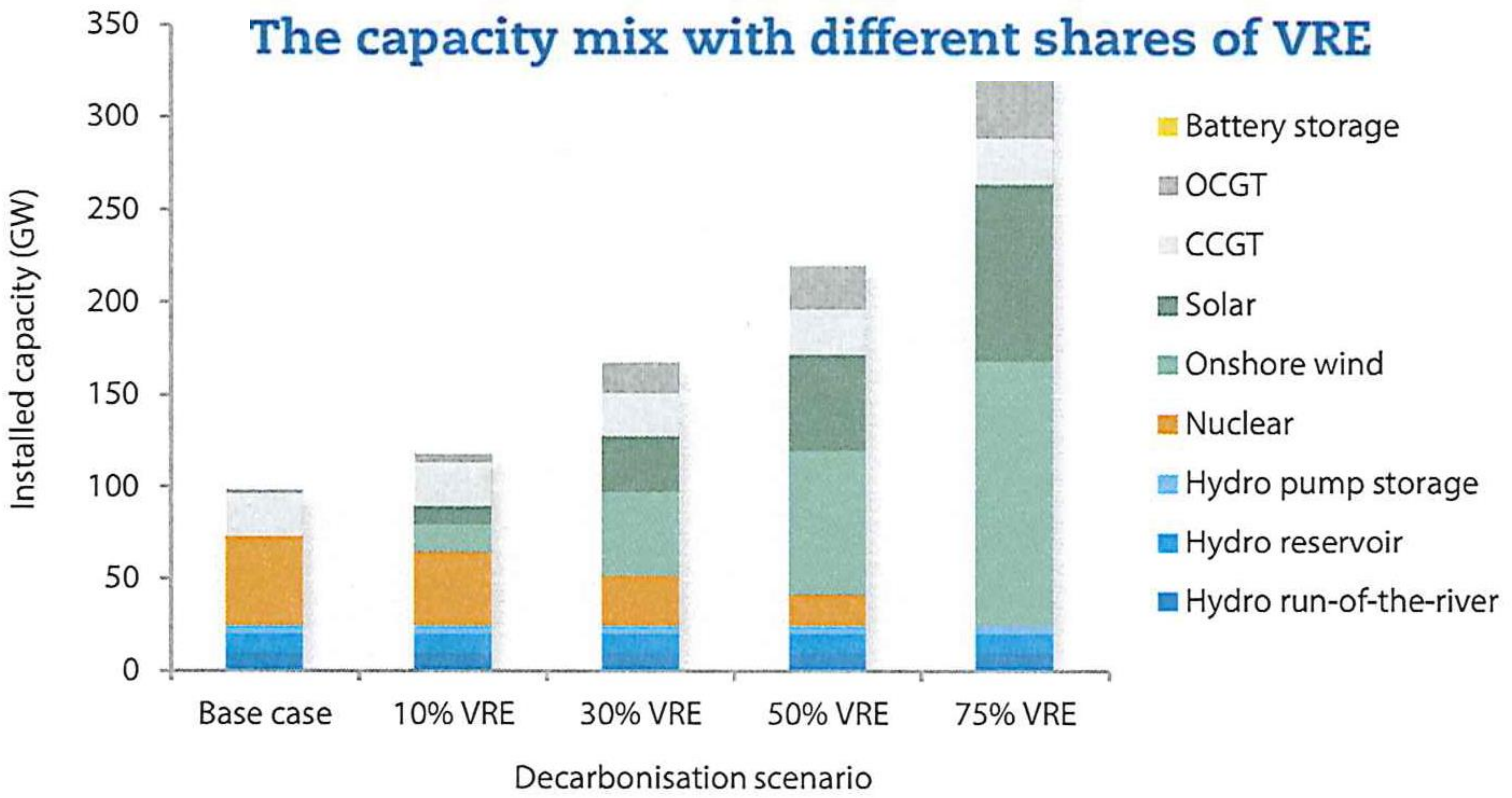
UJV Group
PEOPLE | INNOVATION | TECHNOLOGY

ISSUE OF EFFICIENCY OF STORAGE ENERGY FROM VRE: ELECTRICITY TO HYDROGEN AND BACK TO ELECTRICITY

- Three steps:1) electrolysis of water producing hydrogen; 2) storage of hydrogen; 3) conversion of hydrogen to electricity using fuel cells
- **Efficiency of electrochemical decomposition of water: 0.60 - 0.80** depending on the type and power of electrolyser (efficiency as the ratio of energy contained in the effluent hydrogen with calorific value H2: 33.3 kWh / kg, resp. 120 MJ / kg) to the electrical energy input
- **Efficiency of hydrogen storage: 1.0** (in case of stable steel pressure vessels operated at a pressure level corresponding to the output pressure of the electrolyser, without compression)
- **Efficiency of conversion of hydrogen to electricity in fuel cells: 0.45 - 0 , 55** (efficiency defined as the ratio of the electrical power of the fuel cell to the thermal energy contained in the input hydrogen) depending on the size and type of the fuel cell
- **Alternatively, combustion processes such as turbines or tandem engines with a generator** can be used to convert hydrogen into electricity, with an electrical efficiency of about **0, 30 - 0.35**
- The whole chain "electricity -> hydrogen -> electricity" can reach an electrical efficiency of **0.27 - 0.44**, while the losses of the cell and the fuel cell are in the form of low-potential (approximately 60 ° C) thermal energy, which could be used to increase overall efficiency

THE NEED OF RESIDUAL (BACK-UP) POWER (EXAMPLE)- THE SAME GENERATION ~550 TWH

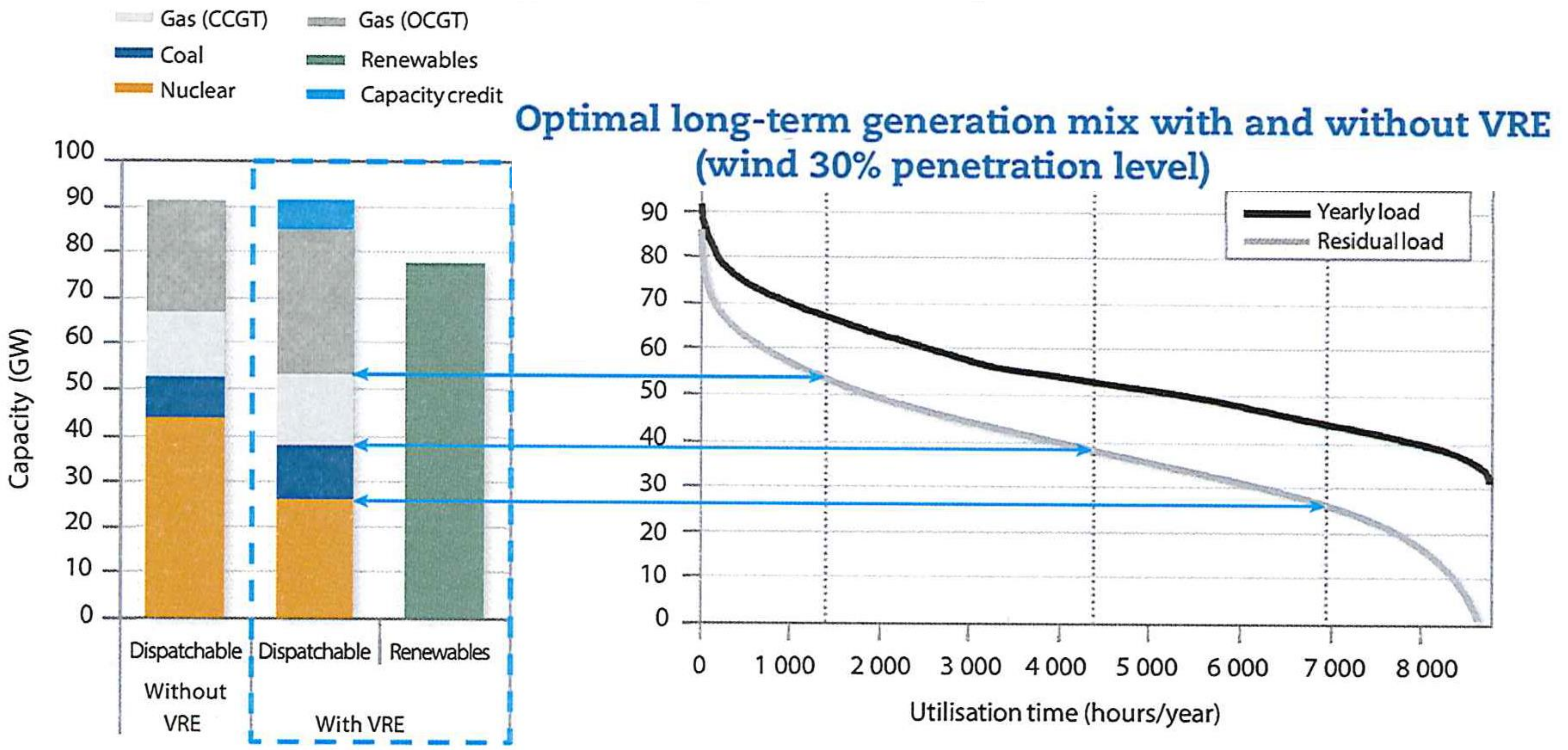
NUCLEAR RESEARCH INSTITUTE



VRE Variable renewable energy; OCGT Open cycle gas turbine; CCGT Combined cycle gas turbine

Source: The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables, OECD/ NEA No. 7299, 2019

THE NEED OF RESIDUAL (BACK-UP) POWER (EXAMPLE)



Source: NEA, 2012.

Note: based on load data and wind profile for France 2011. Calculation has been performed by scaling the wind generation in 2011 to a level corresponding to a generation share of 30%. This may overestimate the impact of variability.

Source: The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables, OECD/ NEA No. 7299, 2019

CUMULATED ENERGY CONSUMPTION WITHOUT FUEL

Source	Build and decommissioning/disposal of PP kWh_{Prim}/kWh_{el}	Use without fuel kWh_{Prim}/kWh_{el}	Total without fuel kWh_{Prim}/kWh_{el}
Coal	0.0176	0.2519	0.2695
Lignite	0.019	0.1415	0.1606
Natural Gas	0.0044	0.1655	0.1699
Nuclear	0.0151	0.0578	0.073
Wood	0.0827	0.0003	0.083
PV(*Crystalline Silicon Solar Cells*)	0.574	0.035	0.609
Wind 1500 kW	0.0784	0.0065	0.0849
Hydro 3.1 MW	0.0401	0.0045	0.0445

SUMMARY ON SUSTAINABILITY OF VRE SOURCES

- Grid-connected VRE are in general not sustainable because they require back-up power for when the wind does not blow or when the sun does not shine.
- Back-up is provided by fast source, such as hydro power or gas-fired generating stations because it has to be fast and flexible.
- Averaged over a year, capacity factor of solar PV is 5-20 %, wind turbines 15% - 40%
- Only if the back-up energy is provided by hydro-electric stations or supplied from energy-storage facilities could VRE be considered sustainable.
- However, hydro-electric energy is limited and energy from storage is in most cases not technically and economically viable for base-load applications.
- VRE require large amount of construction materials, what can become a limiting factor for their implementation

CONTRIBUTION OF VARIABLE RENEWABLE ENERGY SOURCES TO REDUCTION OF GREENHOUSE GAS EMISSIONS

COMPARISON OF TOTAL EMISSIONS (including construction, decommissioning and fuel cycle)

NUCLEAR RESEARCH INSTITUTE

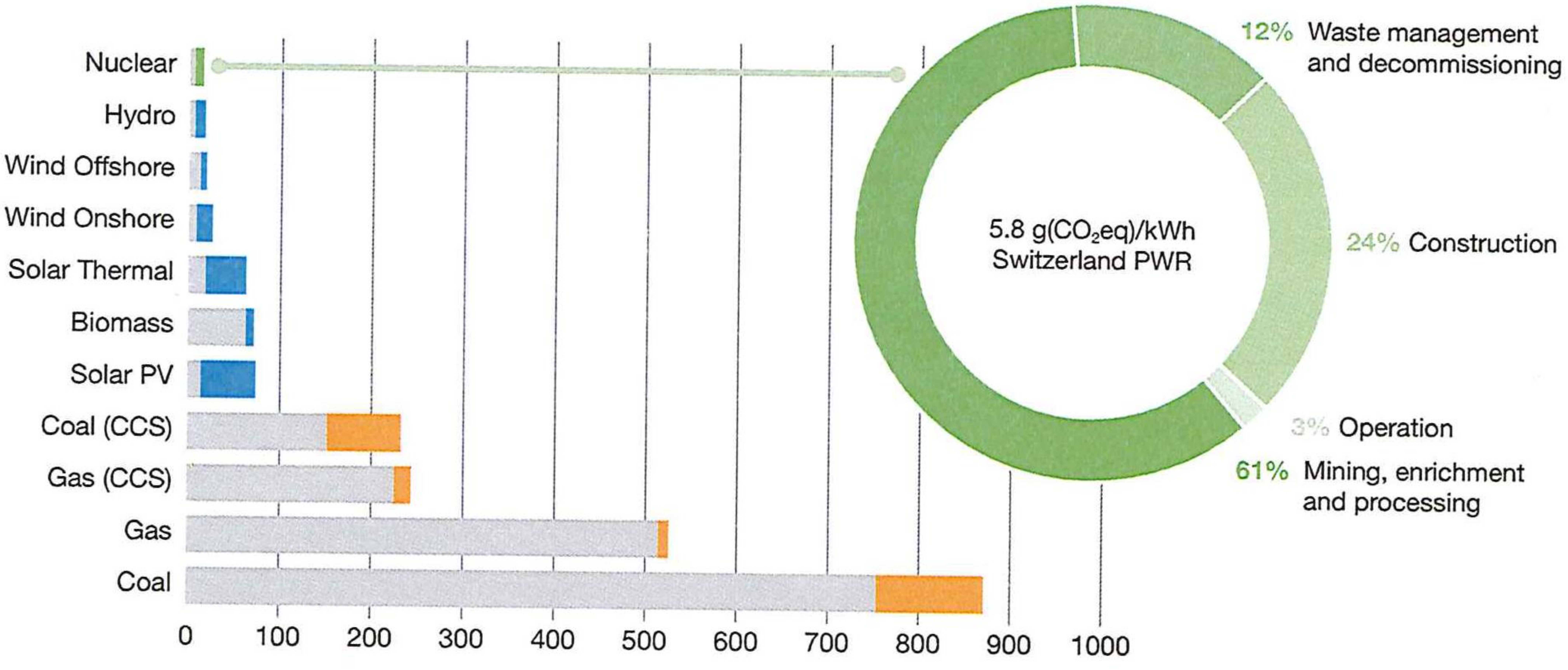
	CO_2 [g/kWh]	SO_2 [g/kWh]	NO_x [g/kWh]
Coal	**793.7**	**800**	**865.5**
Lignite	**977.1**	**740.2**	**739.7**
Natural Gas	**413**	**71**	**385.9**
Nuclear	**15.7**	**34**	**35.8**
Wood	**40.5**	**156.1**	**1137.7**
PV	**156.1**	**341.6**	**272.5**
Wind 1500 kW	**16**	**40.1**	**33.4**
Hydro 3.1 MW	**12.5**	**24.8**	**41.5**

Compared to coal, burning natural gas reduces production of CO_2 about 2-times, but incomplete burning and leakages of methane are very significant sources of GHGs

Source: University of Stuttgart, Institute of Energy Economics and Rational Use of Energy, November 2005, updated July 2007.

UJV Group
PEOPLE | INNOVATION | TECHNOLOGY

COMPARISON OF GREENHOUSE GAS EMISSIONS

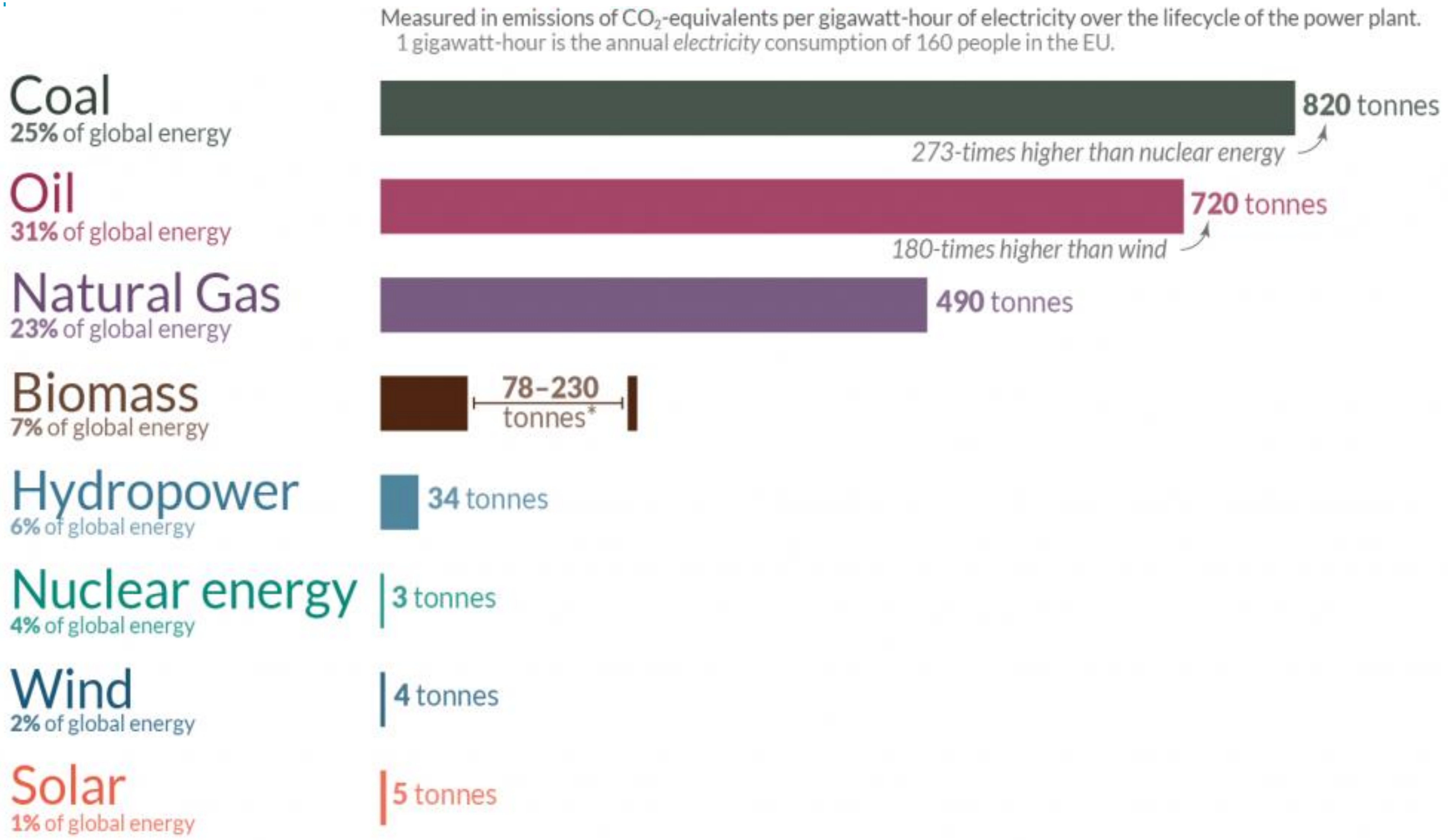


Life cycle greenhouse gas emissions per kilowatt-hour (g CO_2-equivalent/kW-h)

(Source: IAEA booklet Climate Change and the Role of Nuclear Power, 2020

COMPARISON OF GREENHOUSE GAS EMISSIONS

NUCLEAR
RESEARCH
INSTITUTE



(Source: What are the safest and cleanest sources of energy? - Our World in Data, Hannah Ritchie, February 10, 2020)

UJV Group
PEOPLE | INNOVATION | TECHNOLOGY

EFFECTS OF METHANE ON GLOBAL WARMING

- In addition to CO_2, methane CH_4 is the second most significant GHG contributing to global warming; molecule of methane is ~120-times more powerful in heating the atmosphere than a molecule of CO_2
- The methane contents in the atmosphere started to grow since 1750, the year considered as the start of the industrial revolution; until 2011 an average increase was plus 138 %.
- The cause are direct atmospheric releases of natural gas during its geological extraction, purification, flaring and venting, liquefaction and transport, as well as storage and manipulation and use of the gas in electricity generating station and from poor gas combustion. The mass fraction of natural gas leakages from all these operations are quoted from 2% to 10% of natural gas delivery.
- When comparing a wind farm that is backed up by a gas-fired station with a coal-fired station, one finds that the wind farm plus gas-fired backup will, (for a time horizon of 20 years) have a larger effective GHG emission if the leakage to the atmosphere of the natural gas exceeds 2.7 % and 4.1 %, respectively for annualized availability values of the wind farm of 25% and 50%.

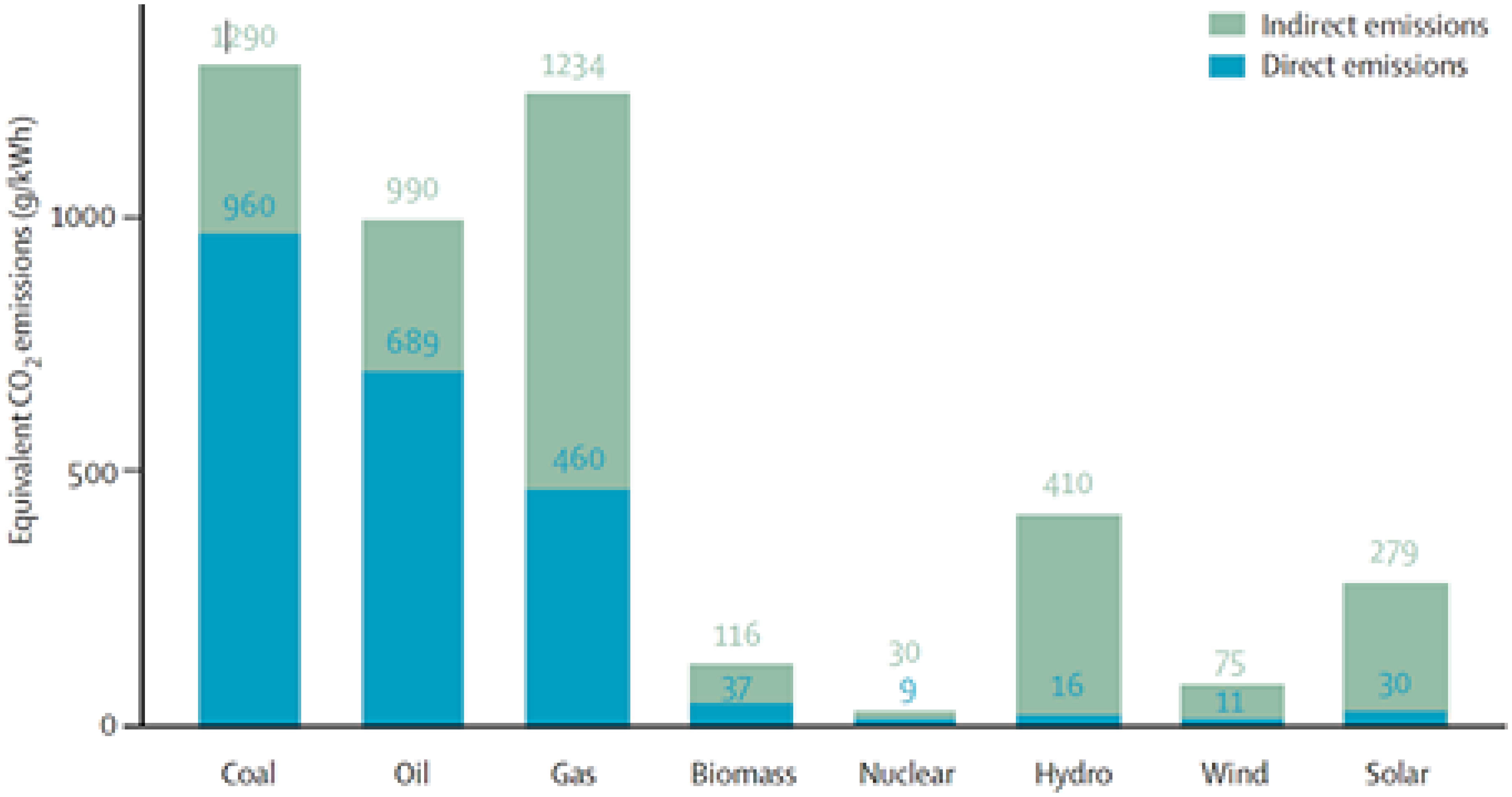
NUCLEAR RESEARCH INSTITUTE

UJV Group
PEOPLE | INNOVATION | TECHNOLOGY

CO_2 FOOTPRINT (DIRECT AND INDIRECT EMISSIONS)

(Source A Survey on Nuclear Energy and Nuclear Pollution, Kemal İhsan Kılıç,Spring 2016, Middle East Technical University, Northern Cyprus Campus)

NUCLEAR RESEARCH INSTITUTE



UJV Group
PEOPLE | INNOVATION | TECHNOLOGY

SUMMARY ON CONTRIBUTION OF VRE SOURCES TO REDUCTION OF GREENHOUSE GAS EMISSIONS

NUCLEAR RESEARCH INSTITUTE

- Total greenhouse gas emissions for the whole life cycle of various sources are comparably very low for nuclear, hydro and wind plant, but they are much larger for PV solar, and very much large for any fossil plants
- However, grid-connected VRE in many cases do not reduce AGHG emissions if they are backed up with gas-fired stations, considering the leakage of natural gas - methane (CH_4) having a Global Warming Potential (GWP) 120 times higher than CO_2.
- Relatively small leakage rate of natural gas (2% - 4%) will make it questionable that the combined plant (i.e., wind/solar plant together with its back-up power), will reduce GHG emissions.
- An additional reason militating against a reduction in GHG emissions, is that the gas-fired back-up power plants will operate below normal efficiency (possibly by some 20%), having to constantly follow the varying output of the “renewables”. This will increase the CO_2 emission rate.

UJV Group
PEOPLE I INNOVATION I TECHNOLOGY

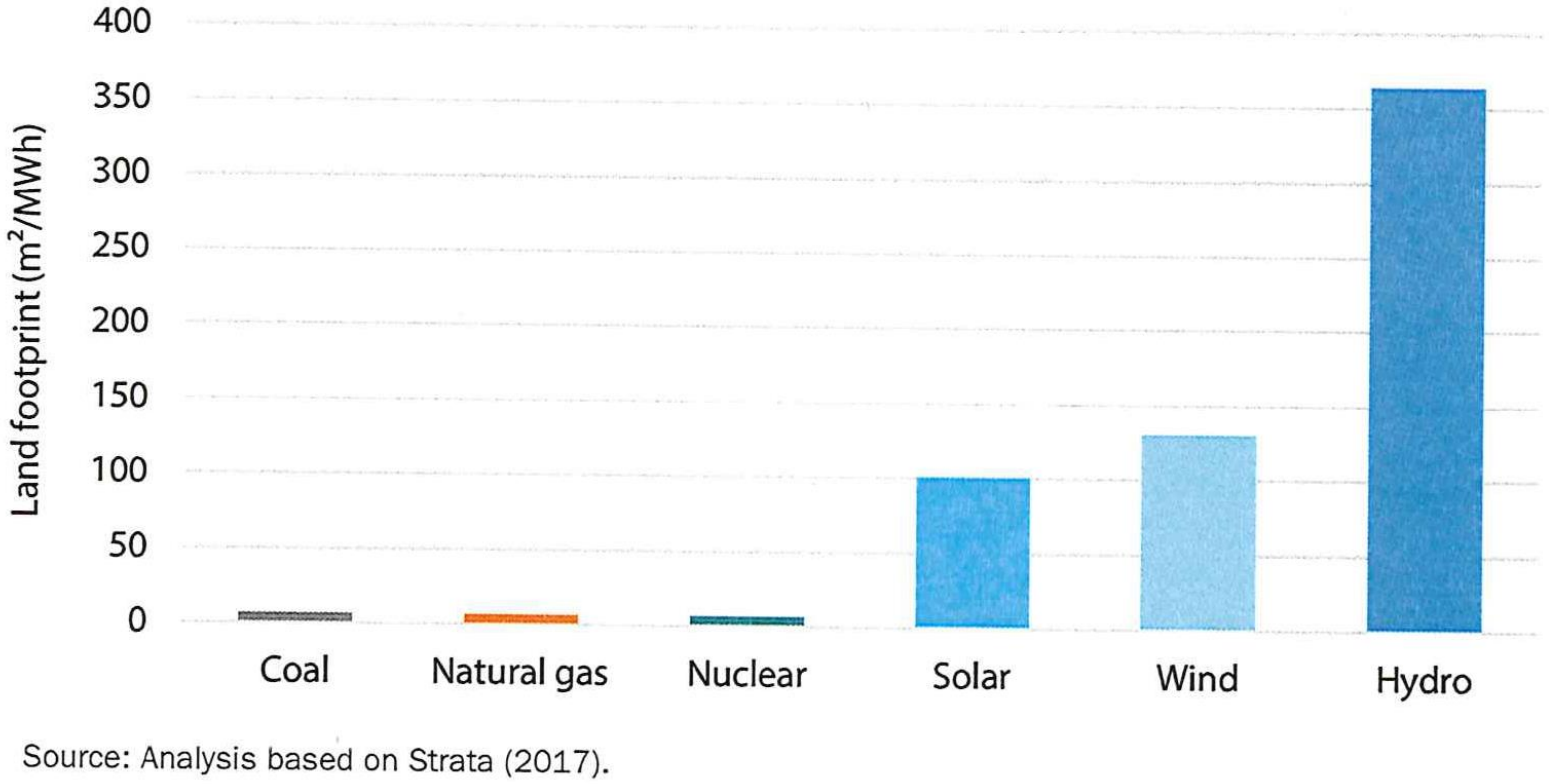
NUCLEAR
RESEARCH
INSTITUTE

VARIABLE RENEWABLE ENERGY SOURCES AND ENVIRONMENT

UJV Group
PEOPLE | INNOVATION | TECHNOLOGY

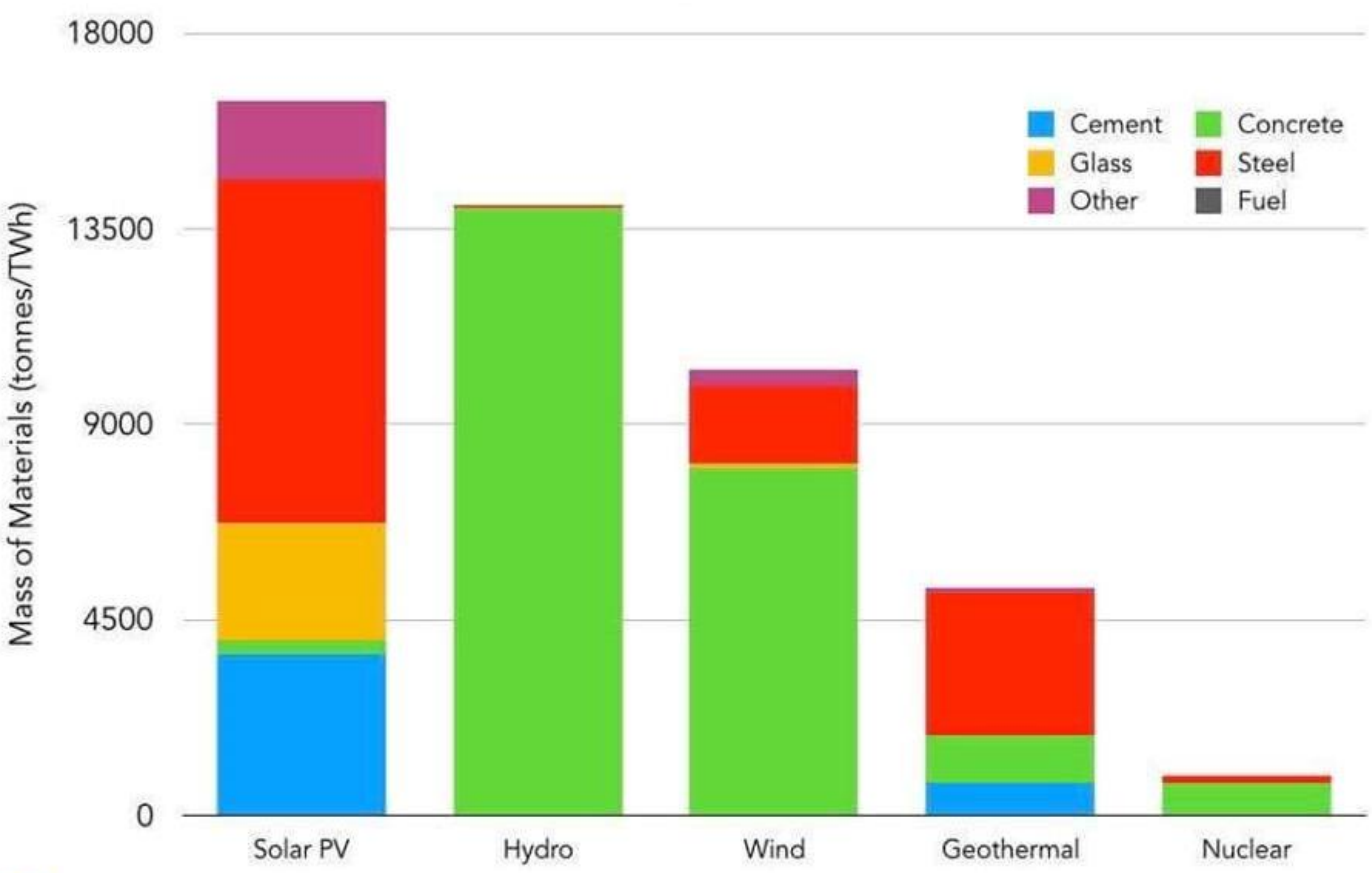
LAND FOOTPRINT FOR DIFFERENT SOURCES OF ELECTRICITY

NUCLEAR
RESEARCH
INSTITUTE



Source: Meeting Climate Change Targets: The Role of Nuclear Energy, OECD 2022, NEA No. 7628

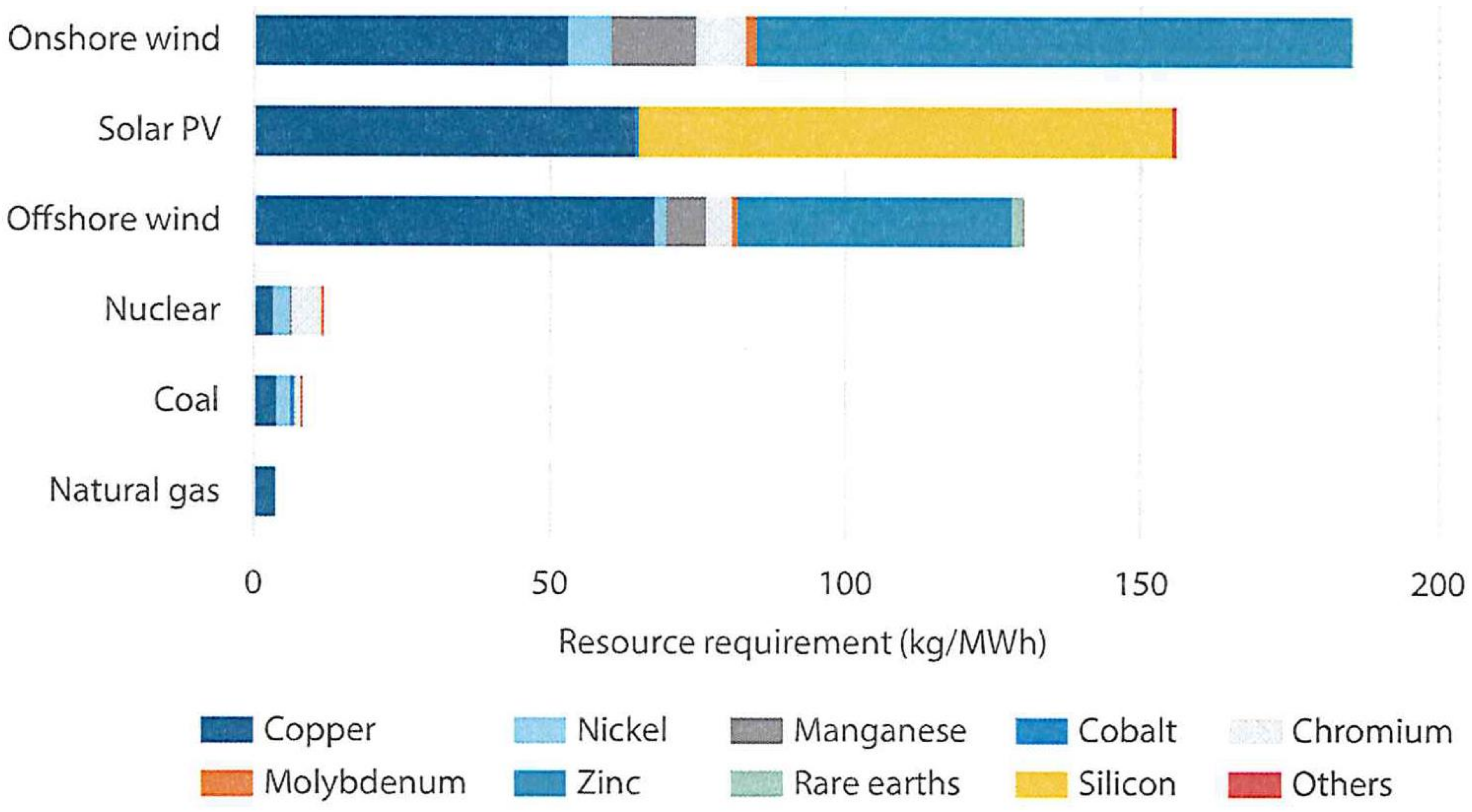
CONSUMPTION OF MATERIALS FOR EACH ENERGY SOURCE



Sources: DOE Quadrennial Technology Review, Table 10.4
Murray, Raymond L. Holbert, Keith E.. (2015). Nuclear Energy - An Introduction to the Concepts, Systems, and Applications of Nuclear Processes (7th Edition). Elsevier. page 97

ENVIRONMENTAL PROGRESS

CRITICAL MINERALS FOR DIFFERENT SOURCES OF ELECTRICITY



Source: Analysis based on IEA (2021) data.

Amount of metals required per unit electricity produced by PV solar system (kg/kW h)	
Aluminium	1.7×10^{-3}
Chromium	2.6×10^{-6}
Copper	4.2×10^{-4}
Iron	1.3×10^{-3}
Lead	1.3×10^{-6}
Magnesium	5.4×10^{-5}
Manganese	4.4×10^{-6}
Molybdenum	4.2×10^{-6}
Nickel	5.0×10^{-8}
Silver	2.9×10^{-6}
Tantalum	7.8×10^{-7}
Tin	1.6×10^{-6}
Zinc	3.1×10^{-6}

PV solar system mounted on a slanted roof in Switzerland (3 KW peak power panel)
Source: UNSCEAR 2016 Report to UN General Assembly Annex B

Source: Meeting Climate Change Targets: The Role of Nuclear Energy, OECD 2022, NEA No. 7628

ARE RENEWABLE SOURCES ENVIRONMENTALLY FRIENDLY?

NUCLEAR RESEARCH INSTITUTE

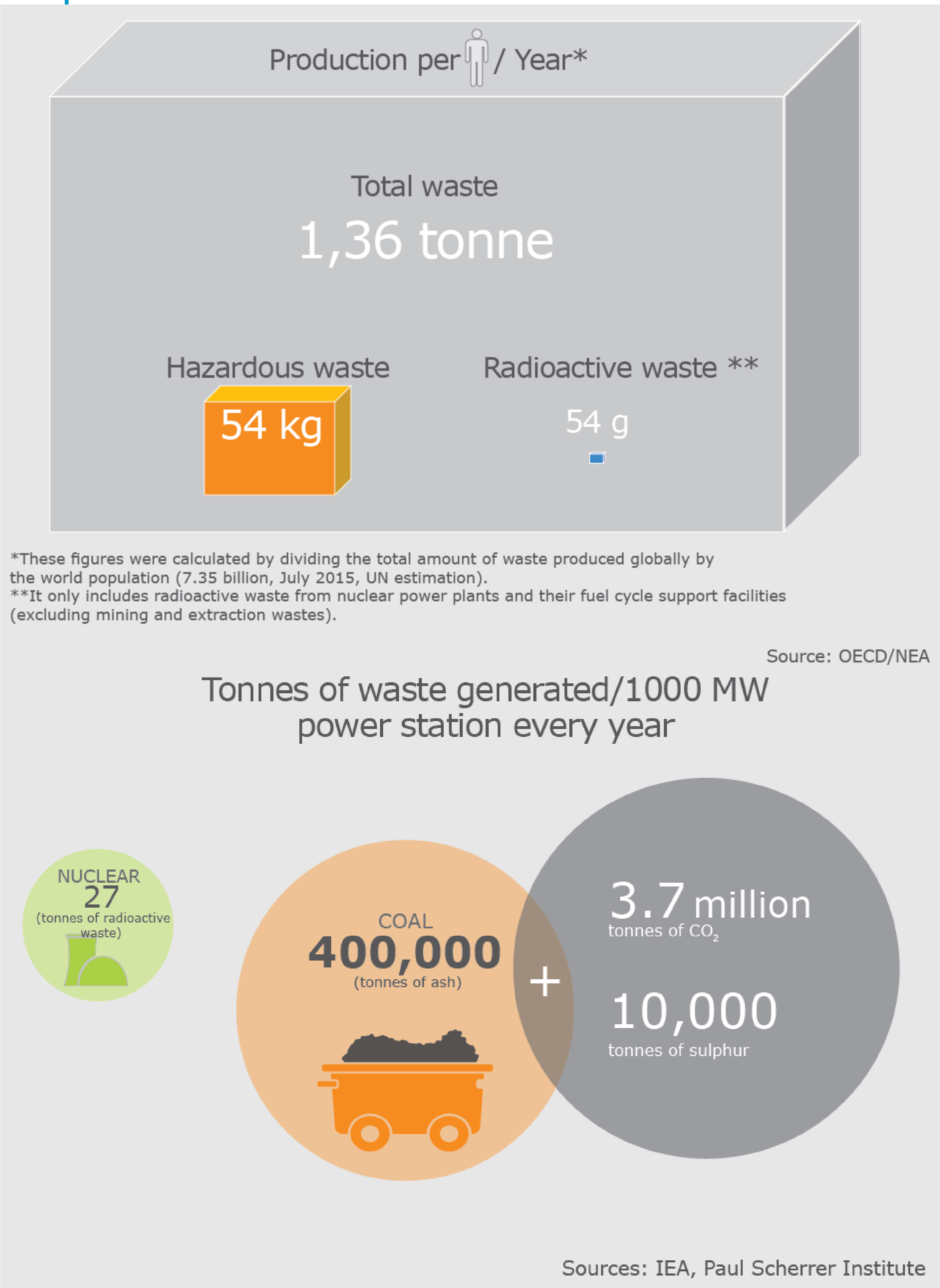
- “Wind and solar plants are gas plants” (M. Conley&T.Maloney, 17 April 2015, Preparation for the book “Power to the Planet”)
- Environmental effects of huge infrastructures and hydro energy storages not to be counted? *(500 MWh needs to pump roughly 1 800 000 tonnes of water 100 m high)*
  - Area of largest hydro storage in Czech Republic covers 15.4+16.3 ha, connecting tunnels with 3.6-5.2 m diameter 2x1.9 km long
- Wind turbines kill between 140,000 and 328,000 birds in the U.S. every year (2013 study of Smithsonian Conservation Biology Institute)
- More than 2,000 wild birds were burned flying through an area of intense heat between the mirrors and the power towers at the US Ivanpah solar plant between March and August of 2015, according to estimates that biologists hired by the plant owners

Largest hydro storage in Czech Republic “Dlouhe strane”

UJV Group
PEOPLE | INNOVATION | TECHNOLOGY

WASTE ISSUE – COMPARISON OF NORMAL WASTE AND RADIOACTIVE WASTE

NUCLEAR RESEARCH INSTITUTE



Single use (disposable) baby diapers in Slovakia

- Annual amount: 20 000 tons
- Time for decomposition of absorbing gel: 350 – 500 years

Radioactive waste from operation of 4 reactor units (producing about 56 % of electricity in Slovakia)

- Annual volume of liquid waste: 75 m3
- Annual amount of solid waste: 82 tons
- Time for radioactive decay to releasable level: 300 years

Waste from 1000 MW coal burning plant

Annual volume of liquid waste: 75 m3

- 200 000 tons/year

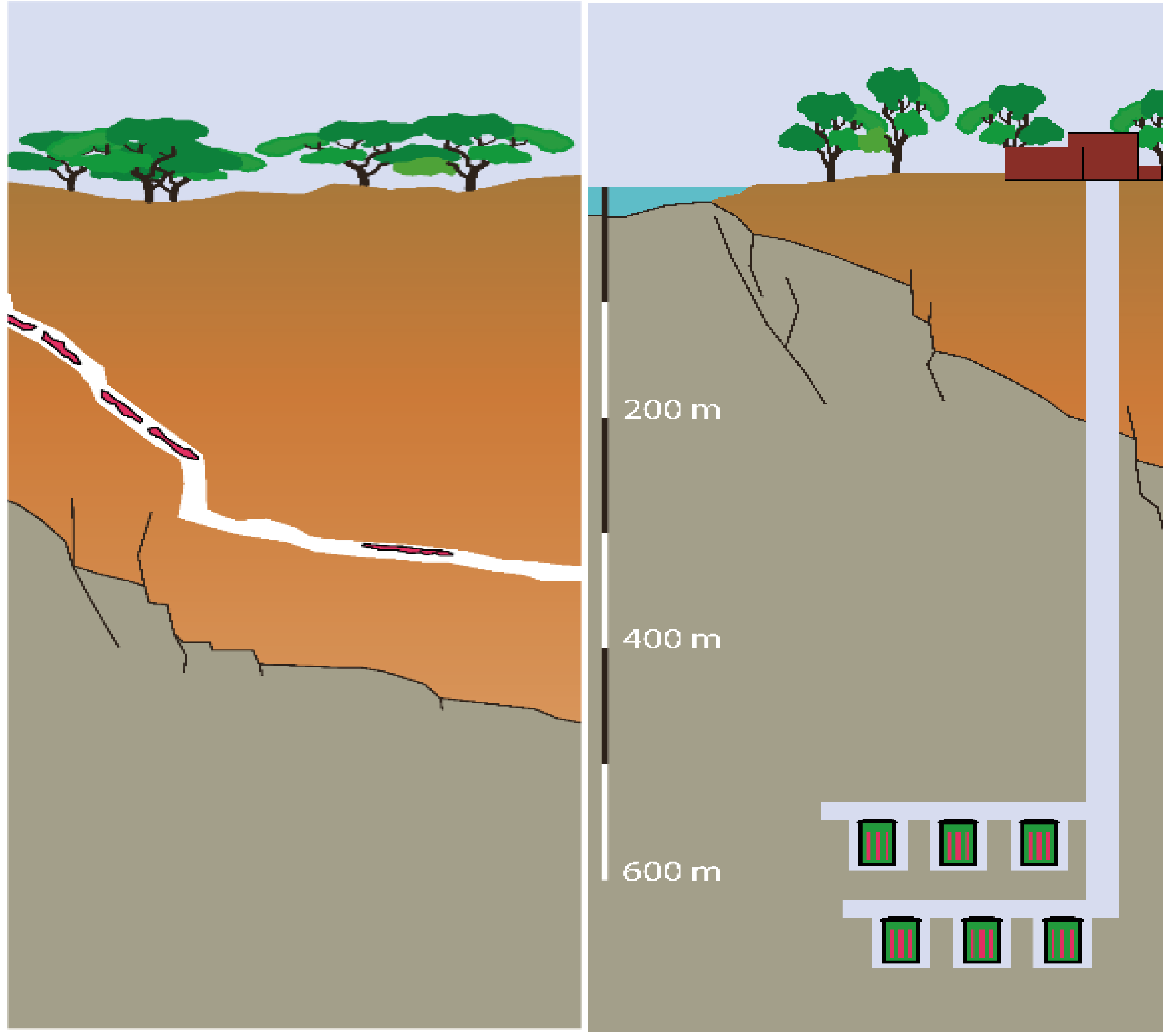
Vitrified high level waste

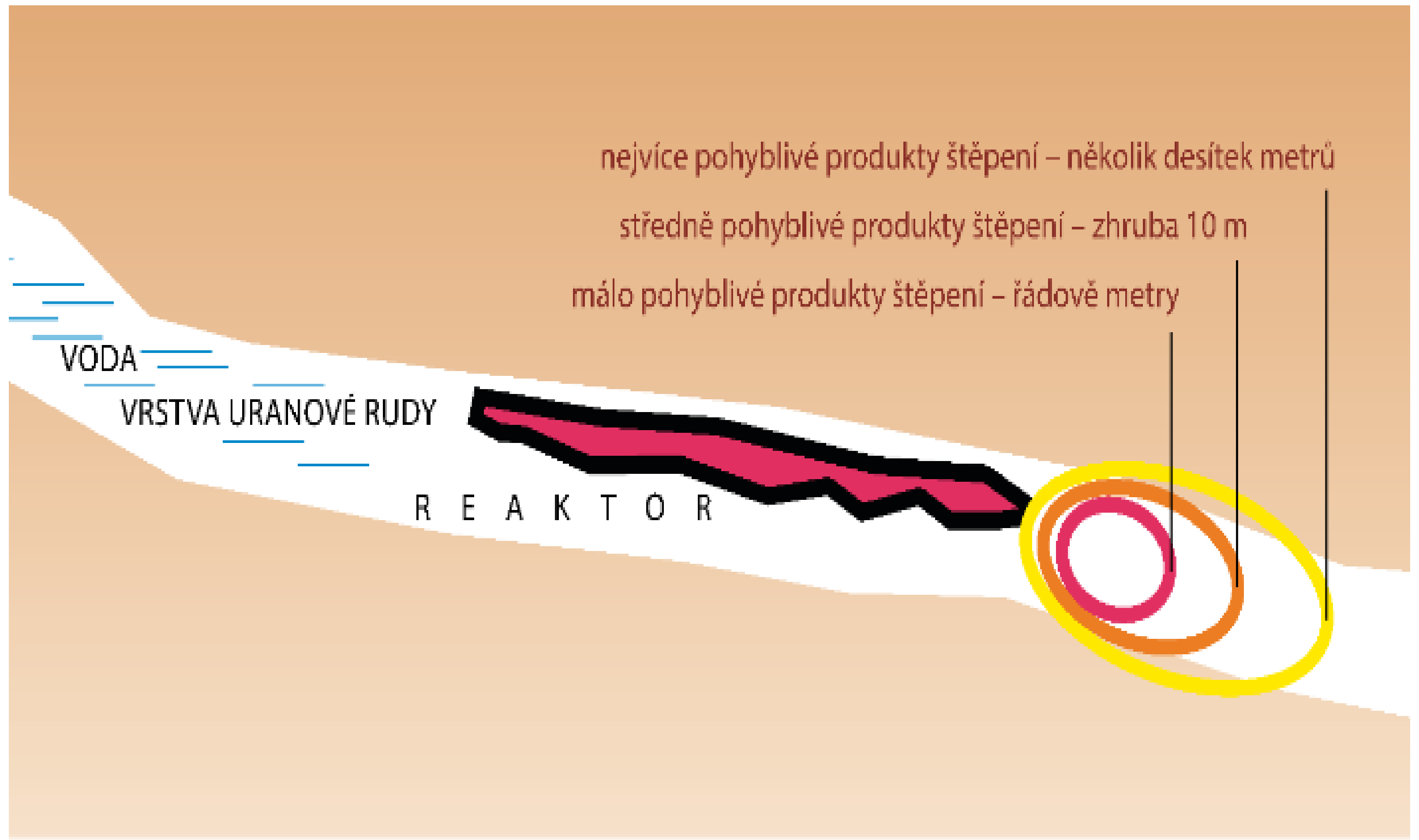
- Waste generated from production of electricity for the average household for 25 years can be fixed in a glass cylinder (ø5 x 5 cm)
- All the high-level waste from fifty years of operation of 2 Cech NPPs would be a glass cube with an edge of 9.5 m

UJV Group
PEOPLE I INNOVATION I TECHNOLOGY

WASTE ISSUE – DEEP GEOLOGICAL REPOSITORY
NATURAL REACTOR, OKLO-AFRICA, 2 BILLION YEARS AGO

NUCLEAR RESEARCH INSTITUTE





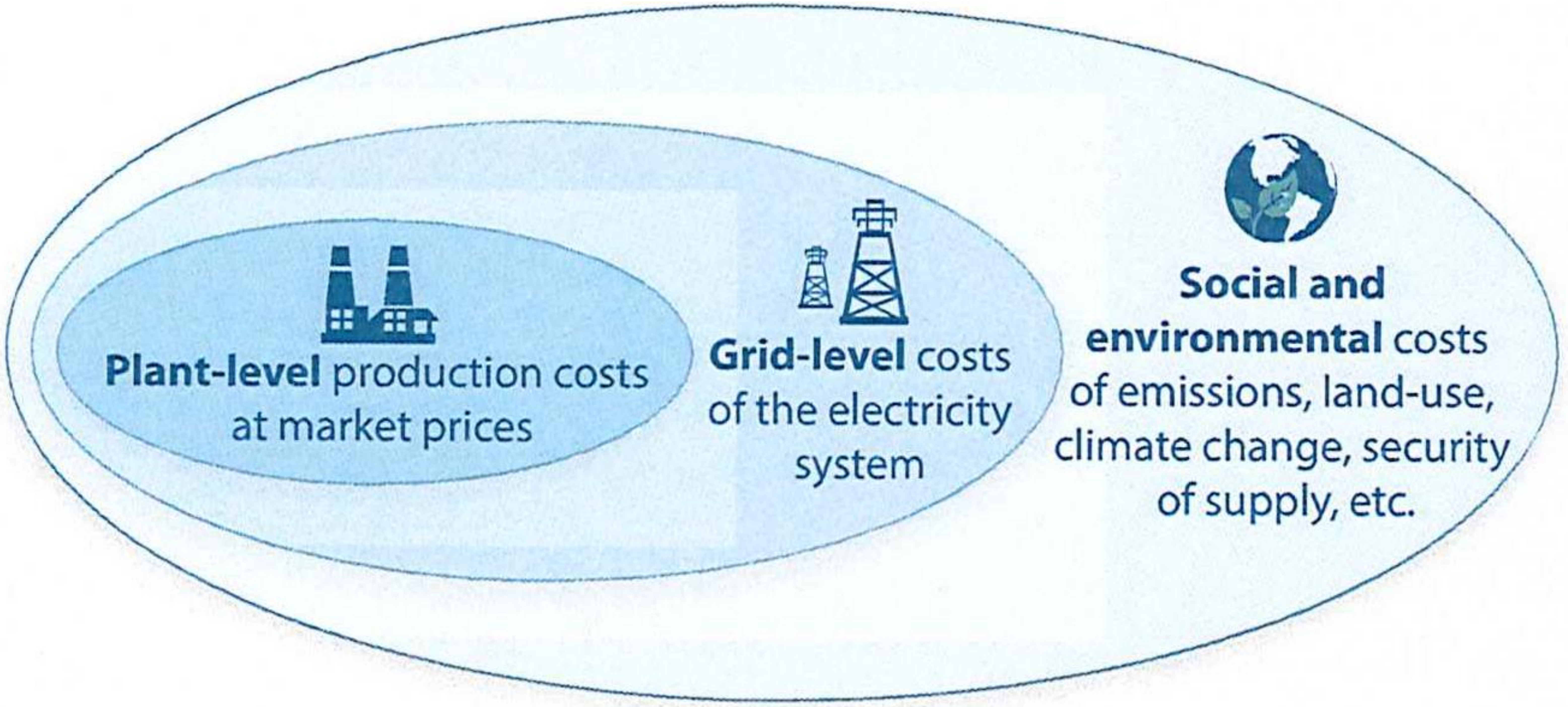
- Natural nuclear reactor
  - Water permeable sandstone
  - Uranium ore layers forming reactors
  - Impermeable rock
- Deep geological repository
  - 1st barrier container, resistance tens of thousands of years
  - 2nd barrier insulation preventing water from entering the containers
  - 3rd barrier high quality no-crack rock (granite)
  - In 2 billion years, the most mobile fission products have reached a maximum distance of hundreds of meters from the reactor

UJV Group
PEOPLE | INNOVATION | TECHNOLOGY

SUMMARY ON VRE AND ENVIRONMENT

- VRE are not environmentally friendly.; they are not dispatchable and thus need back-up sources with significant harm on the environment
- VRE require very large areas, for the same average power about 1 500 – 3000 times more space than nuclear
- Consumption of materials for any VRE source is much higher compared to nuclear power, with the need of extensive mining activities
- Complexity of final repository of low and medium level radioactive waste is comparable with many kinds of other wastes, volume of high level waste is small and can be safely placed in deep geological repository
- The residents in the area with wind turbines are subjected to noise by the rotating turbine blades, kill birds and cause visual disturbance

ECONOMICAL COMPETITIVENESS OF VARIABLE RENEWABLE ENERGY SOURCES



Source: Adapted from NEA (2012).

EXPECTED EFFECTS OF LARGE PENETRATION OF VRE ON ELECTRICITY PRICES (JOINT MIT-JAPAN WHITE PAPER: COMPATIBILITY OF NUCLEAR AND RENEWABLES WITH GRID STABILITY, ECONOMICS AND DEREGULATION)

NUCLEAR RESEARCH INSTITUTE

- VRE are high-capital-cost low-operating-cost power sources, similarly as NPPs
- In opposite, fossil plants are low-capital- cost high-operating-cost power sources
- If share of VRE will become high, at sunny days all solar plants would like to deliver to the grid and prices of electricity will be low (if not subsidized) and fossil plant are not needed
- At the time with low solar output other sources will be required to operate, but due to low-capacity factor not economically, unless price of electricity will become very high
- Use of NPPs at low solar output would be a solution, but at present they do not have needed load follow capability
- If VRE are not subsidized, price collapse at the time of high solar output will limit the use of VRE due to revenue collapse

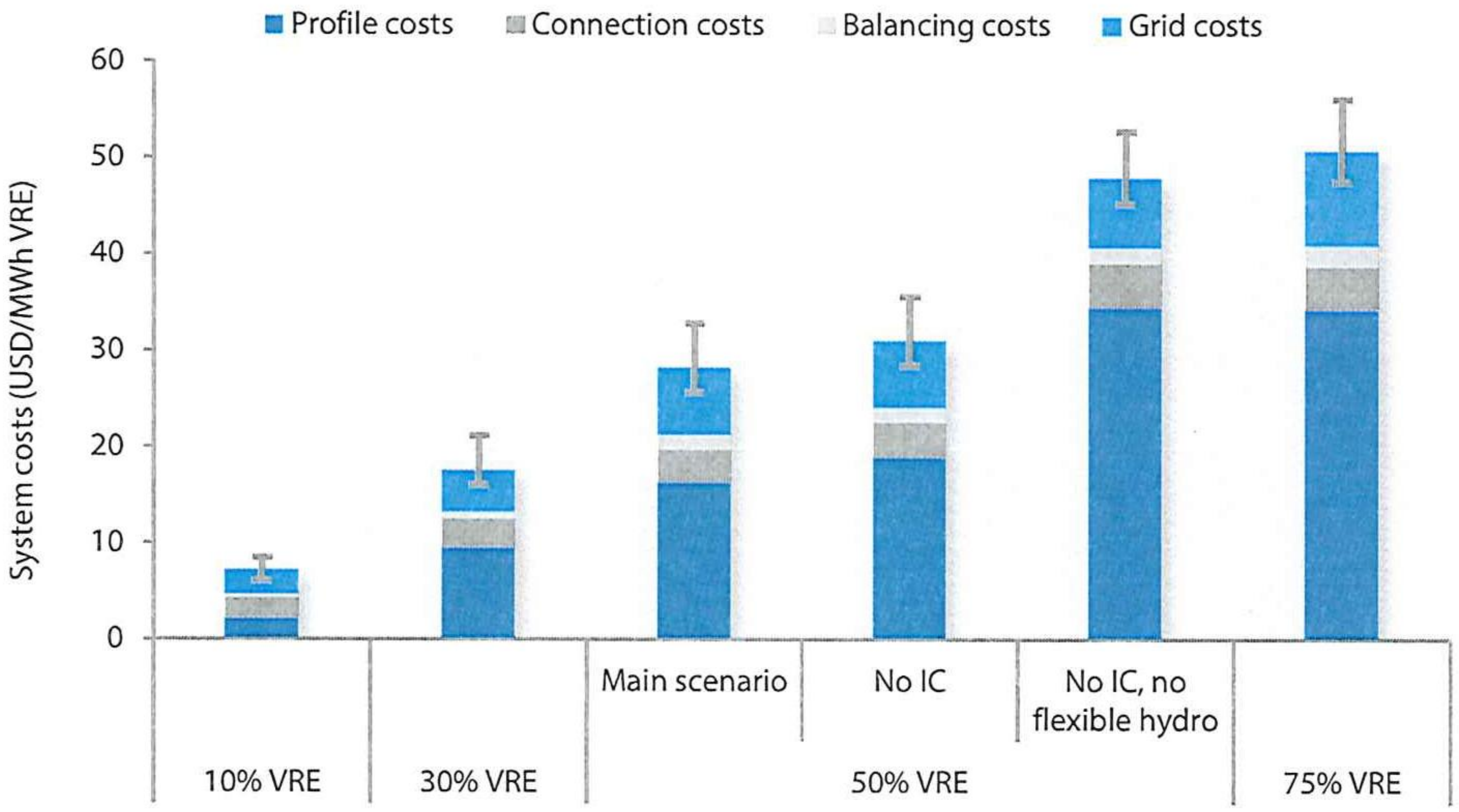
COMPONENTS OF SYSTEM COSTS

- **Profile costs:** (or utilization costs) refer to the increase in the generation cost of the overall electricity system in response to the variability of VRE output.
- **Connection costs** consist of the costs of connecting a power plant to the nearest connecting point of the transmission grid.
- **Balancing costs** refer to the increasing requirements for ensuring the system stability due to the uncertainty in the power generation (unforeseen plant outages or forecasting errors of generation).
- **Grid costs** reflect the increase in the costs for transmission and distribution due to the distributed nature and locational constraint of VRE generation plants. Grid costs include the building of new infrastructures (grid extension) as well as increasing the capacity of existing infrastructure (grid reinforcement).
- Not addressed in the list of four cost categories is the provision of **physical inertia**, which is implicitly provided by dispatchable plants but not by VRE, not yet resolved.
- All technologies have system costs; nuclear, for instance, requires strong network connections and access to reliable cooling sources. However, these costs are an order of magnitude lower than those imposed by the variability of renewable energies.

Source: The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables, OECD/ NEA No. 7299, 2019

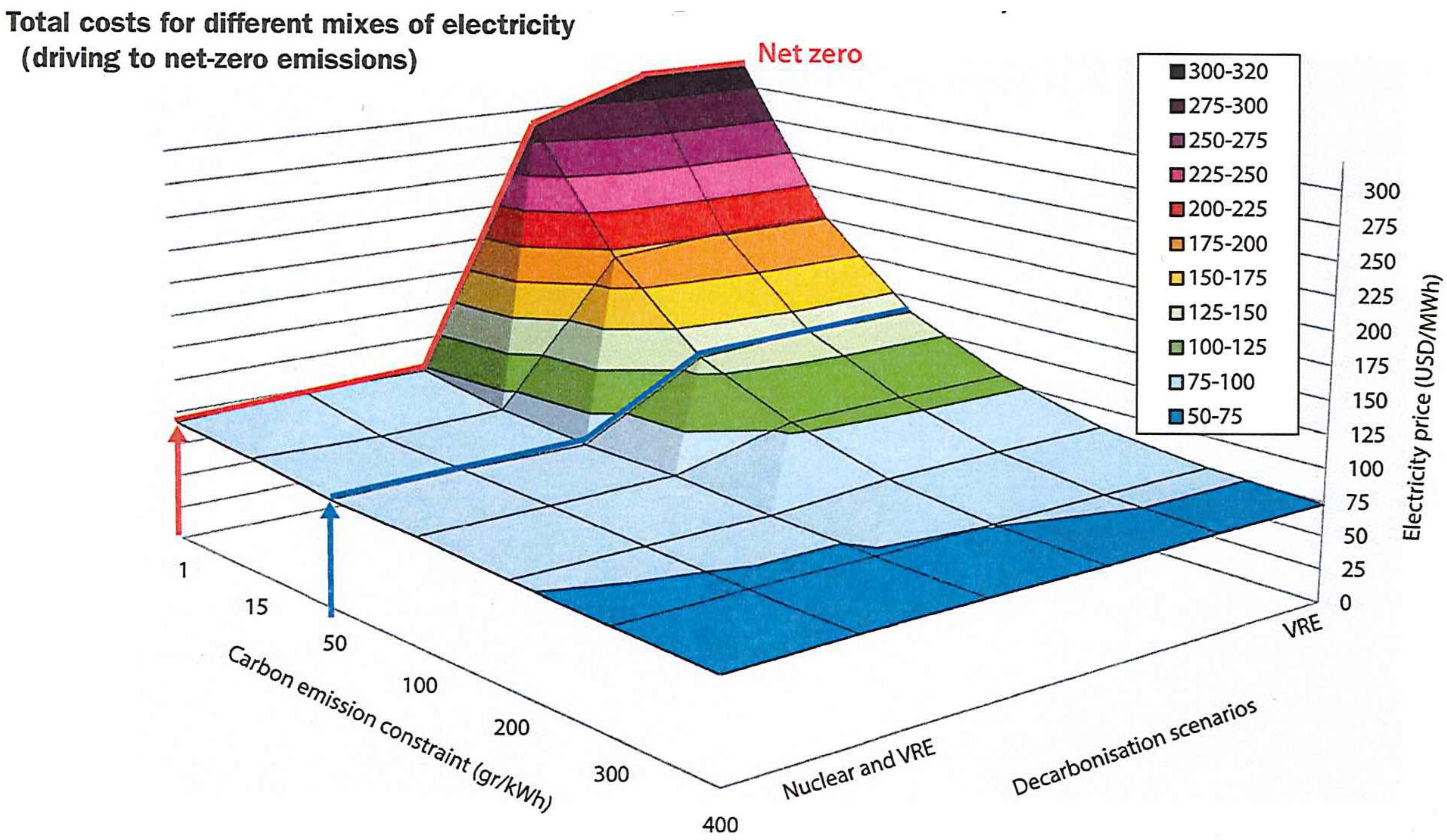
SYSTEM COSTS TO BE ADDED TO GENERATION COSTS

- System costs per MWh of VRE



Source: The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables, OECD/ NEA No. 7299, 2019

INCREASE OF SYSTEM COSTS WITH SHARE OF VRE



Source: Based on Sepulveda (2016).

Source: Meeting Climate Change Targets: The Role of Nuclear Energy, OECD 2022, NEA No. 7628

EFFECTS OF SYSTEM COSTS

NUCLEAR
RESEARCH
INSTITUTE

- System costs can be substantial and depend on the level of VRE penetration
- At 10% of VRE electricity generation the system cost of VRE is about 7, at 30% it is 17.5, at 50% it is 30 and then up to 50 USD/MWh_{VRE}
- System cost needs to be added to the plant generation costs from USD 60 per MWh for onshore wind to up to USD 130 per MWh for solar PV.
- VRE revenues from electricity markets decline significantly and non-linearly as their penetration level increases; zero-level electricity prices start when VREs reach a penetration level of 30%.
- The higher frequency of hours with zero prices needs to be compensated by an increase of the number of hours with high electricity prices
- The number of hours in which electricity price is higher than USD 100 per MWh increases substantially when the generation share of VRE exceeds 30%
- High volatility of prices significantly increases the electricity market risk for all generation technologies.

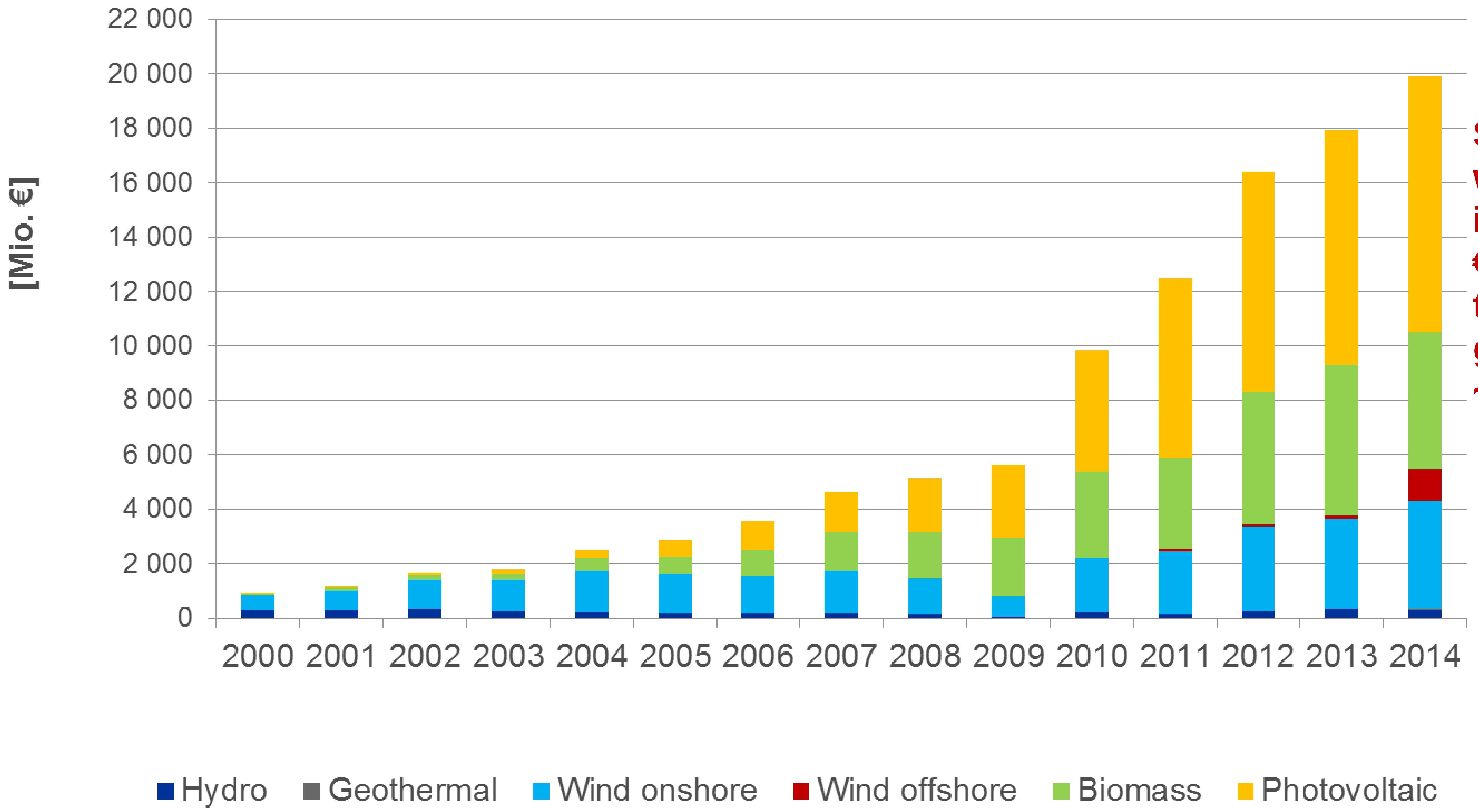
Source: The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables, OECD/ NEA No. 7299, 2019

SUBSIDIES IN GERMANY TO RENEWABLE SOURCES UNDER THE RENEWABLE ENERGY SOURCE ACT (EEG)

NUCLEAR RESEARCH INSTITUTE

Support until 2014: ~ 106 billion €

Future funding of existing capacities: ~ 300 billion €



Subsidies to PV, wind and biomass in 2014~ 145 €/MWh compared to current generation price ~25€/MWh

Prof. A. Voß, 8th International School on Nuclear Power, 28 October, 2015 Warsaw, Poland

UJV Group
PEOPLE | INNOVATION | TECHNOLOGY

SUMMARY ON ECONOMICAL COMPETITIVENESS OF VRE SOURCES

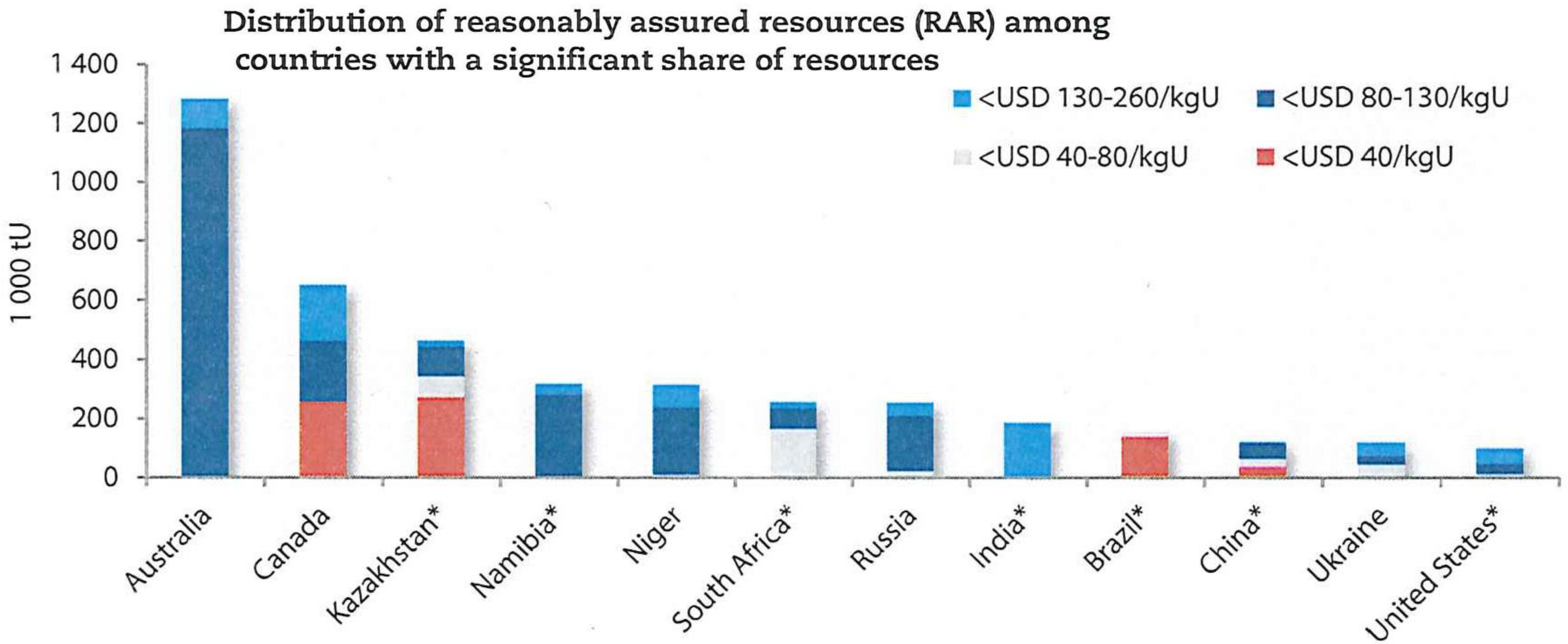
NUCLEAR RESEARCH INSTITUTE

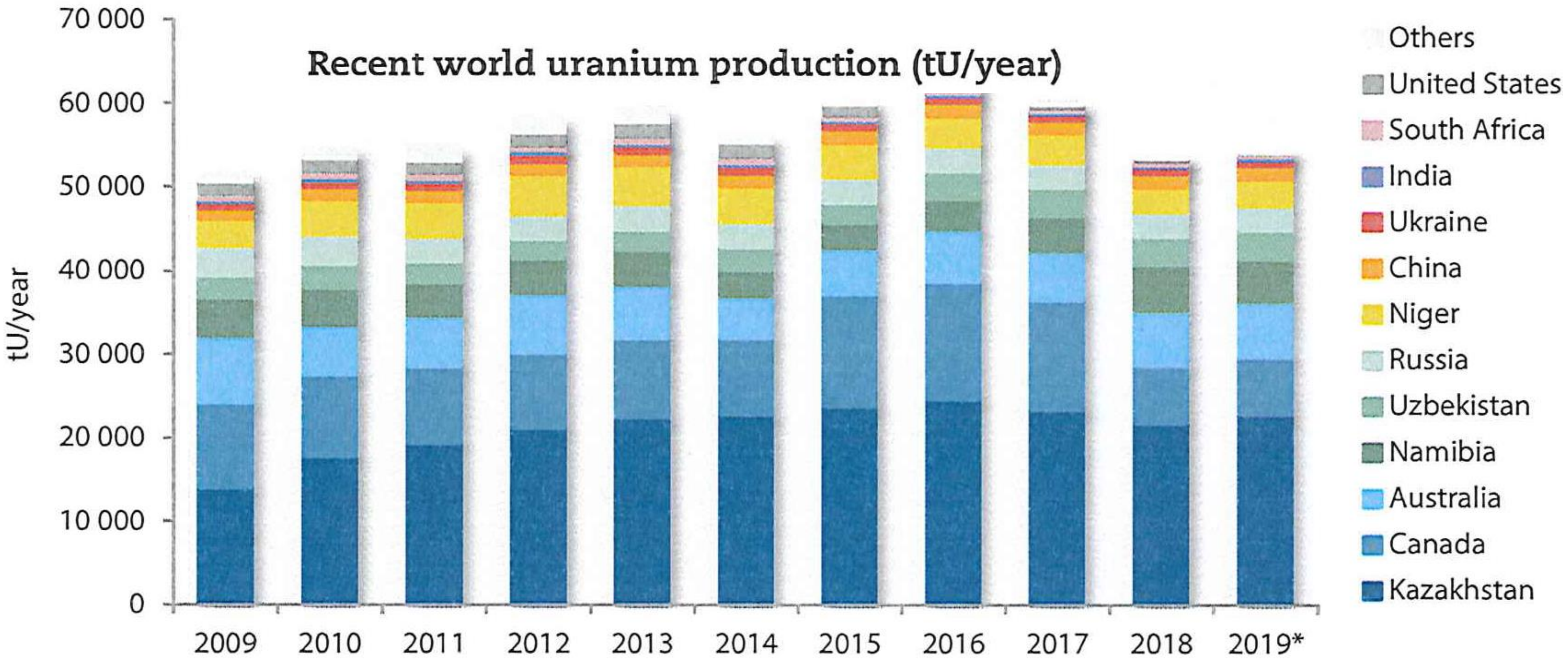
- VRE are not competitive and are dependent on subsidies or on favorable legislation.
- There is big difference between the production cost of a kWh generated and consumed locally and the cost of a kWh delivered to the electrical grid.
- In addition to production cost it is necessary to account for the system cost, including profile costs, connection costs, balancing costs and grid costs
- System costs can be substantial and strongly increase with the level of VRE penetration
- Increased periods with very low prices from VRE needs to be compensated by increased periods with high electricity prices from back-up sources
- High volatility of prices significantly increases the electricity market risk for all generation technologies
- VRE deleteriously affect grid reliability, with serious economic and social consequences of blackouts occurred in large urban areas.

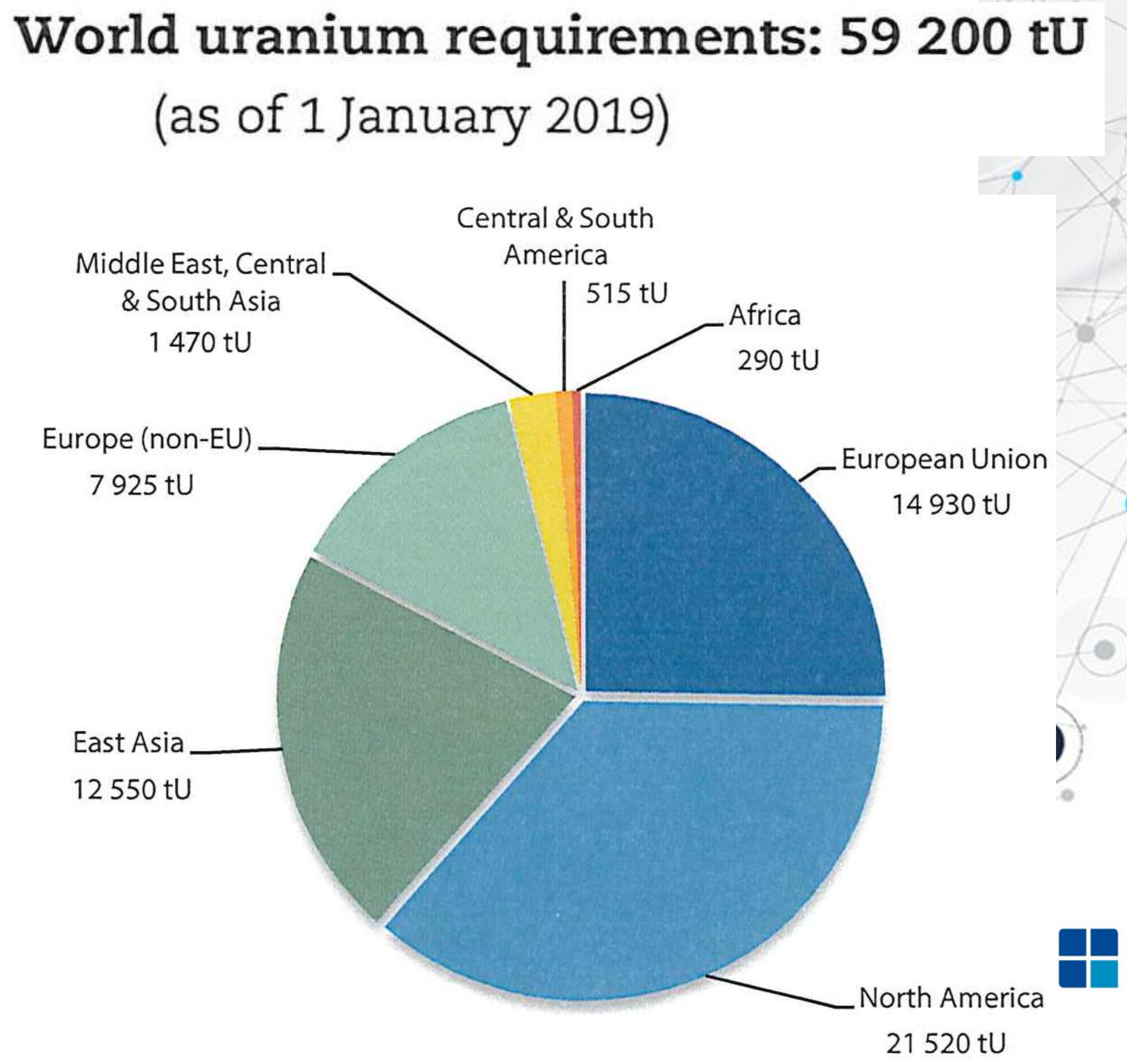
SUSTAINABILITY OF NUCLEAR POWER (URANIUM RESOURCES)

URANIUM RESOURCES (AS OF JANUARY 2019)

Source: Uranium 2020: Resources, Production and Demand, OECD 2020, NEA No. 7551

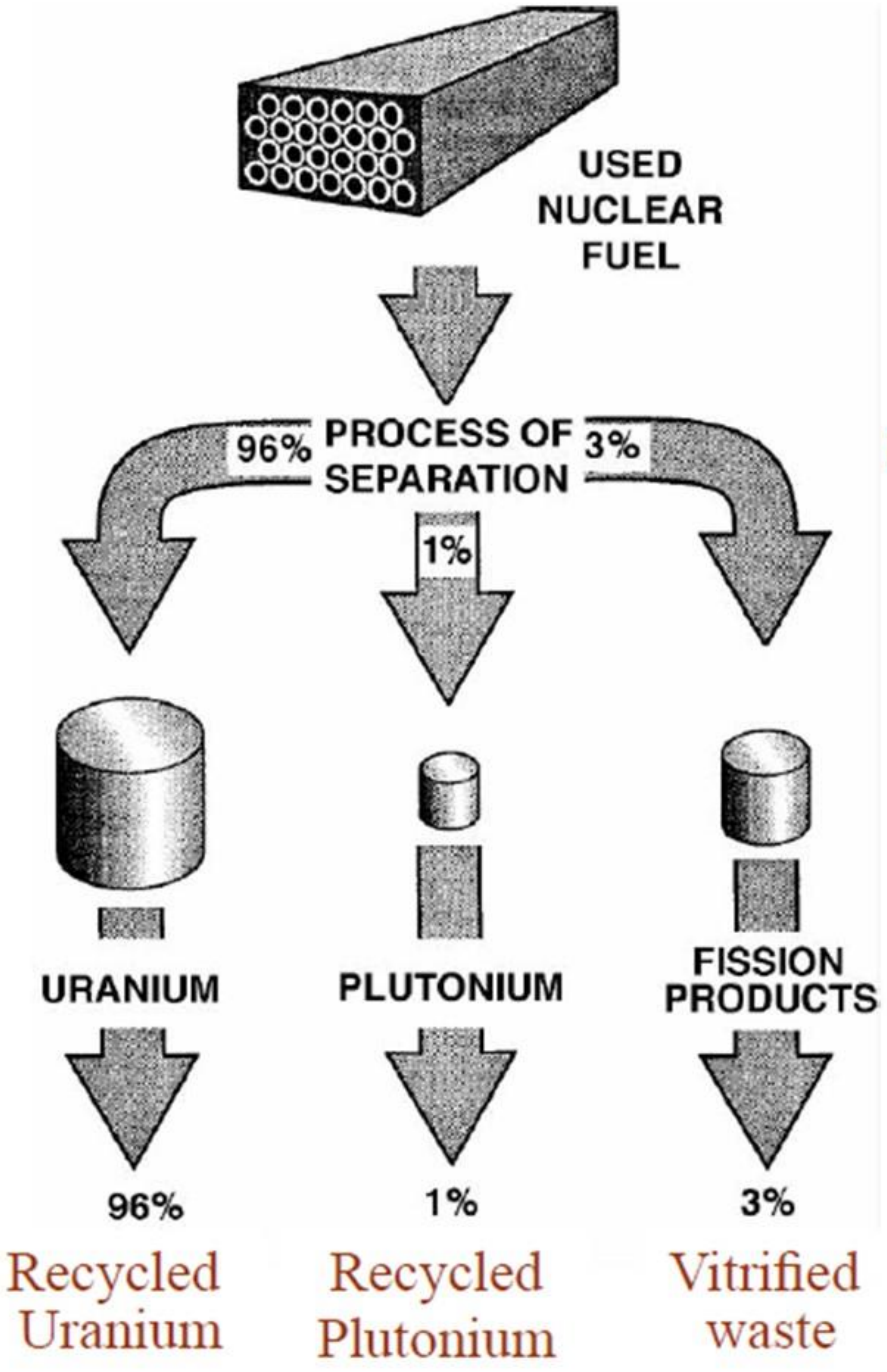


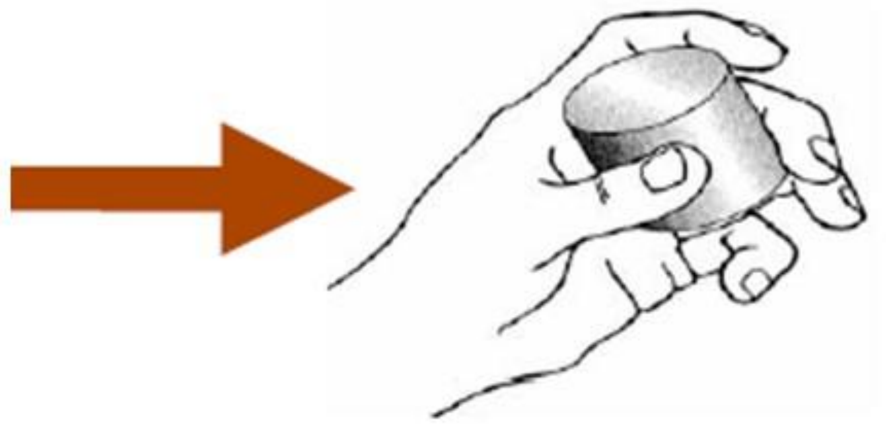




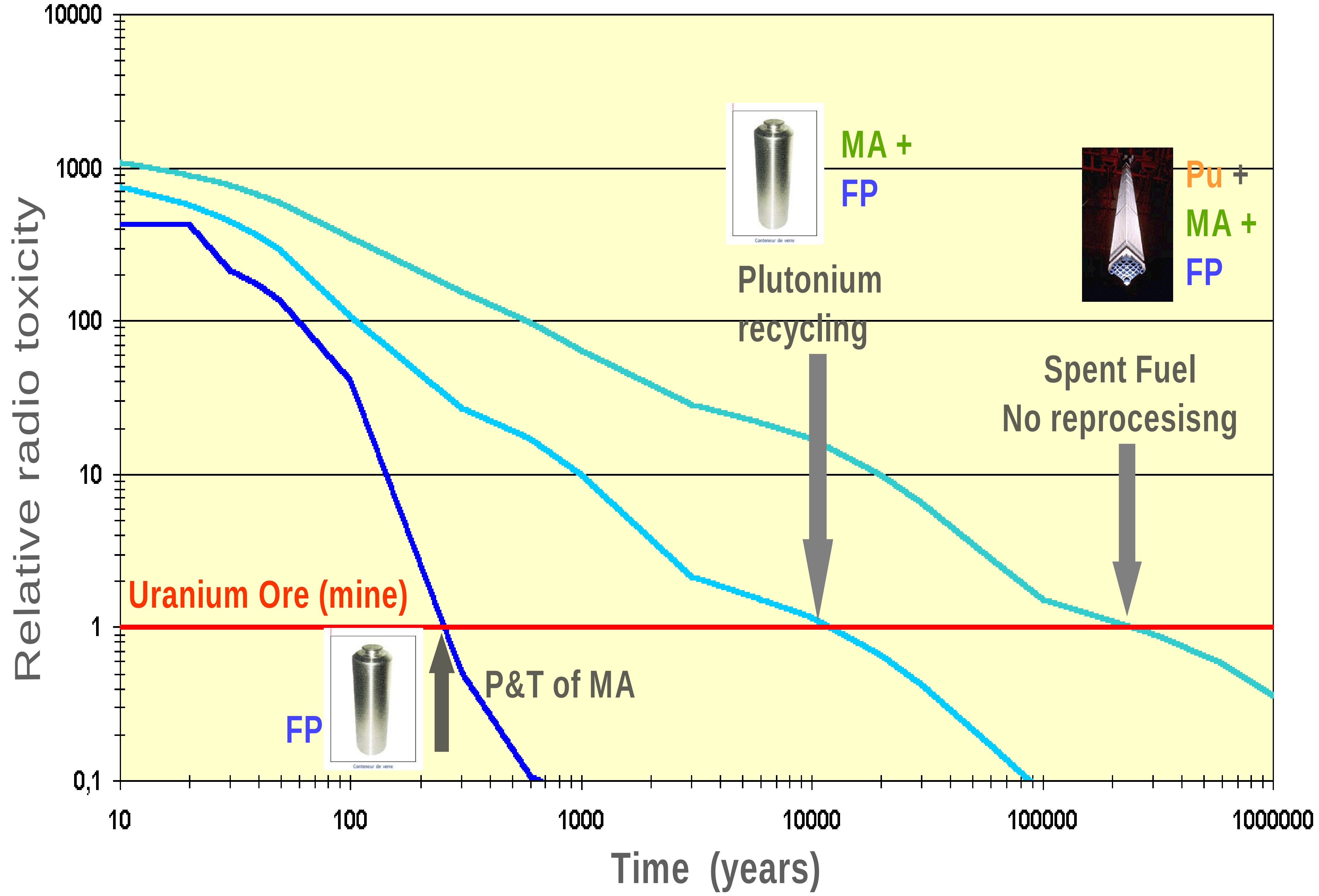
REPROCESSING OF USED NUCLEAR FUEL

NUCLEAR RESEARCH INSTITUTE





Volume of vitrified waste produced by a typical French family in 30 years



Composition of natural uranium:

^{234}U 0,0058%, ^{235}U 0,72%, ^{238}U 99,27%

Nuclear reactions producing new fissionable material:

$^{238}U + n \rightarrow {}^{239}U \rightarrow {}^{239}Np + \beta^- + g \rightarrow {}^{239}Pu + \beta^- + g$

$^{232}Th + n \rightarrow {}^{233}Th \rightarrow {}^{233}Pa + \beta^- + g \rightarrow {}^{233}U + \beta^- + g$

B. Comby, President of Environmentalists for Nuclear Energy, 8th International School on Nuclear Power, 28 October, 2015 Warsaw

TIME SUSTAINABILITY OF NUCLEAR ENERGY

NUCLEAR RESEARCH INSTITUTE

- Deployment of fast-neutron fission reactors will harvest up to one hundred times more energy from the same amount of mined uranium
- Mining of small quantities of uranium in future centuries, including extracting uranium from lower-grade ores and from seawater, could satisfy global energy needs economically for as long as human civilization will endure.

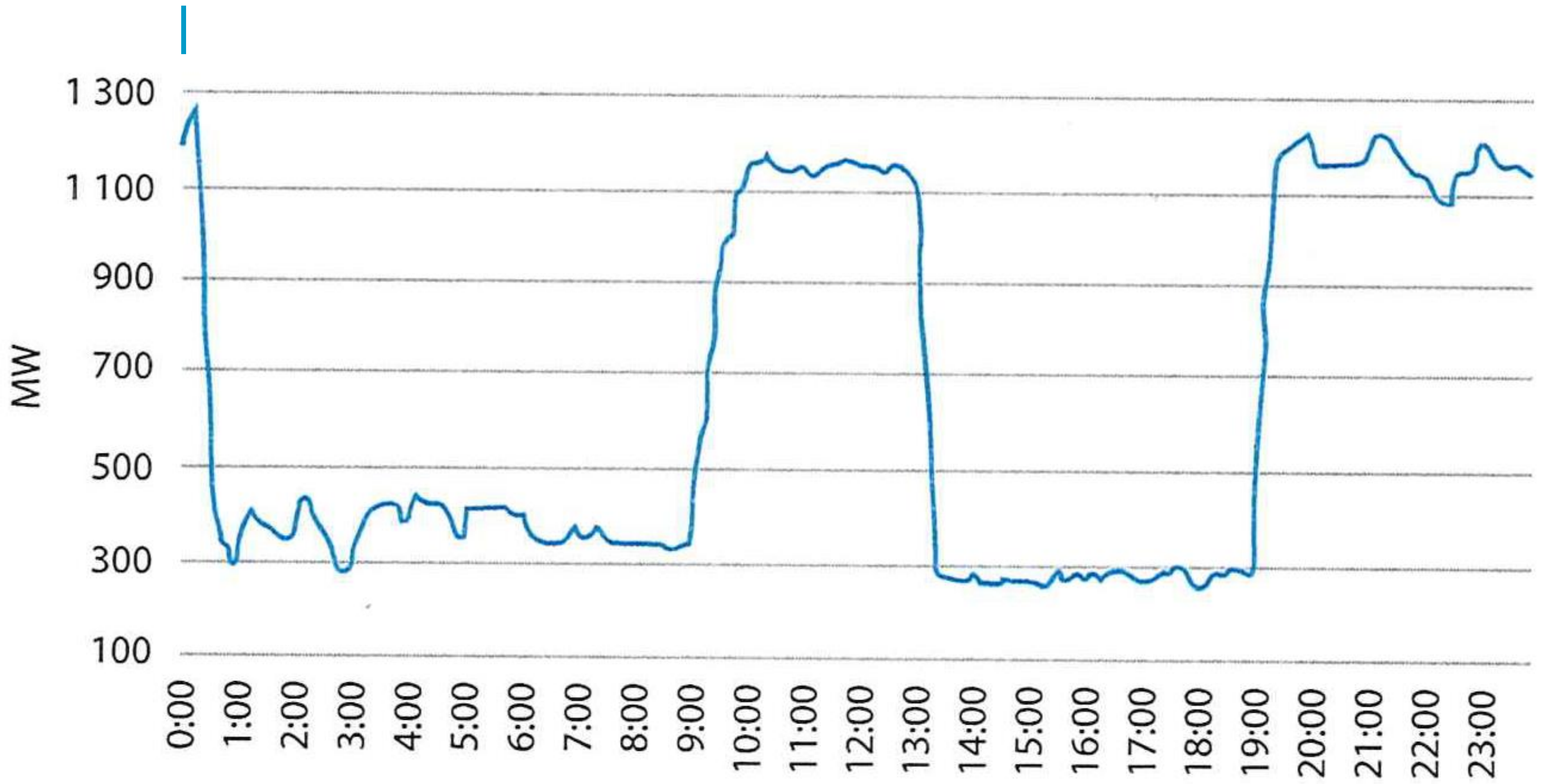
Results of simplified calculation of energy accumulated in the spent fuel In Slovakia

➢ Electricity produced in Slovak NPPs till 2050	5 496,56 PJ
➢ Mass of minor actinides in spent fuel	4,1 t
➢ Mass of plutonium in the spent fuel	41,0 t
➢ Mass of fission products in the spent fuel	187,7 t
➢ **Thermal energy stored in the spent fuel**	**327 921,2 PJ**
➢ Potential for electricity produced in a FBR (assuming 45 % efficiency)	40 990,15 TWh
➢ Current annual electricity consumption in Slovakia	30 TWh
➢ **Coverage of current consumption**	**1 366 years**

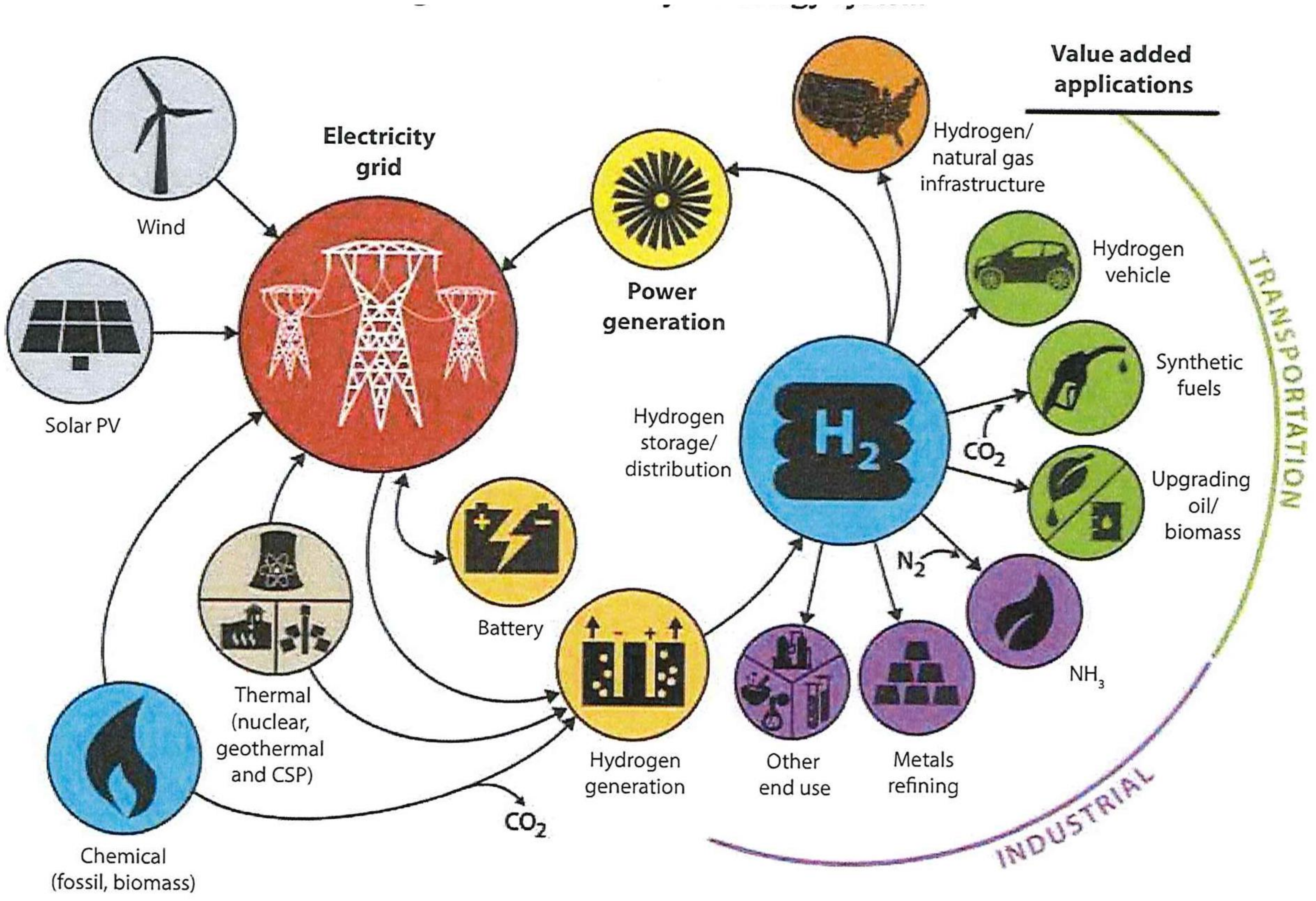
UJV Group
PEOPLE | INNOVATION | TECHNOLOGY

FLEXIBILITY AND MULTIPURPOSE USE OF NUCLEAR ENERGY

NUCLEAR
RESEARCH
INSTITUTE



Example of power variations over 1 day, Golfech nuclear power plant, 1 300 MW



Source: Bragg-Sitton and Boardman (2017). Graphic created by Dr Bryan Pivovar, NREL.

Nuclear power plants can operation in load following mode and have many different applications

Source: Meeting Climate Change Targets: The Role of Nuclear Energy, OECD 2022, NEA No. 7628

UJV Group
PEOPLE | INNOVATION | TECHNOLOGY

SUMMARY ON URANIUM RESOURCES (JANUARY 2019)

NUCLEAR RESEARCH INSTITUTE

- Total in-situ resources: 10 584 500 tU
  - Total identified resources (reasonably assured and inferred): 6 147 800 t U
- Prognosticated and speculative resources: 7 220 300 tU
- Unconventional resources: 39 000 000 tU
- Current annual U consumption (for 450 reactors, 396 Mwe): 59 200 tU
- Planned high increase scenario 626 GWe by 2040: 100 225 tU
- Other resources are available in Thorium
- Existing resources are sufficient for hundreds of years
- Use of uranium with reprocessing provides fuel for thousands of years

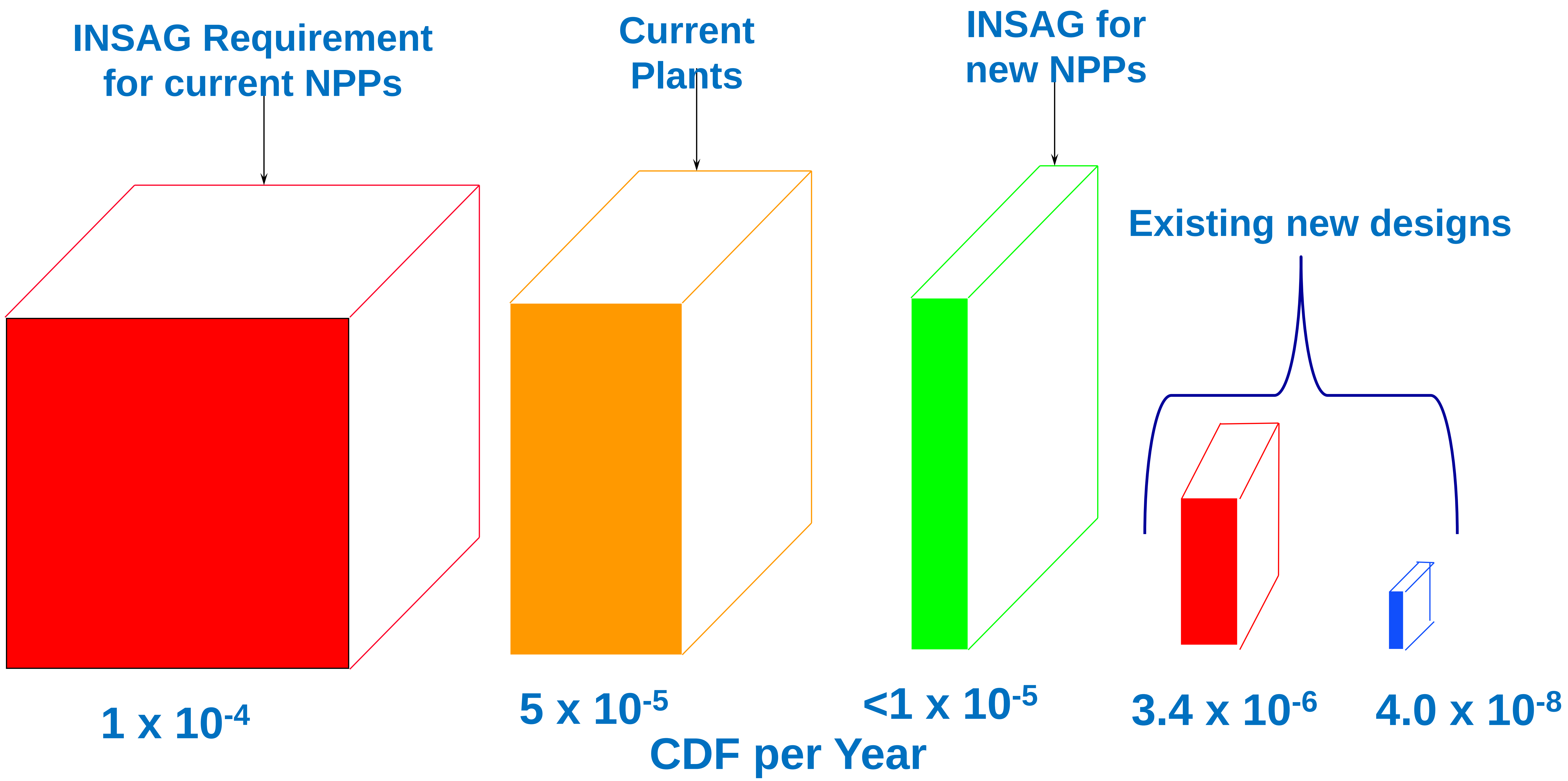
Source: Uranium 2020: Resources, Production and Demand, OECD 2020, NEA No. 7551

UJV Group PEOPLE | INNOVATION | TECHNOLOGY

SAFETY OF NUCLEAR POWER
(RISK OF RADIATION EXPOSURE)

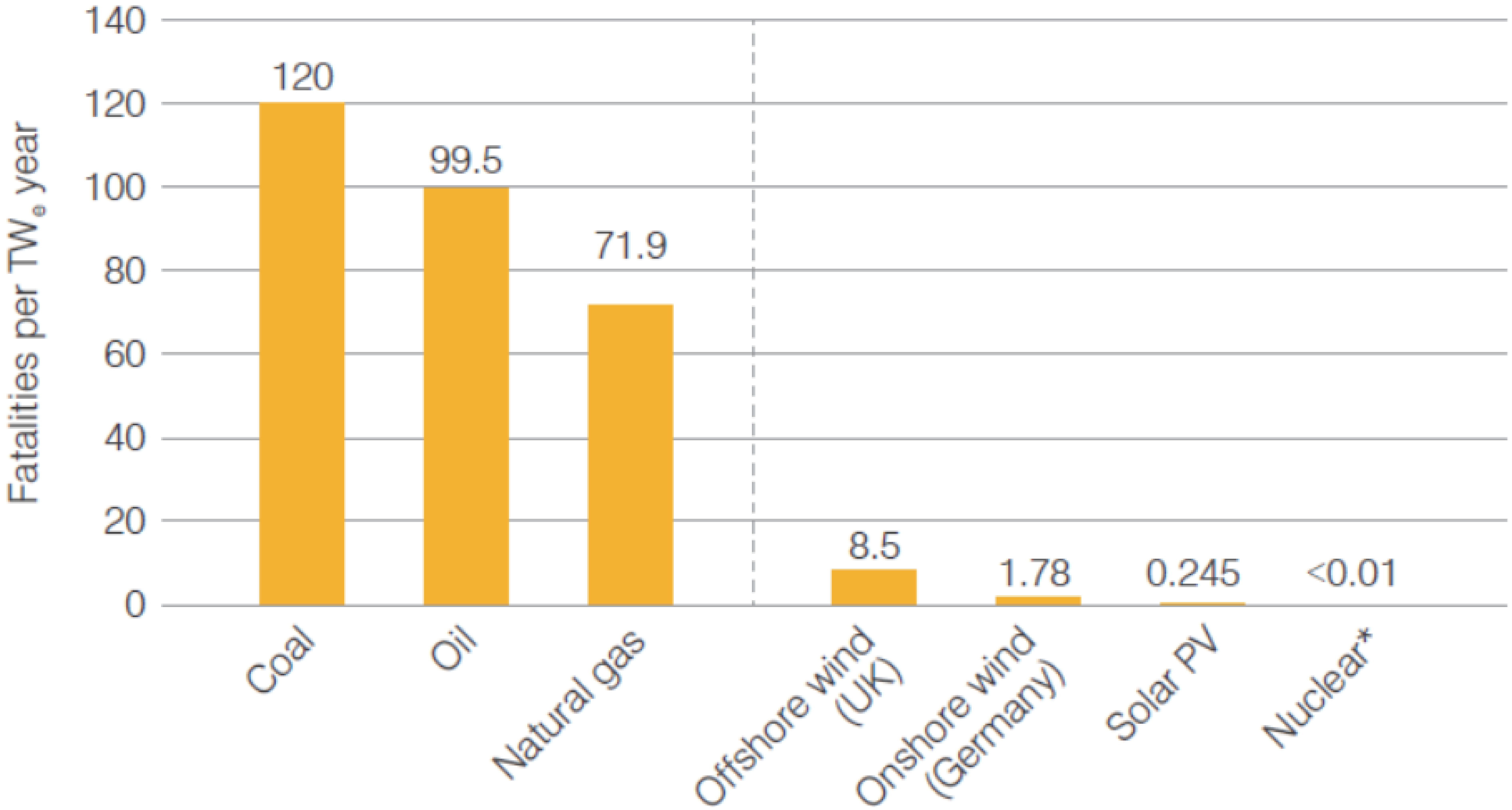
NUCLEAR POWER PLANTS ARE VERY SAFE

Range of quantified safety level for new NPPs:
CDF= 3.8E-8 – 3.39E-6/year, LRF= 3.67E-9 – 6.3E-8/year



COMPARISON OF NUMBER OF FATALITIES DUE TO ELECTRICITY GENERATION (DEATHS PER TW.YEAR)

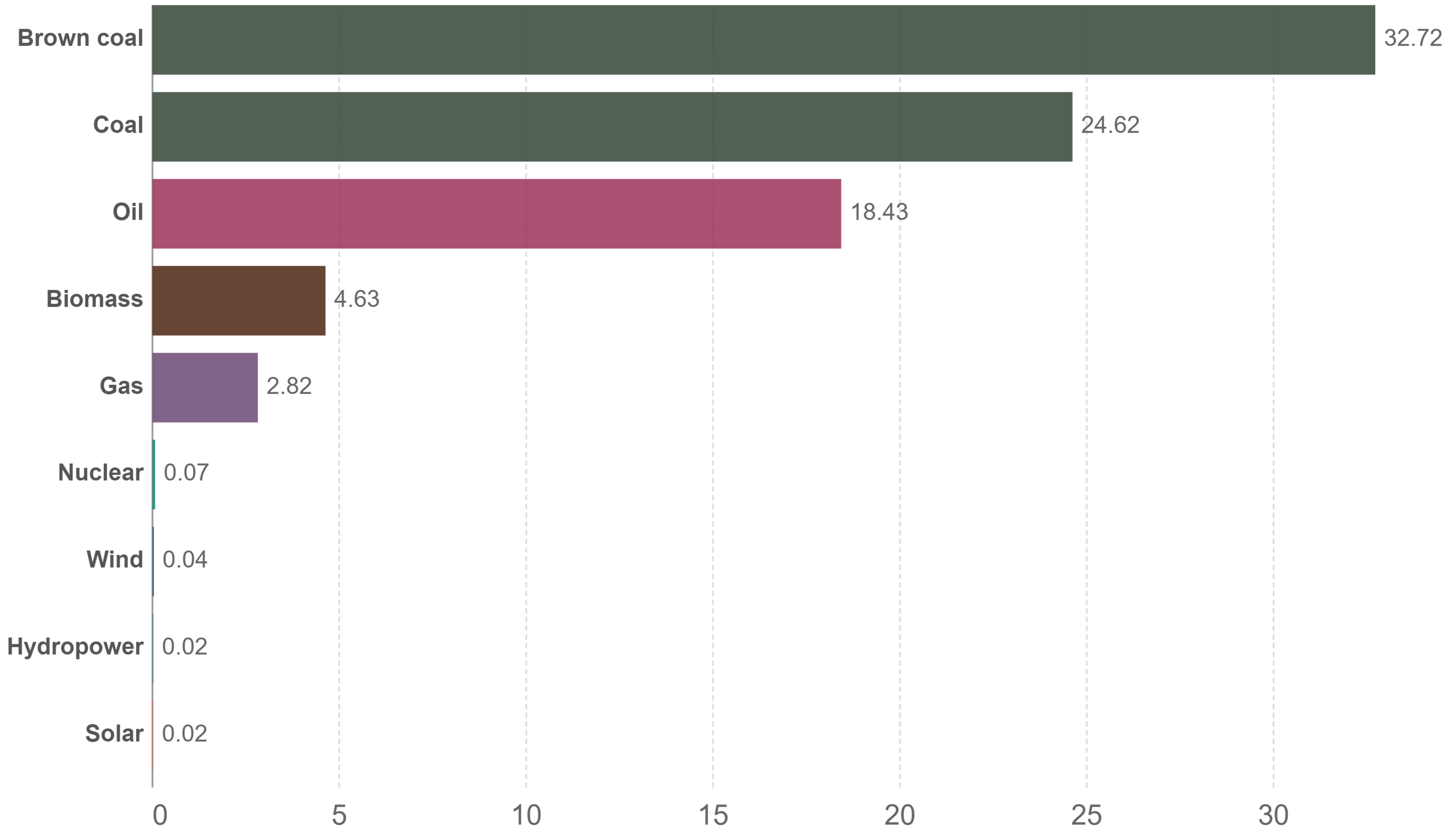
NUCLEAR
RESEARCH
INSTITUTE



Source: ** The Silent Giant. The need for nuclear in a clean energy system, WNA, https://www.world-nuclear.org/getattachment/Our-Association/Publications/Position-statements/the-silent-giant/the-silent-giant.pdf.aspx

NUMBER OF FATALITIES AND EMISSIONS DUE TO ELECTRICITY GENERATION

Death rates are measured based on deaths from accidents and air pollution per terawatt-hour (TWh).



(Source: What are the safest and cleanest sources of energy? - Our World in Data, Hannah Ritchie, February 10, 2020)

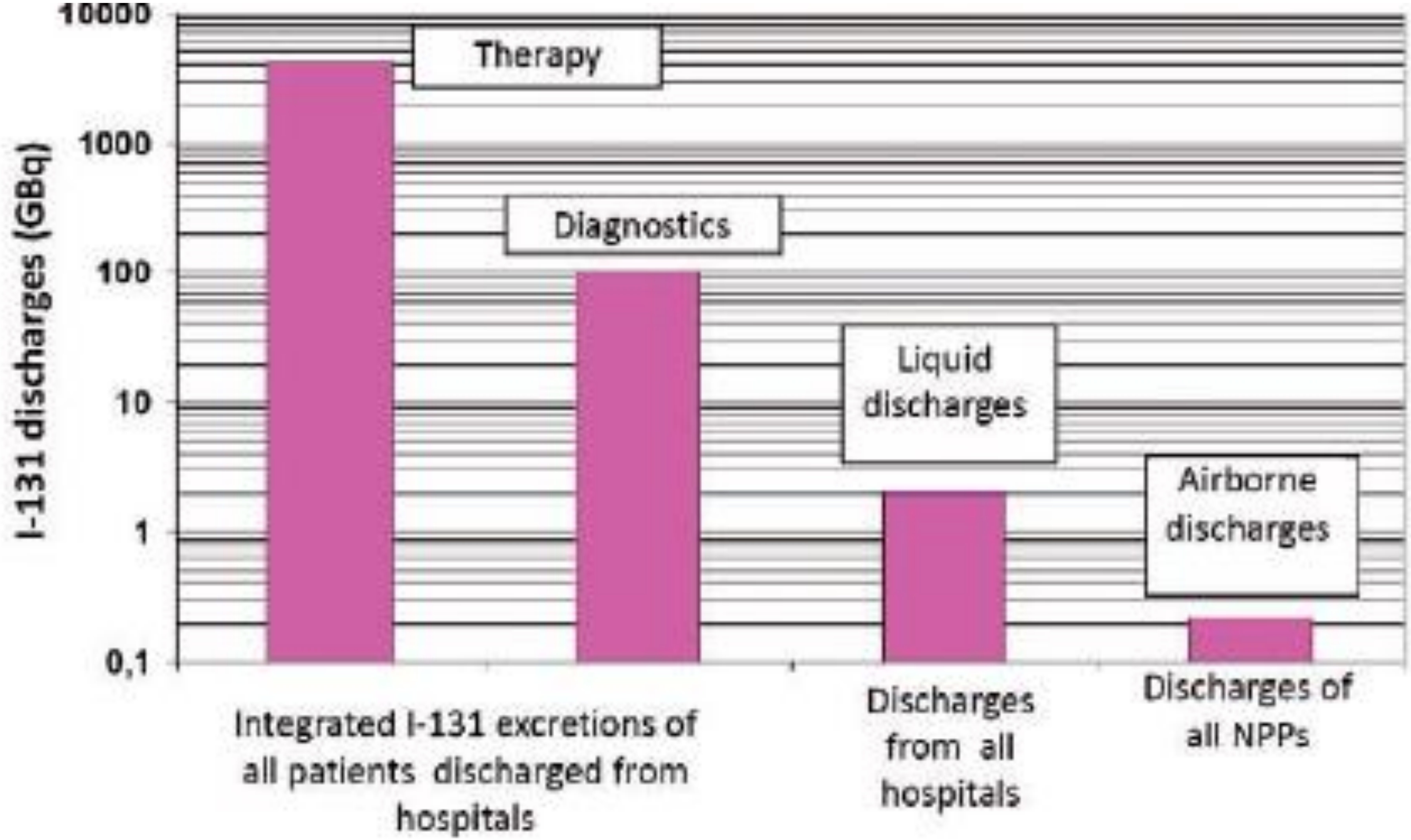
NUCLEAR RESEARCH INSTITUTE

UJV Group PEOPLE | INNOVATION | TECHNOLOGY

CALCULATION OF FATALITIES FROM NUCLEAR ENERGY (Source: What are the safest and cleanest sources of energy? - Our World in Data, Hannah Ritchie, February 10, 2020)

- Estimate by the World Health Organization using a very conservative methodology called the linear no-threshold model, not appropriate according the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).
- The WHO estimates that 4000 people have or will die from the Chernobyl disaster, including the death of 31 people as a direct result of the disaster and the rest from cancers due to radiation exposure.
- Fukushima killed 574 people: in 2018, that one worker died from lung and 573 people died due to the impact of the evacuation and stress.
- Death rate for occupational deaths, most from milling and mining. 0.022 deaths per TWh.
- The sum of these three data points gives us a death rate of 0.07 deaths per TWh.

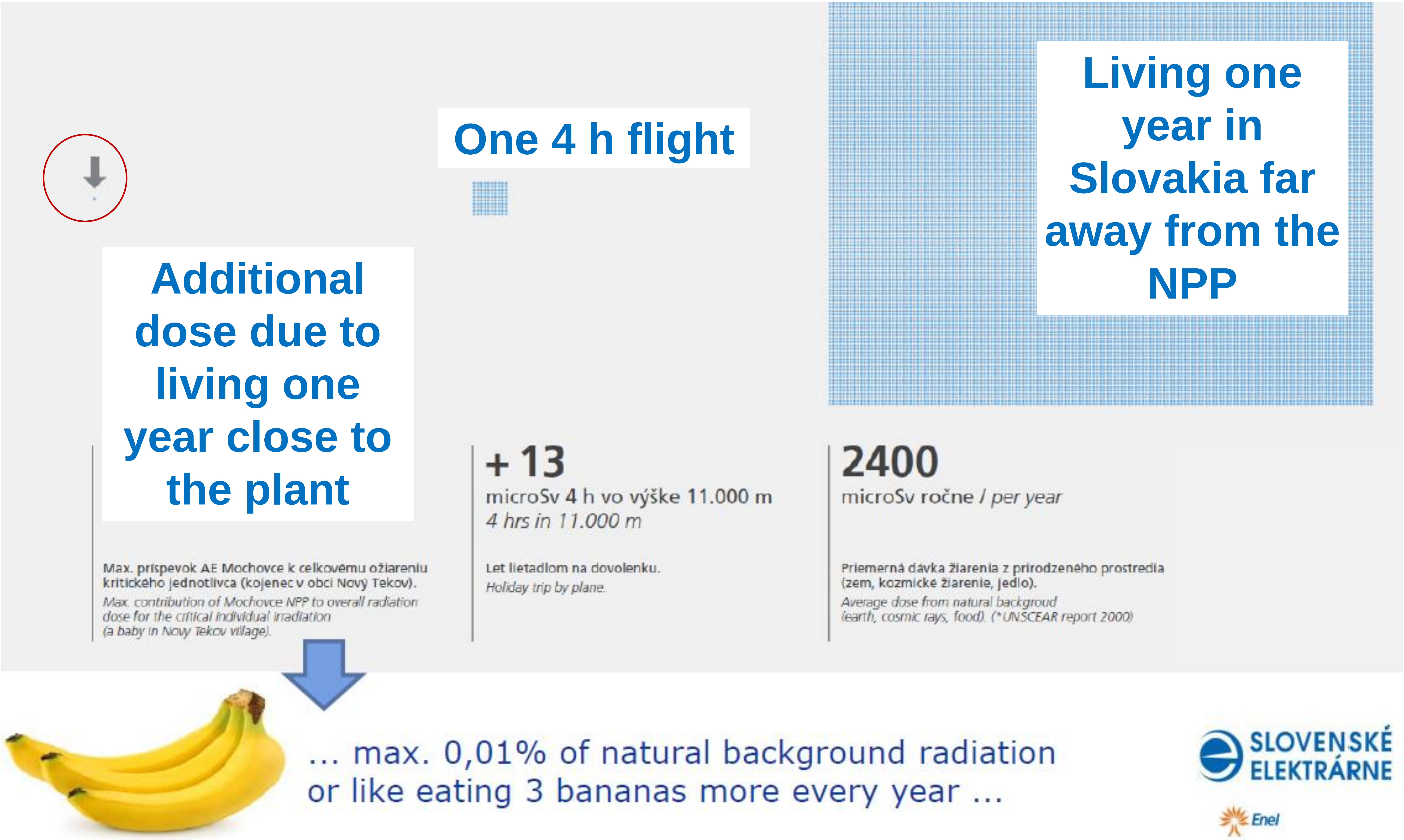
COMPARISON OF IODINE-131 DISCHARGES IN 2000 FROM SEVERAL SOURCES IN GERMANY (IAEA SR NO. 64)



In Germany, in 2000 the releases of I-131 from medical treatment were 20 000-times higher than discharges from all NPPs (before closing some of them)

COMPARISON OF EFFECTIVE DOSES FOR CITIZEN OF SLOVAKIA

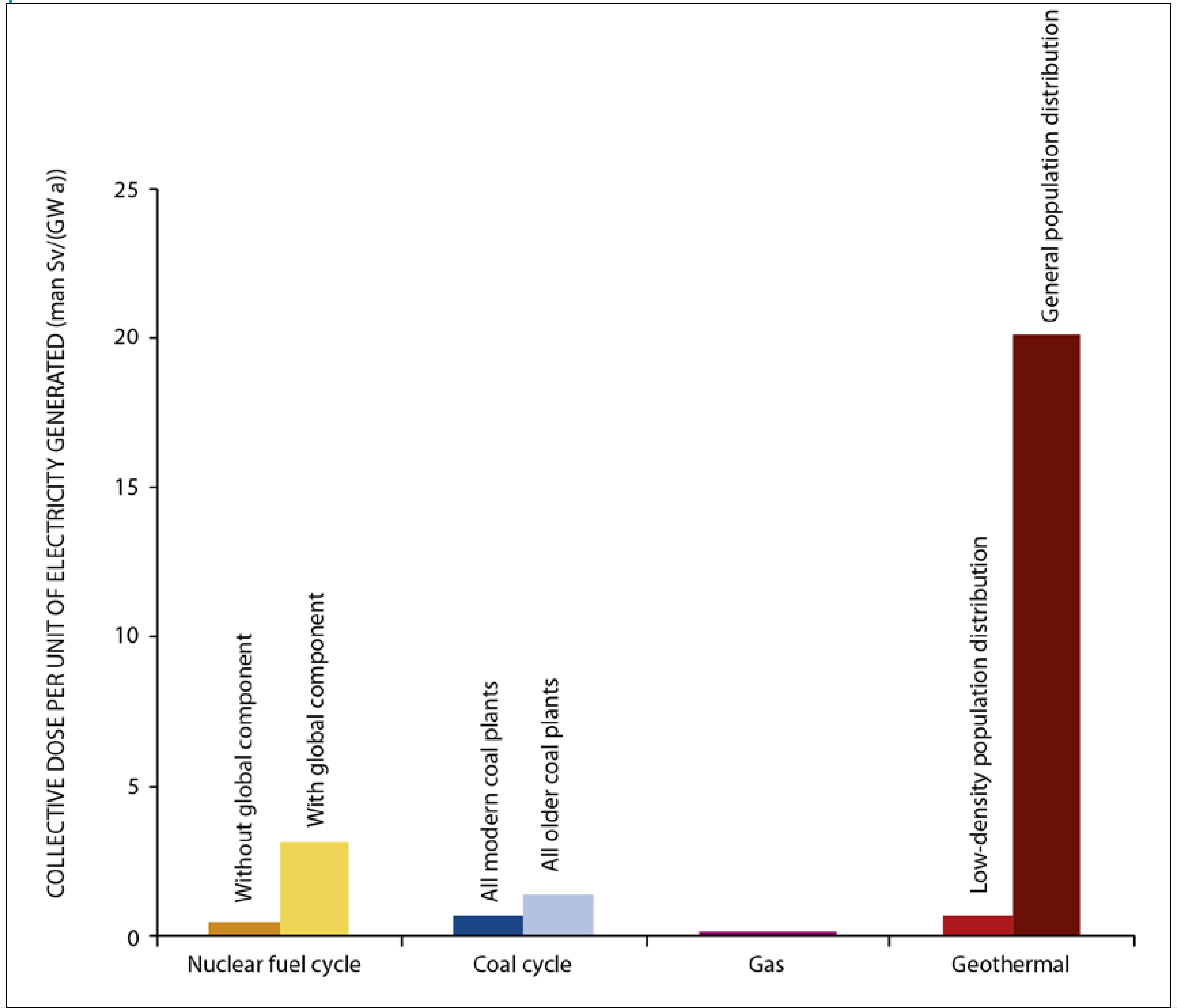
NUCLEAR RESEARCH INSTITUTE

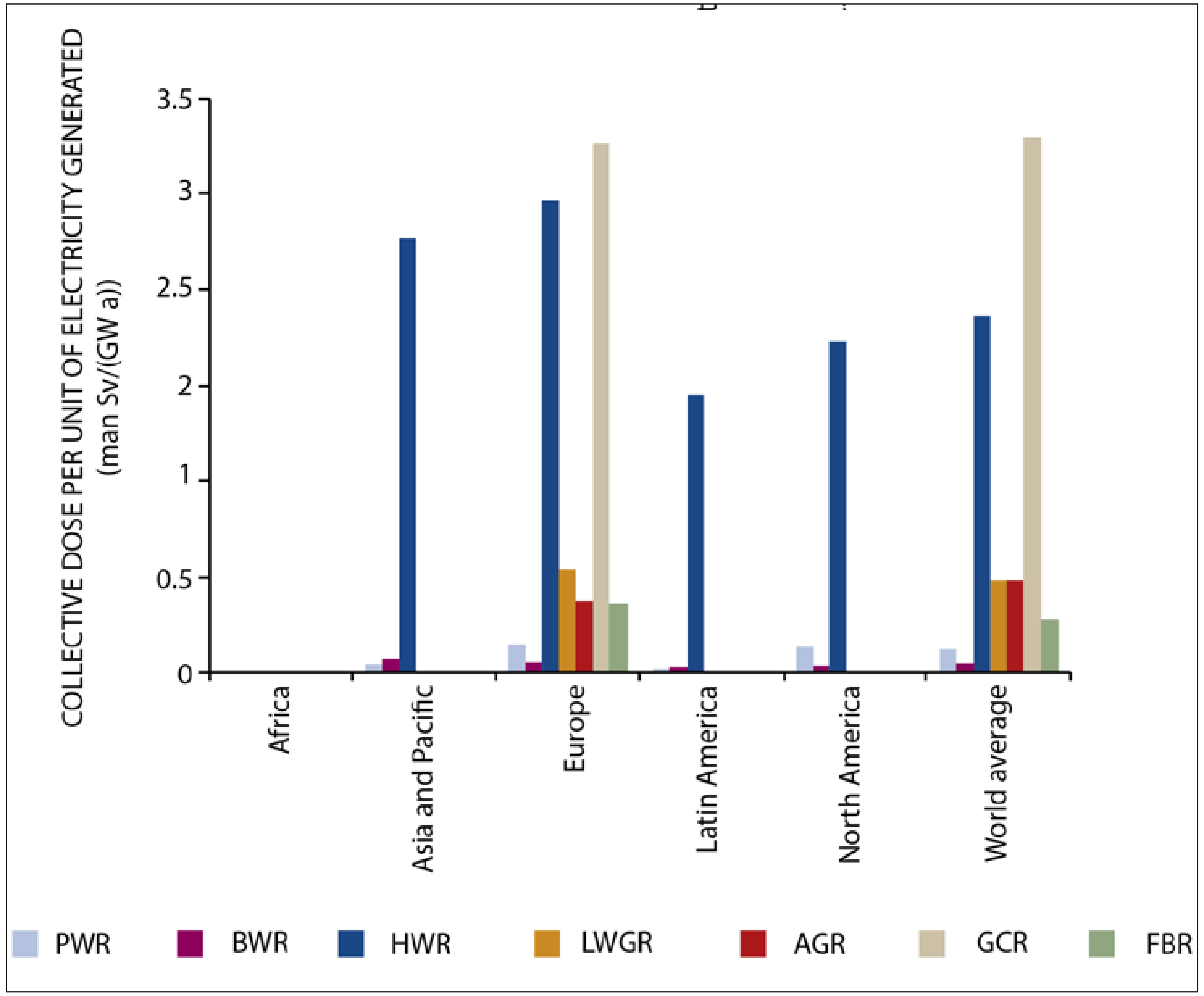


UJV Group
PEOPLE | INNOVATION | TECHNOLOGY

COLLECTIVE DOSES NORMALIZED TO ELECTRICITY GENERATION (MAN SV/(GW A))

NUCLEAR RESEARCH INSTITUTE





	Nuclear	Coal	Natural gas	Oil	Geothermal	Solar PV	Wind	Biomass
Public (mining, milling, operation, reprocessing)	0.43	0.7/-1.4	0.1	0.0003	1-20	-	-	-
Occupation (operation, decom-missioning, mining for construction	4.52	11.01	0.02	0.15	0.05	0.8	0.1	0.01

Source: UNSCEAR 2016 Report to UN General Assembly Annex B

UJV Group PEOPLE I INNOVATION I TECHNOLOGY

SUMMARY ON NUCLEAR SAFETY

- Nuclear power is very safe compared to other ways for production of electricity.
- Radiation from nuclear power plants in normal operation is negligible compared to other sources of natural radiation
- Number of fatalities due to production of electricity from any fossil fuels (including gas and biomass) is very much higher than from nuclear accidents
- Number of fatalities due to production of electricity from VRE is also much higher than from nuclear accidents; they are comparable only if the linear no-threshold model of radiation effects (very questionable) is used

CONCLUSIONS

NUCLEAR
RESEARCH
INSTITUTE

- Nuclear energy is long term time sustainable, climate friendly, safe, reliable and economically viable and it should be a major component in the world electricity generation mix
- Nuclear power plants are capable of reliably supplying the large quantities of clean and economical energy needed to run industrial societies with minimal emission of greenhouse gases
- The key advantage of nuclear power in the economic competition with wind and solar PV is the fact that nuclear power plants are dispatchable, i.e. they can produce large amounts of carbon free baseload power in a reliable and predictable fashion.
- Renewables, backed up with gas-fired stations, will in many cases not be able to make a worthwhile contribution towards reducing the rate of AGHG emissions, even for relatively low atmospheric leakage rates of natural gas.
- Because of their uncontrollable intermittence, intermittent renewable sources are not sustainable and economically viable to replace, fully or in a great part, the current fossil-derived with renewable energy sources
- Renewable energy sources (in particular intermittent solar and wing plants) can help but cannot be presented as the only solution to control global warming

UJV Group
PEOPLE I INNOVATION I TECHNOLOGY

CONCLUSIONS

NUCLEAR RESEARCH INSTITUTE

- Large portion of intermittent renewable sources in the grid is possible only with major subsidies both for renewable as well as for conventional back-up sources
- Distorting the electricity market with subsidies and by favorable legislation for the purpose of steering intermittent energy technologies into applications for which they are not well suited, is costly, economically wasteful and counterproductive
- The most effective way to reduce AGHG emissions is to replace fossil-fuel-based electrical energy generating stations by nuclear power plants. Industrial nations should take the lead in this, thus allowing developing countries more time to reduce their use of fossil fuels.
- A solution with low carbon sources could be a combination of intermittent renewable sources with a NPP with a capability to accumulate part of energy quickly convertible into electricity (e.g. producing hydrogen)
- In specific cases and for some isolated locations without access to an electric grid, may the use of intermittent energy sources for electrical energy generation be acceptable and economically viable

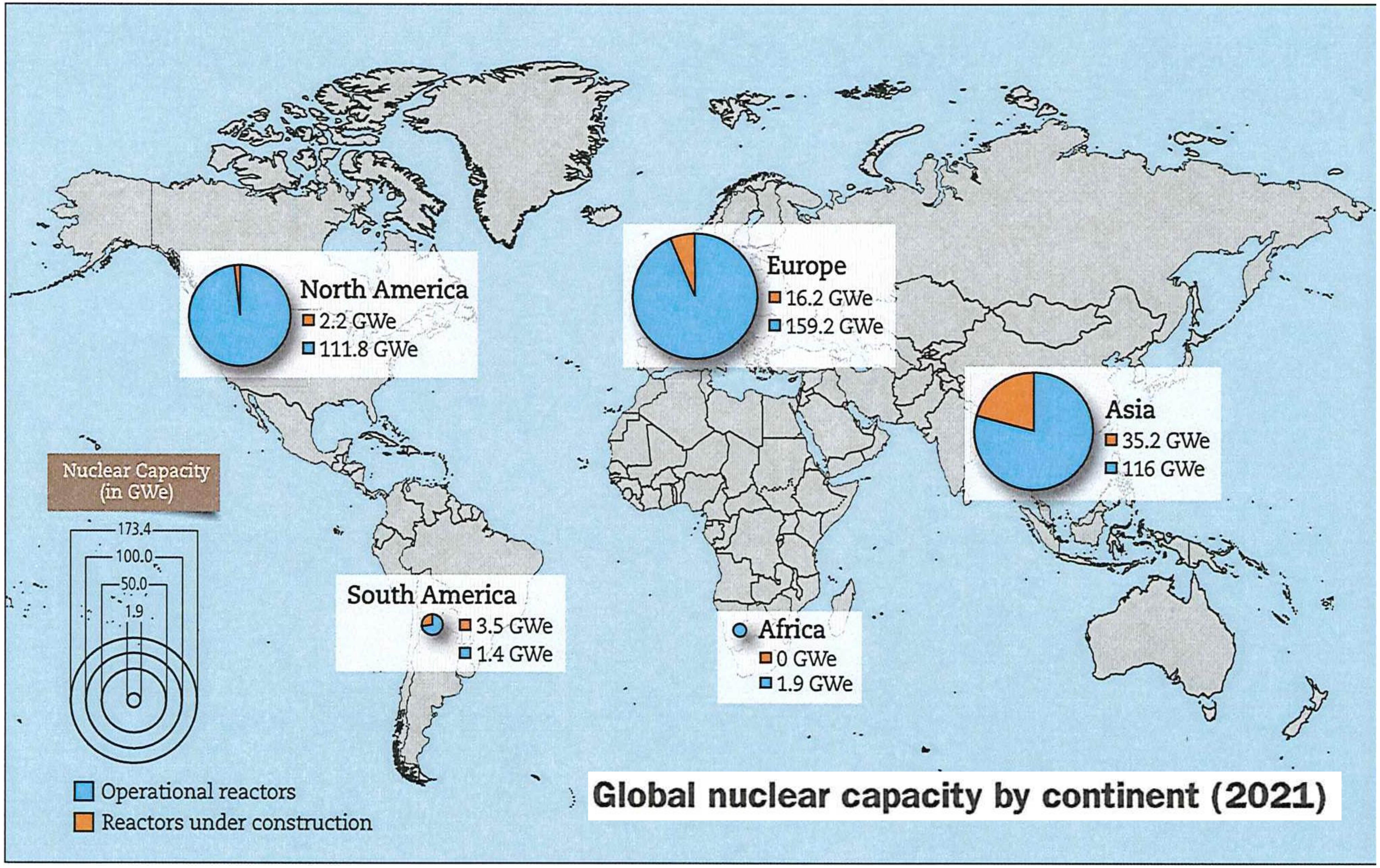
REFERENCE DOCUMENTS

NUCLEAR RESEARCH INSTITUTE

- Carbon Neutrality in the UNECE Region: Integrated Life-cycle Assessment of Electricity Sources, United Nations, Geneva, 2022
- Greenhouse gas emission intensity of electricity generation in Europe, https://www.eea.europa.eu/ims/greenhouse-gas-emission-intensity-of-1
- Uranium 2020:Resources, Production and Demand, OECD 2020, NEA No. 7551
- NEA Policy Brief: The System Costs of Electricity, http://oe.cd/nea-system-costs-2019
- What are the safest and cleanest sources of energy?, by Hannah Ritchie, February 10, 2020, Our World in Data
- The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables, OECD 2019, NEA No. 7299
- Sources, Effects and Risks of Ionizing Radiation: United Nations Scientific Committee on the Effects of Atomic Radiation, 2016 Report to the General Assembly, with Scientific Annexes — Scientific Annexes A, B, C and D
- Meeting Climate Change Targets: The Role of Nuclear Energy, OECD 2022, NEA No. 7628

UJV Group PEOPLE | INNOVATION | TECHNOLOGY

IF WE ARE SERIOUS IN FIGHTING WITH CLIMATE CHANGE, IT IS IMPOSSIBLE WITHOUT NUCLEAR POWER



Source: Meeting Climate Change Targets: The Role of Nuclear Energy, OECD 2022, NEA No. 7628

THANK YOU FOR YOUR ATTENTION

Jozef.Misak@ujv.cz

Phone: +420 602 293 882

www.ujv.cz