Nuclear power **in global energy transition scenarios**

Sandra Bouneau, physicist, University of Paris Sud

Studies on energy transition, aimed in particular at reducing greenhouse gas emissions, are based on the development of scenarios. Designed to quantitatively evaluate the impacts of an energy policy on the climate, they represent real decision-making tools. However, scenarios should be handled with caution because they are built on complex models and use a large number of poorly-defined hypotheses, which are sometimes based more on political than technical or scientific considerations.

In order to stem climate change, the use of fossil fuels, which today account for 80% of the world's energy consumption, will have to decrease drastically. A scenario is a scientific tool that can be used to analyze future energy production and consumption. While most of the global scenarios[(a)] envisage a large increase in the use of renewable energies, nuclear energy production may stop by 2050 or could increase ten-fold. It is therefore important to understand the reasons for the marked variability of the proportion of nuclear energy in prospective studies.

Building Global Energy Transition Scenarios

The purpose of a scenario is to explore possible energy futures by providing, among other things, a trajectory of energy consumption and production to 2050 or beyond. The scenario is based on a set of hypotheses and variables to model the socio-economic evolution of the world (population, urbanization, GDP, consumption), itself coupled with models describing the evolution of the availability of energy sources, the cost of technologies and their performance. Moreover, a given parameter – e.g. the trend in GDP – is sometimes a hypothesis and sometimes the result of modelling.

In most scenarios, the energy production system is optimized to meet energy demand at all times at the lowest cost. The cost of a technology is therefore an input whose value over time determines its share in the energy mix. A scenario based on a large increase in emerging renewable electricity sources (wind, solar) assumes a cost reduction of up to a factor of 10 compared to today's costs. Conversely, a technology considered undesirable to meet future demand, from a societal or climatic point of view, has an artificially increased cost so it doesn't feature significantly in the projected energy mix.

Without a quantitative objective set in advance, the scenarios are called "trend scenarios". Depending on the assumptions and parameters chosen, energy consumption in 2050 can be increased by 20% or multiplied by a factor of 3 compared to today's consumption. When a target is set for a given time frame, for example the halving of greenhouse gas emissions worldwide by 2050, the scenario attempts to describe a trajectory to reach it subject to additional constraints and assumptions.

Many of the scenarios in the scientific literature are complex to grasp, making comparative analysis difficult or even impossible. A scenario is not intended to be predictive but rather to represent an energy trajectory, through a set of hypotheses and values attributed to economic and technological variables. While it sometimes serves to inform the debate and to feed into the reflective process prior to decision-making, it is often relegated to the role of a tool designed to validate and support choices that have already been made.

Taking climate constraint into account in global scenarios

By integrating climate modelling, some scenarios can also predict trends in greenhouse gas concentrations through to 2100. On the basis of several hundred of these scenarios, the Intergovernmental Panel on Climate Change (IPCC) has defined four reference pathways of greenhouse gas concentration trajectories (Representative Concentration Pathway, or RCP). These pathways result in four values of additional energy fluxes received on average per m^2 of the Earth's surface causing it to warm ("radiative forcing"). The lowest value, 2.6 W/m^2, induces an average increase in temperature by 2100 that does not exceed 2 °C; the highest, 8.5 W/m^2, leads to a rise of more than 4 °C. These profiles provide a common framework for developing new scenarios, known as "climate scenarios", aimed at assessing the impact of an energy policy on the climate in relation to trend scenarios.

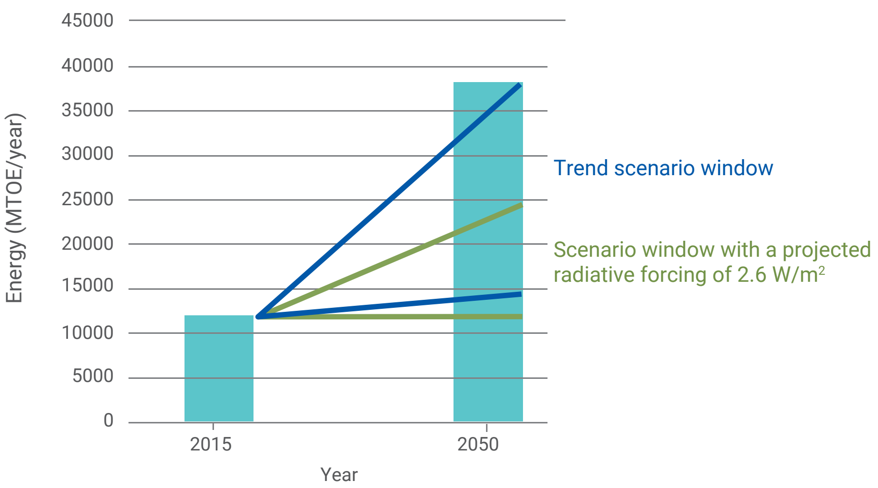
In most of the trend scenarios, fossil fuels remain the main source of energy and the associated CO_2 emissions give radiative forcing greater than 2.6 W/m^2. The increase in energy needs, whether moderate or strong, comes from the

Translation: In the time it takes to read this statement, you emit more CO_2 than a nuclear power station

populations of Asia and, to a lesser extent, Africa. Depending on the assumptions of the capacity of countries to control their energy consumption in the future, and the degree of progress of developing countries, global energy consumption in 2050 varies from a very slight to a three-fold increase (fig. 1, in blue).

On the basis of the trend scenarios used as a reference, additional hypotheses to do with energy consumption and technological progress of non-CO_2 emitting sources are introduced. These assumptions simulate more proactive policies to reduce greenhouse gas emissions than are currently in place, thus making it possible to achieve quantitative targets compatible, for example, with a RCP of 2.6 W/m^2. In most scenarios, setting ambitious climate targets is accompanied by a signifi c ant reduction in energy consumption by 2050 compared to the trend scenarios (fig. 1, in green).

In some scenarios, this reduction is presented as desirable and remains compatible with sustained economic growth through, for example, ambitious assumptions about the ability of societies to change their lifestyles and improve the performance of energy installations. In others, the reduction in energy consumption is lowered, since it results from a very restrictive greenhouse gas emission reduction policy, such as the introduction of a high carbon tax, and induces a slowdown in economic growth.



1. World energy consumption, in megatons of oil equivalent per year, estimated in the trend (blue) or climate (green) scenarios.

The conditions for carbon-free energy generation

Depending on the assumptions in the scenarios, the transition towards a carbon-free world is more or less rapid and can take place according to several options: maintaining the use of fossil fuels by favoring the substitution of coal and oil by natural gas with large-scale recourse to CO_2 Capture and Sequestration (CCS) technology, use of renewable energies including biomass (wood and biofuels) or nuclear power.

In most of the scenarios put forward, production of electricity or heat from nuclear power, although competitive, does not emerge as an efficient way to provide the world with the non CO_2-emitting energy it needs. However, the underlying arguments are rarely explained. Sometimes, the difficulty of mastering this complex technology while respecting Western safety standards is invoked, or the fact that this technology would not be accepted by future societies. These arguments result in an artificial extra cost

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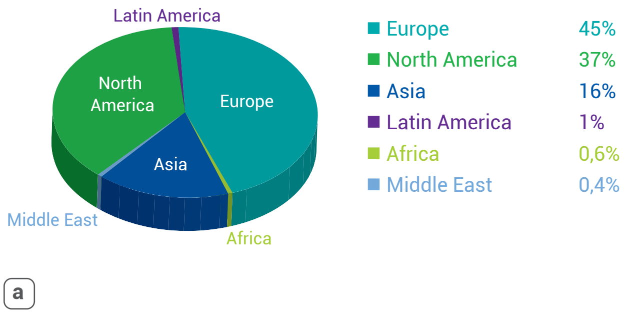

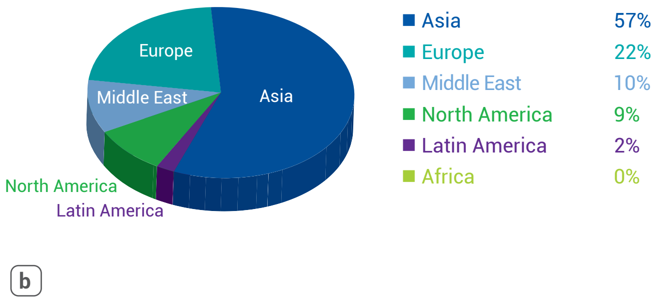

2. Proportion of nuclear reactors (a) existing and (b) under construction in the world.

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attributed to nuclear power, which ranks it last among non-CO_2 emitting energies in the energy mix. Limiting global nuclear use is therefore often an input assumption rather than an outcome.

On the other hand, in the scenarios that remove these constraints, nuclear production in 2050 is multiplied by a factor ranging from 2 to 10 compared to today, depending on future energy demand.

Currently, there are more than 400 nuclear reactors in the world, mostly pressurized water reactors, generating 2.4 million GWh electricity annually with an operating capacity of 350 GW, which represents 10% of total electricity production, and their geographical distribution is shown in fig. 2a. In addition, 68 reactors are under construction, more than half of which are located in Asia, with the remainder divided between Europe, North America and the Middle East (fig. 2b).

In the 2000s, nuclear power appeared to be on the rise again, but the Fukushima accident brought it to a halt, making any prediction of a move towards deployment or decline somewhat uncertain. Nevertheless, whatever the decision of European countries regarding nuclear power, its use seems to be continuing in the rest of the world and is now taking place mainly in Asia.

In a high nuclear growth scenario, world nuclear power output could reach 20 million GWh per year by 2050. Assuming that the main populations concerned would be located in the cities (where demand is concentrated) of countries already nuclearized, particularly in Asian countries such as China and India, about 5 billion people would benefit. On the basis of 1 GW reactors operating at full power 85% of the time, the total number of corresponding reactors is about 2300, i.e. about 450 reactors for one billion people. Compared to France, which has built 60 reactors in 25 years for 60 million inhabitants, this type of global deployment does not seem so unrealistic. Even if there are currently questions about the ability of the Western nuclear industry to engage in ambitious reactor construction programs, Asia could soon have the means to do so.

Increasing nuclear output by a factor of 10 over the next century would come up against the issue of uranium reserves. Estimated today at around 15 million tons, these reserves are incapable of fueling such an increase of current systems, which consume 150 to 200 tons of uranium to deliver 1 GW over a year. Moreover, the mining industry's capacity to make these resources available remains to be seen. Finally, the oceans contain several billion tons of uranium, but the concentrations are so low that the energy efficiency of extraction and the associated environmental impact make it hard to imagine exploiting this resource today. Carbon-free energy development would therefore seem possible only through a transition to renewable industries, making it possible to reduce uranium consumption by a factor of 200. The development and operation of hundreds of fourth generation reactors worldwide, meeting the highest safety standards, would represent a major technological and industrial challenge.

In conclusion, scenarios relying on sustained growth of nuclear power to meet climate challenges do not feature highly in the political, technical-economic and media spheres. Significant deployment at the global level would require tough political choices to be made that would involve future generations and make nuclear power a serious gamble on the future. But scenario analysis shows that doing without nuclear power is also a gamble on the future. Indeed, the corresponding scenarios are based on the ability of societies to reduce their energy consumption and improve energy efficiency very significantly, and are based on very optimistic assumptions about CCS technology and the means to manage substantial intermittent electricity production. If we fail to meet these ambitious targets, fossil fuels will remain the main source of energy for a very long time to come and we will have irreversibly set the world on a major climate change trajectory. ▮

To find out more

- This document is mainly based on the International Institute for Applied Systems Analysis (IIASA) scenarios developed as part of the IPCC work: https://secure.iiasa.ac.at/web-apps/ene /SspDb/dsd?Action=htmlpage&page=about
- Figures on nuclear power generation are taken from the ENERDATA database: www.enerdata.net/
- "Building future nuclear power fleets: The available uranium resources constraint", Resources Policy **38** (2013) **458**-469.
- "The representative concentration Pathways: an overview", Climatic Change **109** (2011) 5-31.

a. For a study of scenarios on a French scale, see the article by N. Maïzi and F. Briens. (p. 49).