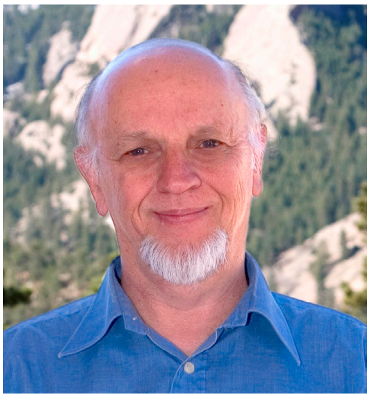
The role of nuclear energy in meeting the Paris Agreement climate targets

By Tom M.L. Wigley



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The potential role of nuclear energy in meeting the targets to limit global warming under the Paris Agreement on climate change depends primarily on what emissions reductions are needed. It is a two step process: we have to make sure that we are working with realistic targets before we can assess how nuclear can help.

Realistic targets

The Paris Agreement, a landmark agreement to combat climate change that builds on the United Nations Framework Convention on Climate Change (UNFCCC), specifies the global warming targets in two ways:
Article 2.1 (a):
Holding the increase in global average temperature to well below 2°C above pre industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre industrial levels …
Article 4.1:
Parties aim to … achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century …
The Agreement further states, in Article 4.1, that emissions reductions should be made "in accordance with the best available science …"

There are some problems with that.

First, Article 2.1 (a) requires temperatures to be kept below the specified warming targets at all times. While this is technically possible, albeit highly unlikely, it would be much easier to allow some warming overshoot until temperatures eventually return to within the stated targets. That, however, raises another scientific question: how large and long lasting can the overshoot be and still meet the more general UNFCCC goal of "avoiding dangerous anthropogenic interference with the climate system", 'anthropogenic interference' here being a reference to the pollution caused by human activities.

Second, the goal in Article 4.1 is, based on the best available science, potentially inconsistent with Article 2.1 (a). If temperature overshoot is permitted, as I think is necessary, there is no need to drop CO_2 emissions to zero before the end of the century in order to reach the 2°C target, which is how Article 4.1 is often interpreted. It is possible even to meet the 1.5°C target with appropriate overshoot without entering negative emissions territory (see Figure). Negative emissions would, however, be necessary with a smaller-scale overshoot, beginning in around 2060, which is consistent with Article 4.1. If that were the case, residual, long-lasting ocean and terrestrial sinks would eventually allow emissions to return to above zero.

Those issues are illustrated in the Figure, where the CO_2 emissions have been derived first by specifying a warming trajectory – see the upper panel, with two cases for the 1.5°C target – and then by running a climate model in inverse mode to back out the required fossil CO_2 emissions (see the middle panel). These allow us to calculate the corresponding CO_2 concentration trajectories.

Nuclear?

What role might nuclear energy play in meeting the emissions trajectory targets indicated in the middle panel of the Figure? We can answer this question, in part, by using results generated with integrated assessment models (IAMs) — energy economics models used to project future energy demand details and consequences — published in the United States Climate Change Science Program.

Three well-established, internationally recognized, integrated assessment modelling teams were tasked to develop a range of policy-driven mitigation scenarios using IGSM, MERGE and MiniCAM models. Targets in those scenarios were achieved by:
- reducing end-use energy demand, such as through conservation and efficiency improvements;
- increasing energy production from biomass, non-biomass renewables – mainly wind and solar – and nuclear; and
- through carbon capture and storage.

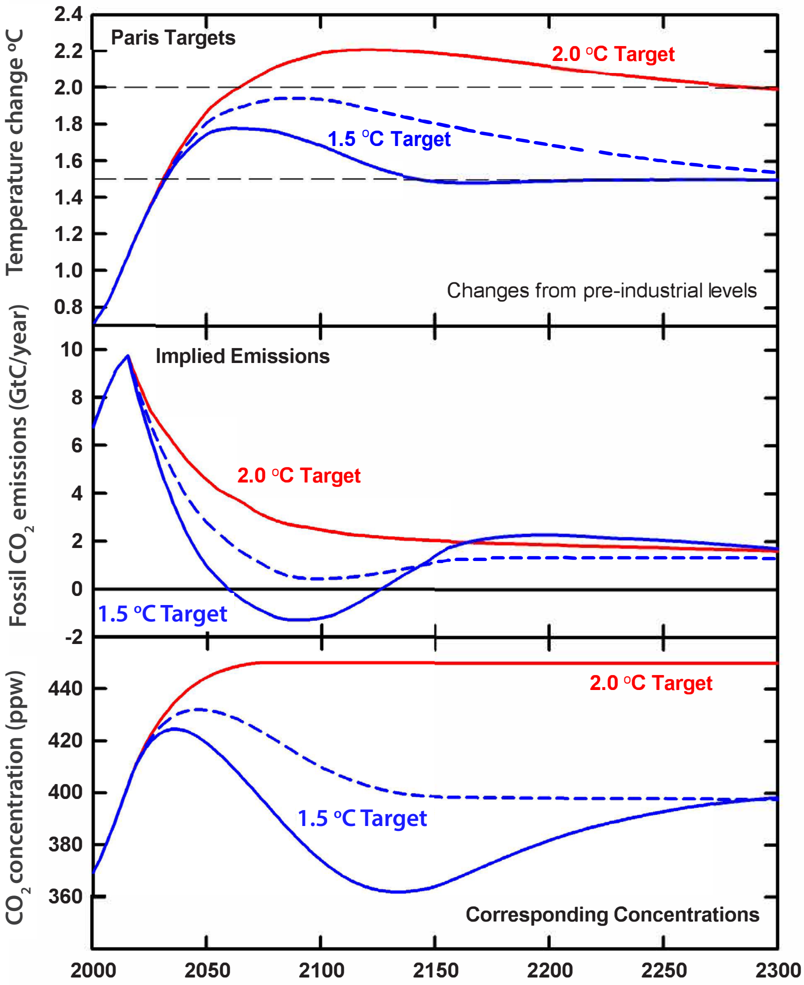
CO_2 emissions reductions in all the scenarios, including the reference scenarios, occur both spontaneously – i.e. in the absence of new mitigation policies – and as a result of the policies implemented. This means that even in the reference scenarios there are increases in carbon-free energy technologies to the extent that 19–29% of primary energy (PE) production is carbon-free by 2100. Further massive reductions in CO_2-producing PE are, however, still required to meet the 2°C target.

The Table below shows a model-by-model percentage breakdown of contributions to overall PE reductions by 2100, relative to the reference PE levels.

The IGSM model is a clear outlier in terms of energy demand reductions. That is because the model developers assumed that changes in nuclear energy production would be minimal, owing primarily to anti-nuclear sentiment on the part of the public. With the role of nuclear minimized, most of the emission cuts would need to come from reductions in demand. The other two models give breakdowns that are quite different from IGSM, and they attribute a much greater role to nuclear.

To put some flesh on the percentages, nuclear PE values in exajoules (EJ) for 2100 per model are as follows: 238 EJ with the MERGE model (for a total 491 EJ of PE); 185 EJ with the MiniCAM (total: 1288 EJ) and only 20 EJ with the IGSM (total: 1343 EJ). In 2000, the 451 nuclear power reactors still operating today generated roughly 8 EJ of electricity, which is equivalent to some 26 EJ of PE, meaning that the IGSM model actually projects a decrease in nuclear energy production. The MERGE and MiniCAM models project increases by a factor of nine and seven respectively from 2000 to 2100.

There is firm evidence, however, that emphasis on nuclear could grow at a much faster rate, as seen in the rapid historical growth in France and Sweden when those countries decided to "go nuclear". If that happens, nuclear could – and should – play a far greater role than the models described above might suggest.



If a temporary overshoot of the Paris Agreement targets is allowed, CO_2 emissions do not need to become negative.

(Source: Wigley, Climatic Change 147, 31–45, 2018)

There are manifest advantages in pursuing nuclear more aggressively. First and foremost, nuclear is the only energy source that can provide carbon-free, continuous (base-load) power, with a footprint much smaller than that of renewables. Perceived disadvantages are largely illusory: recent construction and electricity generation cost estimates for small modular reactors are at least as competitive as for fossil fuel and renewable technologies; waste problems can potentially be resolved with fourth generation technologies; modern reactors are passively safe; and proliferation risks are minimal. In the climate context, with its challenging targets, to ignore a significant role for nuclear would, in my view, be foolhardy.

Model	Demand	Biomass	Renewables	Nuclear	Carbon capture	Residual
IGSM	50.4%	17.3%	3.3%	1.5%	16.8%	10.7%
MERGE	27.6%	17.5%	12.3%	16.0%	21.1%	5.6%
MiniCAM	18.7%	17.9%	13.7%	14.4%	22.8%	12.5%

The contribution of various sources to the reduction of primary energy production. Residual refers to amounts of PE production still emitting CO_2.