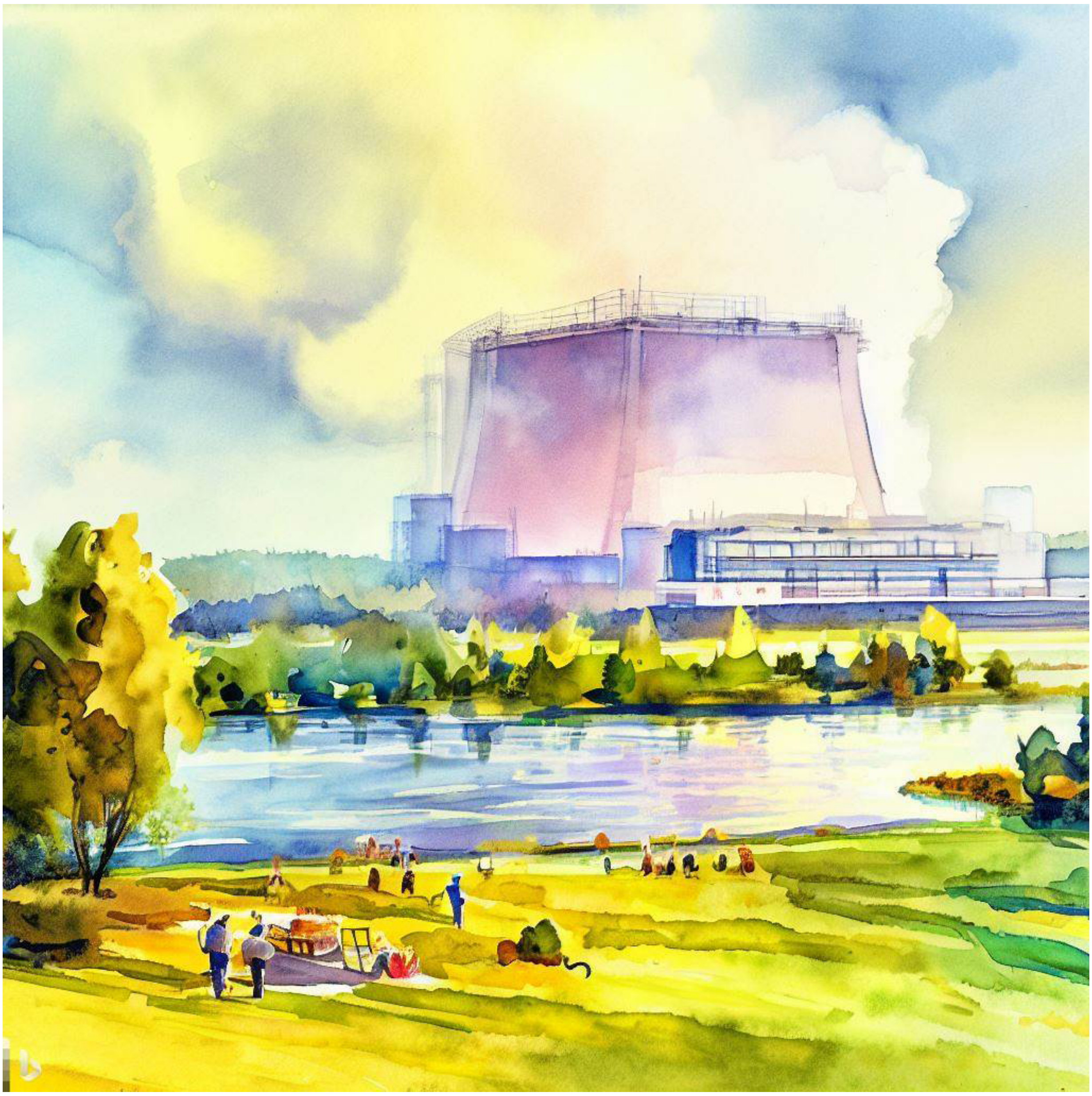
WHY WE NEED NUCLEAR



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TOWARDS A FUTURE OF PLENTY

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1. Executive Summary

- Without nuclear energy, there will be no decarbonisation of electricity production – unless we are willing to accept big cuts in living standards.
- The decline of nuclear energy was primarily driven by a relentless anti-nuclear lobby that effectively shaped a negative public perception of nuclear power.
- Fukushima and Chernobyl do not provide evidence for abandoning nuclear power. On the contrary, a closer look at both incidents shows that nuclear power is much safer than many available alternatives.
- Ever-stricter regulations have deliberately driven up costs and construction times for nuclear power plants. This is a political problem, not an economic or technological one.
- Nuclear waste is not a problem. There is no documented case of a single person being harmed, much less killed, by nuclear waste.
- After the energy crisis of 2022, public opinion in most Western nations has switched from opposing to supporting nuclear energy.
- Nuclear energy could play a key role in reducing Europe's dependency on Russia and China.

2. A Problem of Politics, not Technology

This report aims to demonstrate that the availability of energy through nuclear fission holds the key to solving many of humanity's problems. This promising technology has been underused, not because of the limitations created by the laws of physics, but because of one of the most successful brainwashing operations in modern history.

The term brainwashing might seem hyperbolic. But once we compare the actual risk and potential of nuclear power to how these issues are depicted by popular culture, NGOs, politicians, and most of the media, 'brainwashing' might seem an understatement.

One must keep in mind that most people first heard the term "nuclear" during a debate about nuclear weapons. It was the atomic bombs, dropped on Hiroshima and Nagasaki in the final days of World War Two, that really brought both the potential and the risks of the nuclear revolution into public focus. Indeed, public scepticism was originally warranted, given the extreme energy densities of uranium and plutonium, which explains both why nuclear weapons are so destructive and nuclear energy is so efficient. Figure 1. shows the energy density of Uranium, the most-used fuel for nuclear power plants[1], and Figures 2[2] and 3[3] show just how energy-dense nuclear fuel is.

If the nuclear age had not begun with a literal bang as part of a world war, but instead had been the result of a search for a clean and reliable energy source, most likely the debate surrounding nuclear would be different. Yet the way history unfolded has tainted nuclear power as being adjacent to nuclear weapons, as if a nuclear power plant is not much different from a nuclear bomb, just waiting to explode. This perception found its way into popular culture and has been a crucial part of the conversation.

The world's most famous and longest-running animated sitcom, "The Simpsons", is only one example. The story's main protagonist, Homer Simpson, works as a control room operator at a nuclear power plant, and every wrong-yet-popular cliché of the supposed danger of nuclear energy is exploited from the opening scene of every episode.[4] Nuclear waste is represented as a glowing, oozy liquid stored in leaking barrels that are illegally disposed of in rivers and forests, leading to mutations, such as three-eyed fish or multi-headed humans. Cooling towers are stitched together with chewing gum, creating the impression that a nuclear power plant is constantly operating on the brink of catastrophe.

None of this resembles the truth. Nuclear waste, for example, consists of solid material stored in casks without any serious risk of leakage (see figures 4[5] and 5a[6] and 5b[7]). Even more importantly, there is not a single documented case of lost life due to spent fuel from a nuclear power plant[8], and the depiction of nuclear waste in popular culture is – for the most part – pure fiction.

> **"The toxic image of nuclear energy in popular culture reinforces negative public sentiments towards nuclear – but it doesnt resemble the truth."**

Another popular depiction, in TV's 24, involved the idea that cyber attackers could gain control of America's nuclear power plants and remotely induce the meltdown of several cores, leading to a nuclear catastrophe. While creating a great storyline, it barely had any connection to reality, according to the U.S. Nuclear Regulatory Commission (NRC).[9]

The toxic image of nuclear energy in popular culture both results from and reinforces negative public sentiments towards nuclear, a trend that was brought to a head by the accidents at Chernobyl and Fukushima.[10] However, the secretive nuclear industry added to its own problems. It failed to invest in improving its image and wrongly considered itself helpless in the face of changing public opinion.[11]

There have been cases like a meltdown in Idaho in 1955 where no one was hurt, but the attempted cover-up that followed increased general suspicion that the industry could not be trusted.[12] Similarly, in 2013 it was discovered that South Korean nuclear plants were using components with faked safety certificates.[13] Although no harm to humans has been reported, these incidents bolstered the idea that a nuclear catastrophe is highly

A Problem of Politics, not Technology

Medium	Energy Density MJ/m³	Electrical Energy Density kWh/m³	Conv. Effic.	Comments
Natural uranium (Fast)	150,000,000,000	12,500,000,000	30%	Fast reactors
Natural uranium LWR	950,000,000	80,000,000	30%	Thermal
Black coal	24,000	2,300	35%	-
Brown coal	15,000	1,000	25%	-
Dry wood	10,000	970	35%	Biomass
Natural gas	38	5	45%	CCGT

Figure 1. Energy densities by source

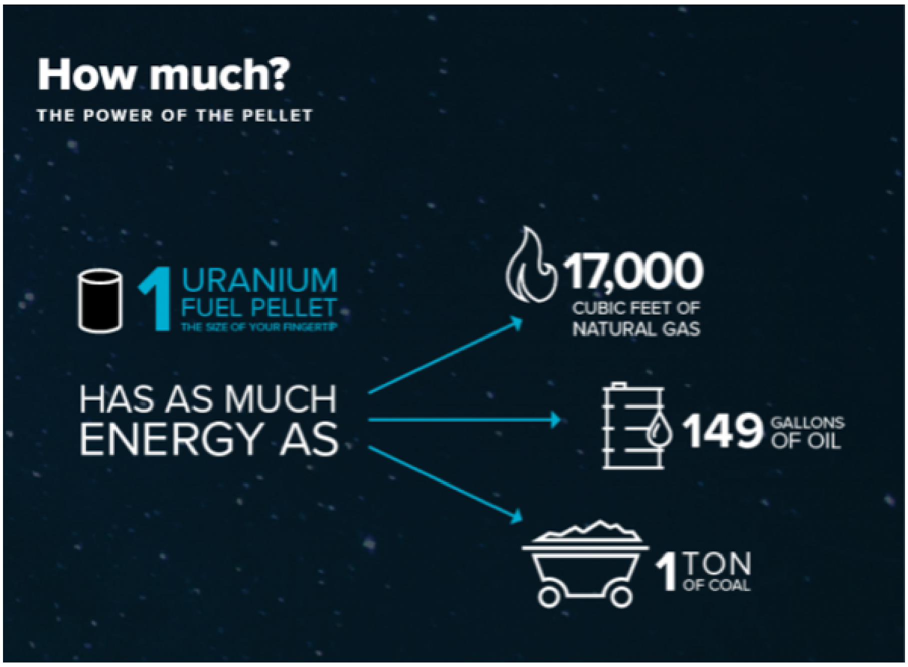

Figure 2. Uranium vs fossil fuels

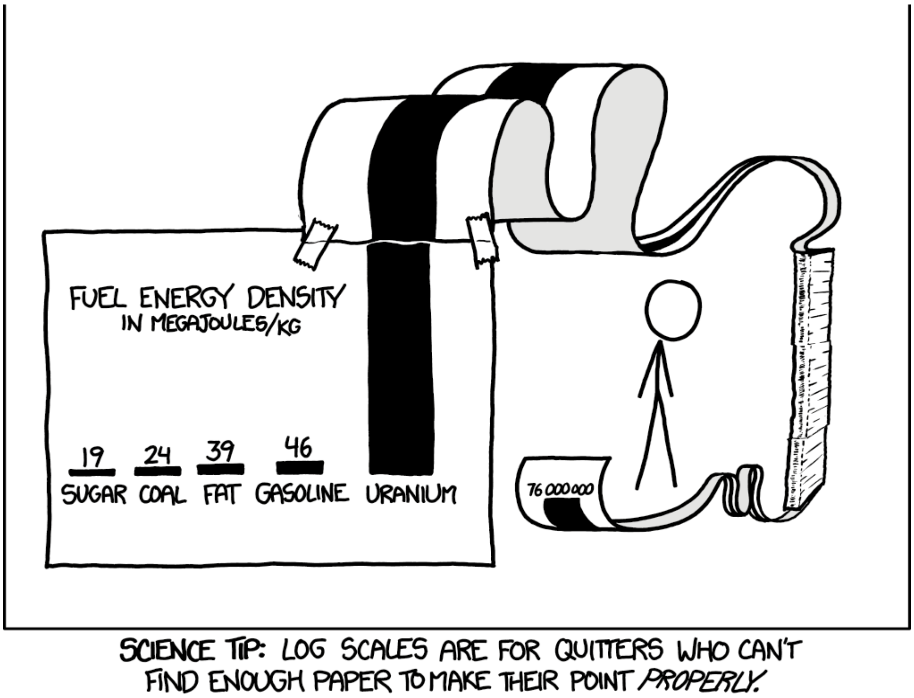

Figure 3. Uranium energy density

A Problem of Politics, not Technology

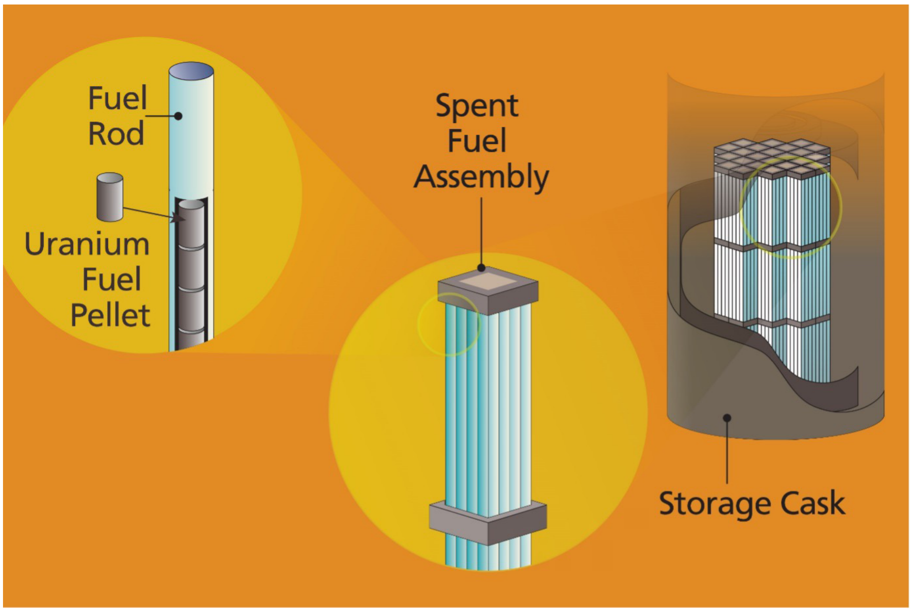

Figure 4. How spent nuclear fuel is stored

Figure 5a. Nuclear waste disposal in "The Simpsons"

Figure 5b. Nuclear waste disposal in reality

likely. As with any technology, there are real risks. For example, a fire at the Windscale Piles nuclear reactor on 10th October 1957 became the worst nuclear accident in the United Kingdom's history. Although there were no immediate casualties, there were an estimated 100–240 cancer fatalities in the long term.[14] Although Windscale was not a power plant in the traditional sense, but served primarily to produce plutonium for nuclear weapons, it demonstrated that no new technology is 100% safe.

Yet for a long time there was significant optimism regarding the potential of nuclear power. In 1957, the Walt Disney Company aired a show entitled "Our Friend the Atom" and there was optimism that nuclear fission would be the future source of cheap, clean, and secure energy[15]. Such sentiments set the tone for much discussion on energy policy, including one government report in Germany which forecast nuclear power becoming by far the predominant source of energy (see figure 6).

"The European energy crisis of 2022 has already created a shift in public attitudes towards nuclear energy."

However, overconfidence arguably added to the downfall of nuclear energy, since its benefits were overplayed and the potential risks ignored, leading to an ever-greater public outcry even after incidents with limited harm to human life. The Three Mile Island accident in Pennsylvania in 1979, which included a partial meltdown, did not lead to immediate deaths. It is still unclear if cancer rates in the area can be causally connected to the incident, but it did mark another negative shift in attitudes towards nuclear energy.[16]

According to J. Samuel Walker, a historian at the US Nuclear Regulatory Commission, the Three Mile Island incident marked the beginning of the end of growth in electricity production via nuclear power plants and helped trigger ever more stringent security requirements. These drove both costs and construction times upwards, making nuclear power increasingly unattractive to investors and utility companies alike.[17] Figure 6 records the slowdown in generation of nuclear power that captures this shift.[18]

In other words, at least since the 1970s, nuclear energy was fighting an uphill battle against negative public perceptions, bad public relations management, and rising regulatory costs. The question that remains is whether this trend can and should be reversed.

The European energy crisis of 2022 has already created a shift in public attitudes towards nuclear energy. This can be explained by a newfound realisation that energy supplies are less secure than many people believed, so it is not only safety concerns that matter, but also questions of energy security. As Figure 7 demonstrates[19], after the Fukushima incident in 2011 opposition to nuclear energy was peaking, but this trend has been reversed in many countries by 2022.

This shift can also be explained by growing global concerns about economic issues (see Figure 8[20]), especially inflation driven by high energy prices. Until recently, energy was often discussed in terms of safety and environmental issues with only a limited focus on the central role it plays in the overall structural health of an economy. While there has always been a sensitivity to oil prices and a faint memory of the 1973 oil crisis, electricity was not viewed as particularly scarce. This changed when prices for electricity became extremely volatile – and high – in 2022 (see Figure 9[21]) because of Russia's war against Ukraine. Although the most extreme price-spikes were temporary, they highlighted for the first time in decades the vulnerability of energy supply. With nuclear power plants being particularly efficient in the production of electricity, it was only natural that this reignited the debate about whether to continue using or build further nuclear power stations.

This shift in attitudes also reflects a broader appreciation of the role energy plays in the sustainability of modern civilisation, and it is in this context that we should evaluate what role nuclear energy could play. Before we investigate the particularities of nuclear energy, allow me to provide a short appraisal of the crucial role energy plays in our lives.

A Problem of Politics, not Technology

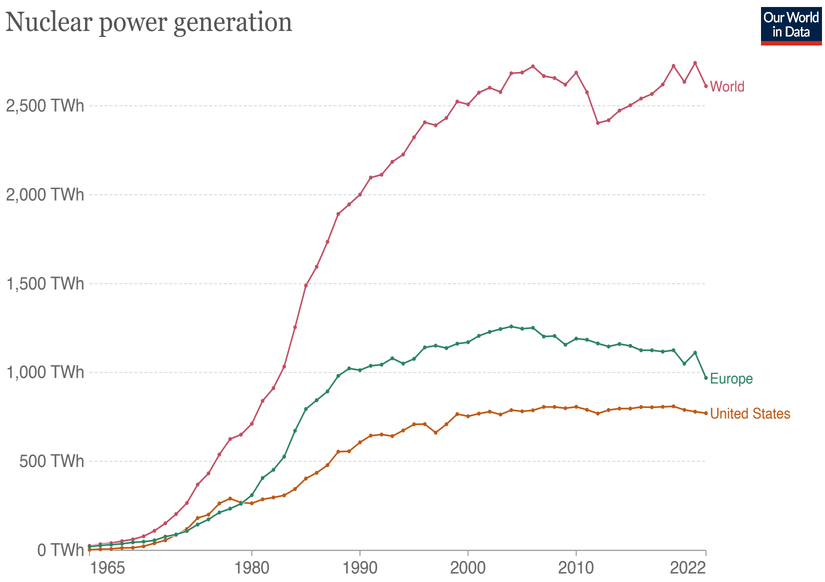

Figure 6. Nuclear power generation starts to slow in the 1980s and 1990s after rapid growth in the previous decades

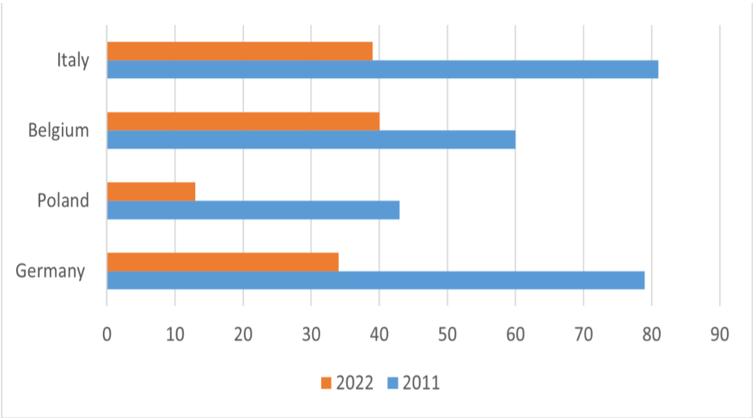

Figure 7. Opposition to nuclear energy production

A Problem of Politics, not Technology

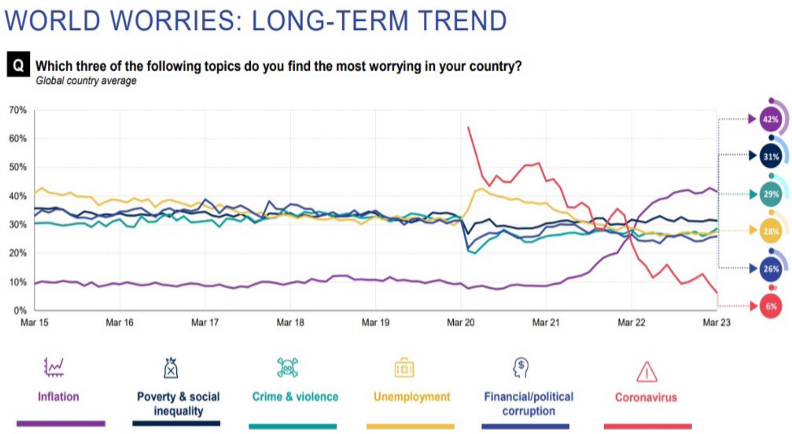

Figure 8. Inflation has become the world's greatest concern

Figure 9. One year ahead electricity prices in France and Germany, August 2022

3. The Question of Energy Revisited

No form of energy production is perfect. All forms involve trade-offs and downsides, which economists sometimes call externalities. But the key question is whether we can manage these downsides.

As outlined in the first part of this report, there is a difference between what these externalities are and how they are perceived. Once we understand what they are, we can compare them to the externalities and problems of other forms of energy production and draw conclusions as to which method is preferable. This report assumes that producing energy to help human life flourish is a shared goal, and that the debate is primarily about how to produce energy, not if we should.

Abandoning all forms of energy production would make the sector 100 percent safe, just as banning cars would lead to a 100 percent reduction in car accidents. Most societies, however, accept some risk if they believe the overall benefits justify it, which is why we have not (yet) banned cars. A world without energy would be a world without civilisation, and many of the comforts we enjoy today would disappear. Modern medicine, communication, agriculture, and the cooling and heating of living spaces all require massive amounts of energy. As the anthropologist Leslie White put it, "Other things being equal, the degree of cultural development varies directly as the amount of energy per capita per year harnessed and put to work."[22]

We tend to tell the story of economic development as a story of institutions and innovations that enabled increasing standards of living, culminating in the Industrial Revolution of the 18th and 19th centuries.[23] This story is not wrong, but it tends to neglect that what made the Industrial Revolution unique was the exponential growth in available energy. In 1870, British steam engines generated four million horsepower, the equivalent of work done by 40 million men. Feeding such a workforce would have required three times Britain's entire wheat output. The steam engine meant that instead of feeding 40 million men with wheat, industry could be 'fed' on an abundantly available, energy-rich, resource: coal.[24]

But coal was just the beginning. Wood was replaced by coal, and coal was replaced by oil – or to be more precise, fuels were added, since we are still consuming wood in different ways for energy. This allowed a tremendous increase in living standards, causing the average Briton in 1960 to be six times richer than his great grandfather in 1860.[25] It also allowed people to move from the agricultural sector to other sectors of the economy, as the industrialisation of farming enabled higher outputs with less labour, freeing human capital for other endeavours and allowing human beings to make a living based on skills other than physical labour.

> **"Civilisation depends on the production of massive amounts of energy, which is provided today by fossil fuels which are not easily replaceable."**

It would probably be more accurate to talk about an energy revolution than an industrial revolution. Vaclav Smil is correct when he points out that "energy is the only universal currency: one of its many forms must be transformed to get anything done."[26] Starting in the 1800s, humanity became ever more sophisticated in extracting and transforming the energy contained in fossil fuels and other reserves, and the growing availability of energy enabled growing living standards. Figure 10 shows the growth of GDP per capita alongside expansion of global energy use.[27]

Modern civilisation depends on four ingredients that emerged out of the industrial revolution on a massive scale: cement, steel, plastics, and ammonia (synthetic fertiliser).[28] The production of these four ingredients requires enormous amounts of energy. This energy is currently provided largely by fossil fuels: "Global production of these four indispensable materials claims about 17 percent of the world's annual total energy supply, and it generates about 25 percent of all CO_2 emissions originating in the combustion of fossil fuels."[29]

None of them is easily replaceable (if at all). Modern life cannot go on without them. Plastics are crucial in the medical industry (from tubes to protective equipment), steel and concrete are needed for construction, and without artificial fertiliser, half the world would starve (see Figure 11[30]).

Energy is not only the universal currency, it is also the major pillar that supports modern life. The growing abundance of useful energy sources over the past two centuries was a (if not the) major factor in the emergence of the modern world with all of its material progress. While one can certainly be critical of excessive materialism, it is important to keep in mind that we are not just talking about luxury goods. Modern hospitals, for example, use about 2.6 times more energy than other commercial buildings.[31] In a warming world, air conditioning will no longer be a luxury but a necessity for people to adapt to higher temperatures.[32] Energy quite literally is a life saver.

Any attempt to reverse these developments will ultimately lead to a reduction in human prosperity. This also underlines the potential importance of nuclear energy. If the energy abundance contained in uranium (and similar elements) can be harnessed for human use, there is real potential for universal human prosperity; but more widespread use of nuclear energy will of course also increase certain risks. The question we have therefore to investigate is whether these risks can be managed and the use of nuclear energy justified.

The Question of Energy Revisited

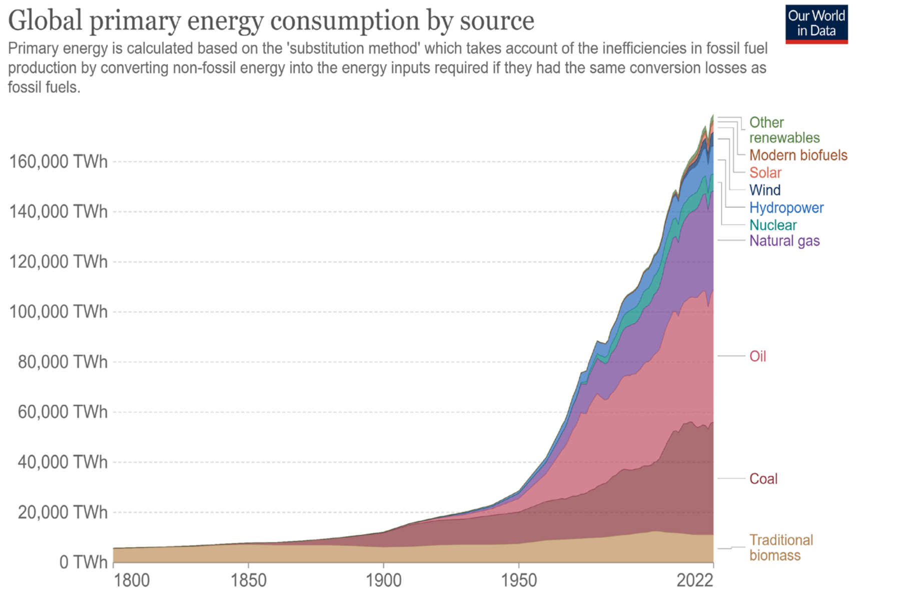

Figure 10a. World energy use

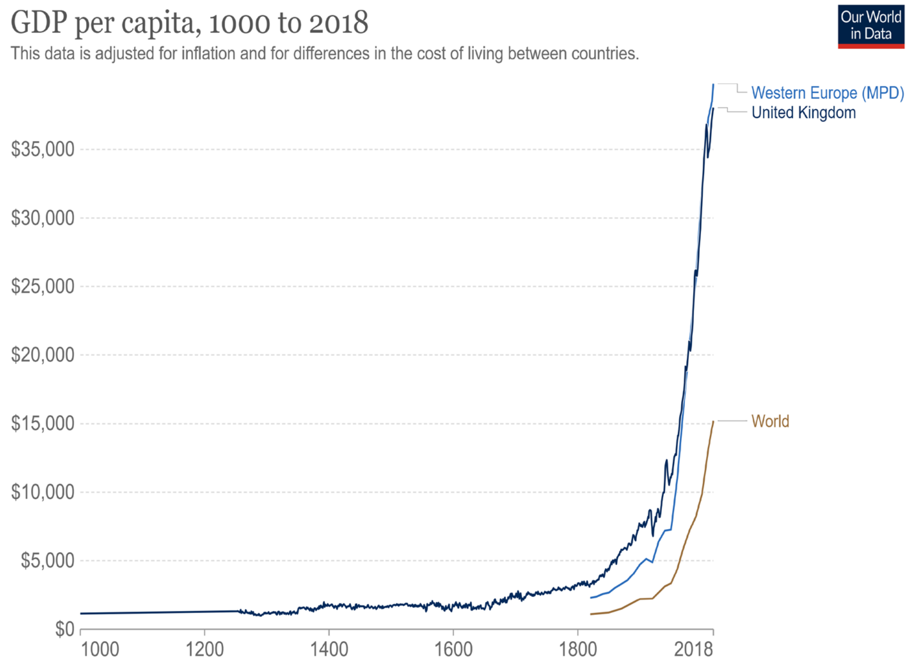

Figure 10b. GDP per capita

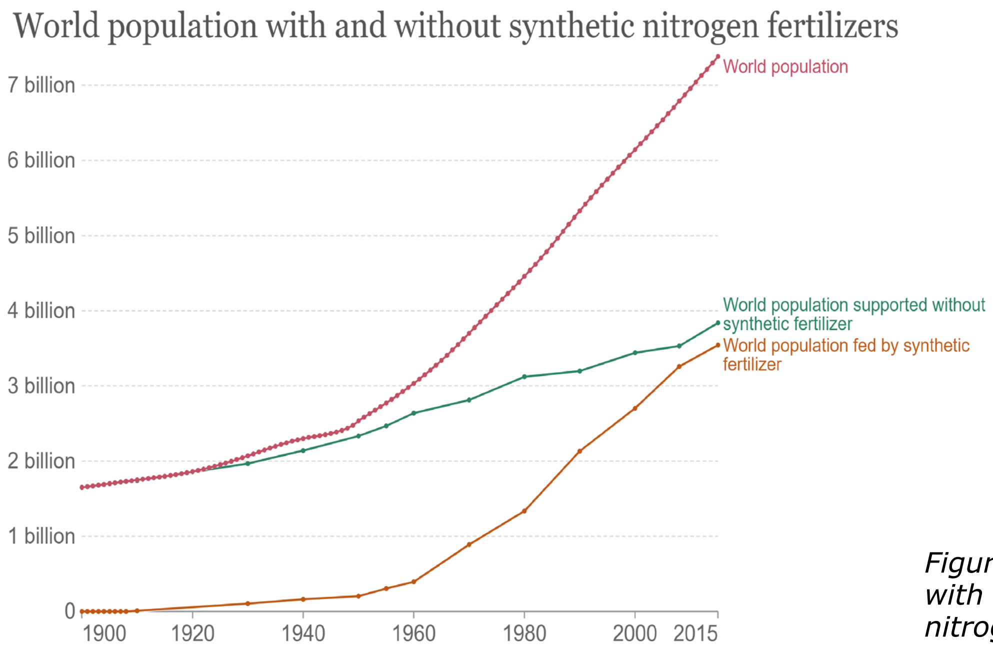

Figure 11. World population with and without synthetic nitrogen fertilisers

4. How Safe is Nuclear Energy?

To evaluate the safety of nuclear power, it is crucial to put it into context with other forms of energy production. The question is not 'energy or no energy', but what forms of energy are preferable. Neither nuclear nor its alternatives are 100% safe, but could it be possible that the process of fission is the best available option? From a safety perspective, it is difficult to make the case against nuclear power (see Figure 12[33]) given its low death rates per unit of electricity production. Despite these numbers, however, the fear of a nuclear meltdown is a permanent presence. For example, in the first week of June 2023 the Kakhovka dam in Ukraine was breached, and almost immediately major news outlets were predicting the imminent meltdown of the Zaporizhzhia nuclear power plant that was supplied with water from the dam. In almost every case this was a massive overstatement that looked like a shameless attempt to generate clicks through overdramatising an already tragic and horrifying event .[34]

The main two incidents that are used to justify resistance to nuclear power are Chernobyl in 1986 and Fukushima in 2011. These were indeed the largest nuclear accidents in recorded history, so it is worth taking a closer look at them.

4.1. Chernobyl

The first and most important point regarding the incident at the Chernobyl reactor is that the accident as it unfolded could only happen in the very specific design of that reactor. This was not a pure electricity-generating nuclear power plant but was also used to produce weapons-grade Plutonium for the Soviet military.[35] The conditions present in Chernobyl are not the typical conditions in which modern nuclear power plants operate, with highly-trained personnel and rigorous safety procedures.

The death toll from Chernobyl is hard to assess accurately if we distinguish between long-term and short-term effects. But based on the available evidence the following picture emerges, according to Hannah Ritchie of "Our World in Data":[36]

- Two workers died in the blast.
- 28 workers and firemen died in the weeks that followed from acute radiation syndrome (ARS).
- 19 ARS survivors had died later, by 2006; most from causes not related to radiation, but it's not possible to rule all of them out (especially five that were cancer-related).
- 15 people died from thyroid cancer due to milk contamination. This could increase to between 96 and 384 deaths; however, this figure is highly uncertain.
- There is currently no evidence of adverse health impacts on the general population across affected countries, or wider Europe.

The confirmed death toll is less than 100, and based on official reports and estimates the true death toll most likely is in the 300 to 500 range. While every death is tragic, this needs to be put into perspective with other incidents at electricity-producing facilities. Taking all consequences into account, the 1975 Banqiao Dam failure in China possibly caused a death toll of over 200,000, and the destroyed Kakhova Dam in Ukraine has ended 13 lives at the time of writing, a number that is unlikely to be the final count.

It is also important to mention that the meltdown in reactor 4 did not end electricity production in the other reactors at the Chernobyl power plant, which kept operating for 14 years after the incident until being finally shut down in 2000.

4.2. Fukushima

Similar to Chernobyl, the conditions leading to the 2011 accident at the Fukushima Daiichi Nuclear Power Plant in Ōkuma, Fukushima, Japan were in many ways unique. The main trigger was the 2011 Tōhoku earthquake and tsunami, the largest earthquake in Japanese recorded history.[37]

Based on the available evidence, the death toll from radiation in Japan was one, happening seven years later by radiation-induced lung cancer. According to the World Health Organisation there is only a very low risk of increased cancer deaths.[38] It is no surprise, therefore, that with the global energy crunch and the shift in focus from safety to economic concerns, the Japanese public has begun to support the use of nuclear power again (see Figure 13[39]).

In conclusion, neither Chernobyl nor Fukushima present compelling cases to abandon nuclear power. While they do highlight the existence of risks, they also show that it often takes extreme circumstances for these risks to materialise. In fact, we could argue that shifting electricity production from coal to nuclear would save lives and mitigate health risks that emerge from the burning of coal. The scientific evidence that connects pollution from coal power plants to excess deaths is undisputed. Indeed, according to two academic studies, a country such as Germany could have saved thousands of lives and avoided up to 800 excess deaths per year if they would have phased out coal instead of nuclear.[40]

4.3. What about the waste?

Nuclear waste is another widespread concern about nuclear power. This is the biggest straw man in the anti-nuclear argument. In short: there is no problem with nuclear waste. There has not been a single documented case of humans being harmed by nuclear waste. Yet thanks to its depiction in the media and popular culture we are led to believe that a nuclear waste catastrophe could happen any second. Worldwide there are about 460,000 tonnes of spent fuel (which is a more appropriate designation than "waste"), and countries from France to Finland have found effective ways to deal with it, including final storage or retaining some of it for further use.[41]

Madison Hill, the founder of the Campaign for a Green Nuclear Deal, provides a detailed description of how nuclear waste is dealt with: "Nuclear fuel is made up of shiny metal tubes containing small pellets of uranium oxide. These tubes are gathered into bundles and loaded into the reactor. After five years of making energy, the bundles come out, containing radioactive particles left over from the energy-making reactions. The bundles cool off in a pool of water for another five to 10 years or so. After that, they are placed in steel and concrete containers for storage at the plant. These casks are designed to last 100 years and to withstand nearly anything – hurricanes, severe floods, extreme temperatures, even missile attacks. To date, there have been no deaths, injuries, or serious environmental releases of nuclear waste in casks anywhere. And the waste can be transferred to another cask, extending storage one century at a time."[42]

Even the release of water containing tritium, which does occur at nuclear power plants, is not as dangerous as often assumed: "You would need to drink over a gallon of the treated water being released from Fukushima to get the equivalent radiation exposure of eating a banana."[43]

Whether we consider spent fuel or the more general operation of modern nuclear power plants, nuclear has demonstrated an impressive safety record. Whichever way you look at it, nuclear power is a very safe form of energy production.

How Safe is Nuclear Energy?

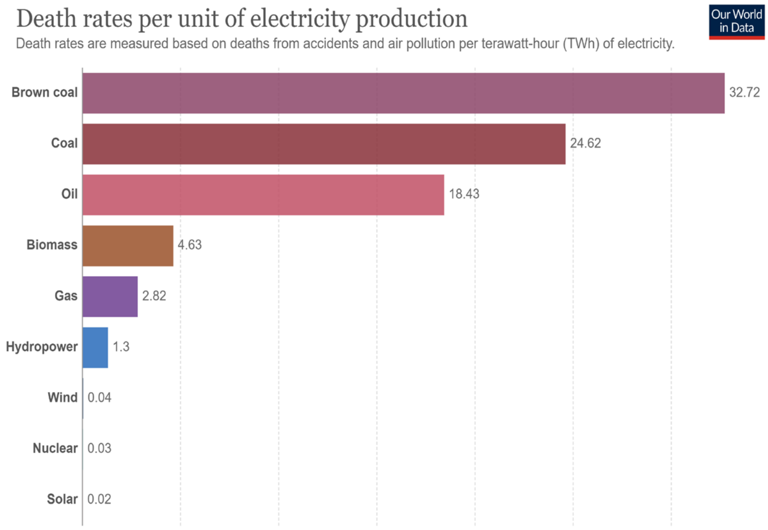

Figure 12. Death rates per unit of electricity production

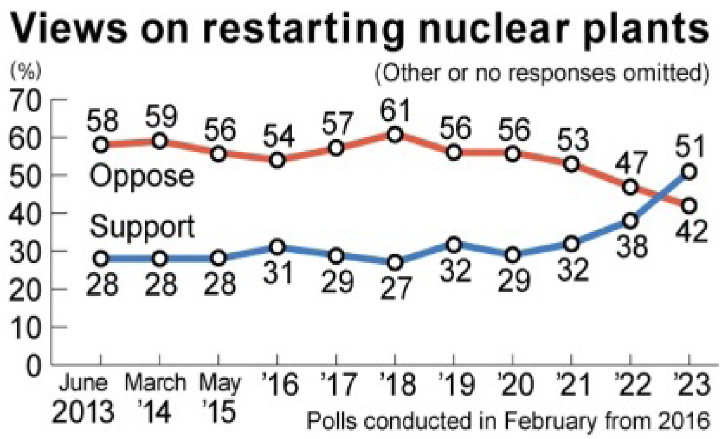

Figure 13. Japanese views on nuclear power

5. Can Nuclear Energy Help to Prevent Climate Change?

The short answer is yes. While there are CO2 emissions during the construction phase of a nuclear power plant, once it becomes operational emissions drop below even wind and solar. It is therefore no surprise that even the International Energy Agency has concluded that global nuclear power capacity has to double by 2050 to reach the goal of capping temperature rises at 1.5 degrees Celsius above pre-industrial levels.[44] The developing world – which has a huge energy deficit compared to industrialised nations – will especially need access to nuclear energy, since it allows for economic growth with a very limited impact on global temperatures.

Based on an assessment of the countries that have moved furthest along on the nuclear path, there is no question that nuclear power has already played a key role in the production of low-emission electricity in Canada, Sweden, France, and other countries. The shift away from fossil fuels both as a source of primary energy and of electricity has been accomplished most impressively by France. The French approach of using nuclear power as their main energy source has proved a more effective path towards a sustainable energy transition than the antinuclear approach of her neighbour Germany (see figures 14a-d overleaf[45]), whose fossil fuel use stood at 51% in 2022 compared to below 20% for Denmark, France and Sweden.

Certainly, nuclear power is not the only means to accomplish this goal, but it has the additional advantage that plants can be built almost anywhere. For example, the Palo Verde Nuclear Power Plant in Tonopah, Arizona is the largest electricity generator in the United States and located in the Arizona desert. The water for its operation comes from treated sewage of nearby cities that are in turn supplied with cheap and reliable energy. By contrast, an alternative to nuclear such as hydropower depends on very specific topographical conditions: it requires a combination of water and mountains that does not exist in many countries. Sweden, Canada, Austria, and Norway are among the countries endowed with ideal conditions for hydropower, which supports a decarbonised grid, but countries such as France or Germany do not have this option to a similar extent, creating the need for alternative sources of energy.

The carbon intensity (and resulting greenhouse gas emissions) of nuclear electricity generation is even lower than that of wind and solar, the oft-preferred source of low carbon electricity for environmentalists, and it has the additional advantage of being more reliable without the need for backup systems, at similar safety levels. Both of these points – the safety and greenhouse gas emissions – are detailed in Figure 15 overleaf.[46]

"Renewables are not reliable enough to become the sole source of electricity, much less of energy."

For this reason alone, it remains a mystery why a country such as Germany – whose population is the most worried about climate change[47] – would give up its nuclear power plants. German reactors have been among the most reliable in the world, operated by excellent staff and in excellent conditions.[48] There is no reliable evidence that wind and solar can replace all the lost electricity production, and it remains to be seen how quickly Germany will turn from being a net-electricity exporter into being an importer. The change will also most likely have a negative impact on CO2 emissions.

Based on data from the energy transition in the United States, there have been three successful ways of moving away from coal and oil, involving the increased use of nuclear, hydropower, and natural gas (see Figure 16[49]).

This puts the idea that renewables can replace both fossil fuels and nuclear into perspective. Renewables are not reliable enough to become the sole source of electricity, much less of energy. This could change after a series of significant technological breakthroughs, especially in battery and storage technology – and after these breakthroughs have become economically viable. To provide just one example: the Lithium-Ion battery was

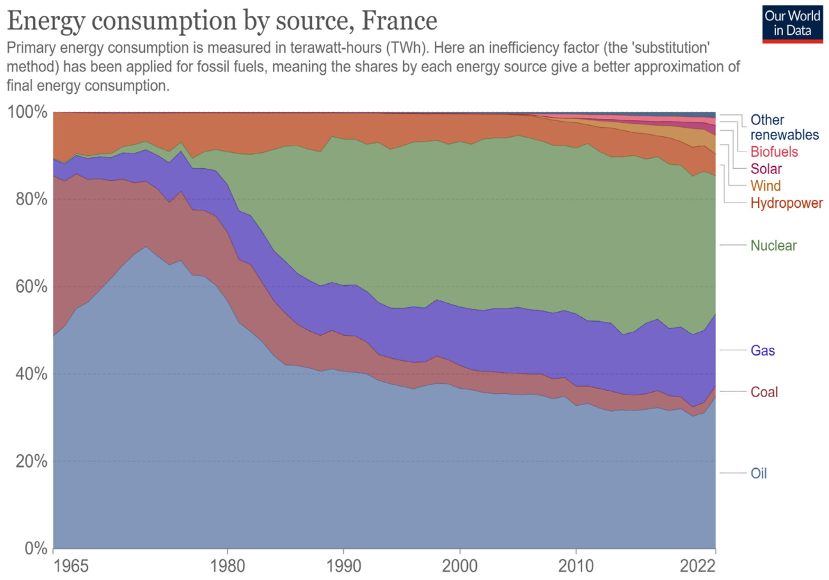

Figure 14a. French energy consumption by source

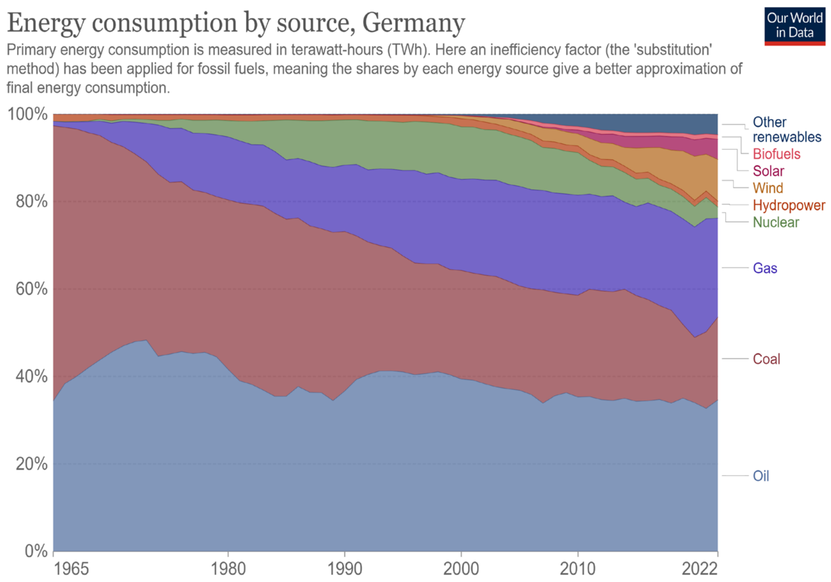

Figure 14b. German energy consumption by source

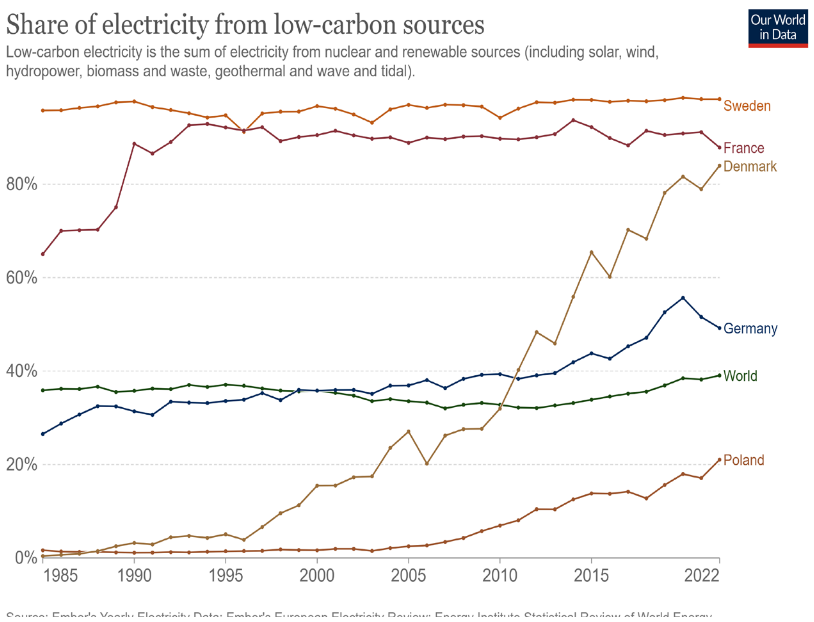

Figure 14c. European low carbon energy by country

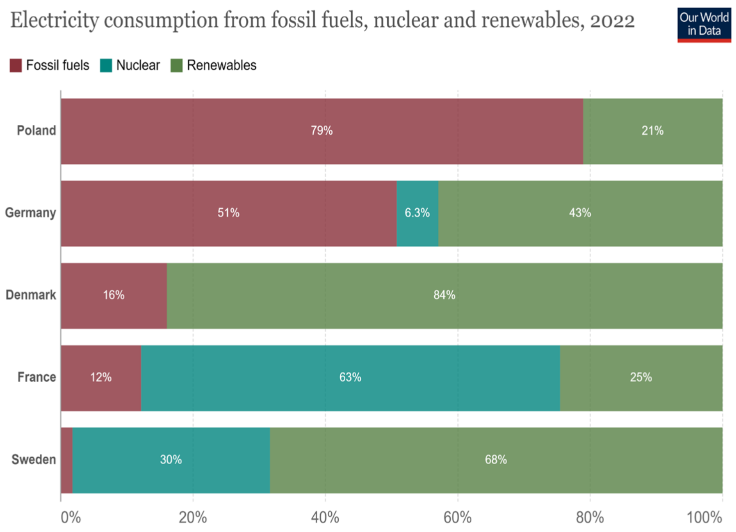

Figure 14d. European sources of energy consumption

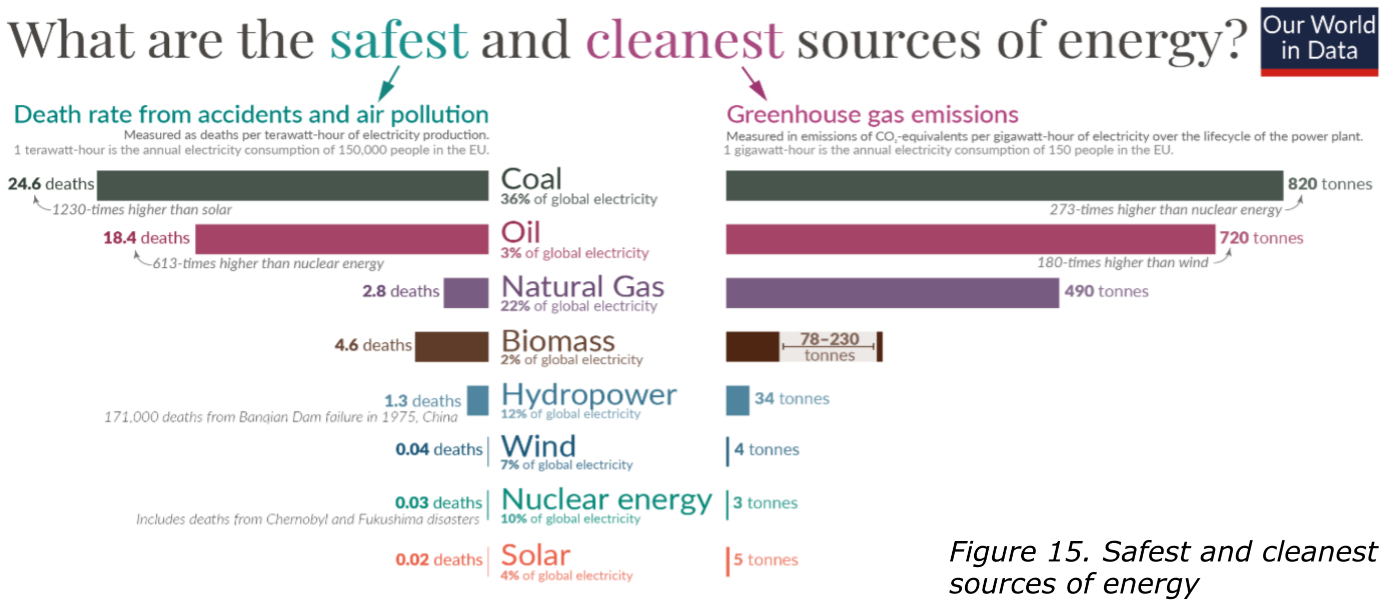

Figure 15. Safest and cleanest sources of energy

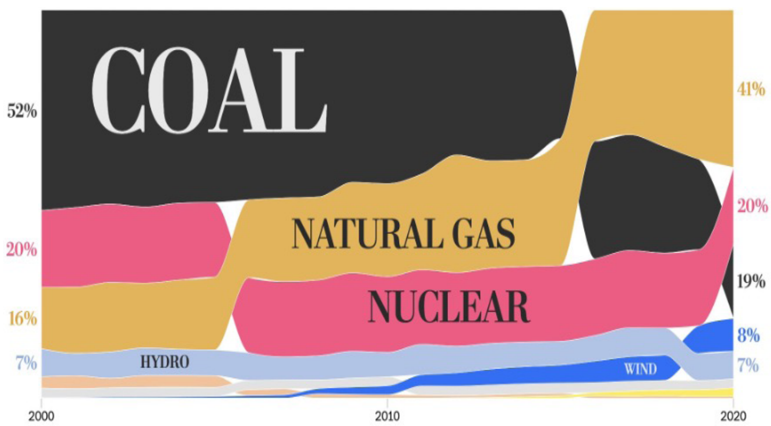

Figure 16. US electricity production in transition

invented in the 1970s but did not become commercially available until the 1990s. This means that whatever promising developments are currently taking place in laboratories and research institutions – and encouragingly, there are quite a few[50] – it will take time until the best of them can be rolled out on an industrial scale. While this also applies to nuclear in the realm of fusion, the technology of fission is readily available and has been for a long time.

One of the main aspects that makes the nuclear option so attractive is what is called its high 'capacity factor'. This is a measure of "how often a plant is running at maximum power. It's … calculated by dividing the actual unit of electricity output by the maximum possible output. This ratio is important because it indicates how fully a generating unit is used."[51] The capacity factor is crucial in any assessment of energy production because it gives us an idea about the energy/electricity that can be produced vs. what is actually produced. Taking a look at US capacity factors reveals the exceptional performance of nuclear power plants (see Figure 17[52]).

"Abandoning nuclear has not been shown to have any positive impact on CO2 emissions ... indeed it will accomplish exactly the opposite."

It is therefore not surprising that abandoning nuclear has so far not been shown to have any positive impact on CO_2 emissions; indeed, there is growing evidence that it will accomplish exactly the opposite. In 2022, six German coal power plants were among Europe's top 10 emitters (see Figure 18[53]), and at that time the three remaining Nuclear Power Plants were still online. The trend to replace electricity production units that possess over 90% capacity factors with units that do not even reach 50% capacity factors means that more of these non-nuclear alternatives have to be built in order to reach the same output. It is ironic that green activists, always the first to resist construction projects in the countryside, find themselves forced to support vast building projects to create 'green' energy.

Despite these impressive numbers, even nuclear cannot reach a capacity factor of 100% since fuel replacement and maintenance are necessary, leading to regular power-downs. Neglecting to carry out regular maintenance can have a significant effect on output, as was well illustrated in France during the summer of 2022, when long-overdue maintance was carried out on a number of plants, reducing output significantly – although we should note that neglected maintenance was in part a result of environmentalist political pressures to move away from nuclear power.[54]

Even though the French nuclear buildout has been a success story overall, governments in Paris have also begun to give in to the anti-nuclear and pro-wind and solar lobby. Plans have been made to dismantle her nuclear fleet, or, in the words of former Électricité de France CEO Jean-Bernard Lévy, "we'd been told for years: please, prepare yourselves to shut reactors. Clearly, we didn't hire people to build [...] reactors, we hired people to dismantle them."[55] In 2014 the French government set a target of reducing the share of electricity generation via nuclear from 70% to 50% by 2025. That target that has now been pushed back to 2035 – and most likely will be given up altogether. In February 2022 France announced that it will build at least six new reactors in the coming years.[56]

For an industry that has been told for years that it will no longer be needed, the French nuclear fleet has operated surprisingly well. It is not easy to recruit a qualified labour force for jobs that have a fixed expiration date. Why would highly skilled engineers start working for EDF, when they know that this employment is going to be temporary at best?

As so often in the nuclear industry, first nuclear gets sabotaged or hamstrung by activist politicians, who then use the results of that very sabotage as a justification to shut down the entire industry.

Unfortunately, this trend has not been fully overcome just yet. Throughout the spring and summer of 2023, member states of the European Union have been engaged in an enormous debate about whether nuclear should be included in renewable energy targets. France led a camp that insisted they should be, with Germany rallying countries opposed. At one stage in the debates, a typically EU fudge seemed to have been agreed, recognising nuclear as 'neither green nor fossil'.[57] But the debate over terminology distracted from the fundamental, and to our mind baffling, refusal to engage with nuclear power as a technology capable of addressing the need to reduce reliance on fossil fuels.

Indeed, based on the facts presented here, that debate makes absolutely no sense unless one takes the ideological zeal of environmentalist campaigners into account. There is no scientific argument against nuclear power as the most efficient way to decarbonise the production of electricity while simultaneously keeping overall electricity production high.

As previously discussed, the resistance to nuclear is primarily culturally and ideologically motivated. This has created significant emotional obstacles that are hard to overcome with reference to the science of nuclear power – which is undisputed. So far, the most effective factor in overcoming these emotions has been replacing fear of nuclear energy with fear of economic decline. As long as there was only a small price tag attached to anti-nuclear policies, most people did not think too much about it. This, however, is beginning to change as energy prices have risen.

Nuclear energy could play a role in bringing down prices. In Finland, for example, a glut of new energy supply triggered by the opening of the Olkiluoto 3 reactor reduced the price of electricity by 75%, from 255 Euros to 61 Euros per megawatt-hour, at one point turning the cost of electricity negative.[58] Energy prices will of course stabilise at a slightly higher rate, but the new reactor has established a permanently lower baseline for energy prices in the country, with nuclear supply increasing by roughly one-third, from around 20% to 30% of total generation.[59]

The Finnish case is instructive in many ways. Even supporters of nuclear energy cannot deny that despite the current positive effects, the construction process of Olkiluoto 3 was hardly a smooth operation; it opened 12 years behind schedule and at a cost of almost four times the initial estimate.[60]

This brings us to the next point: Can nuclear energy ever be economical and built out quickly, or is it just too slow and too expensive?

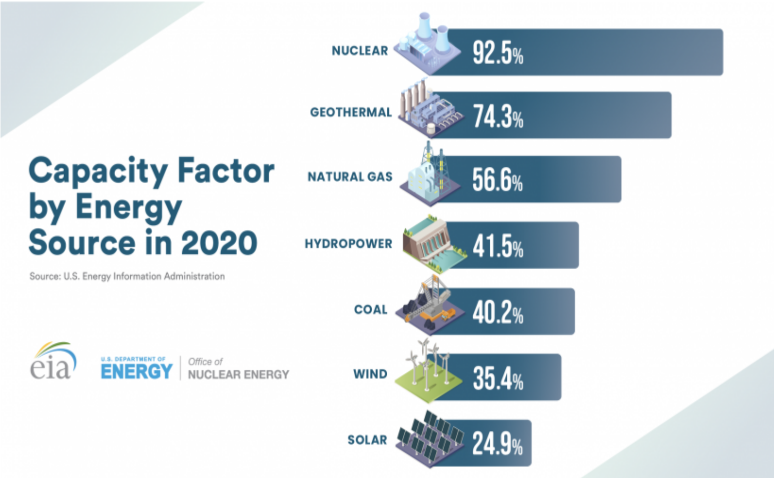

Figure 17. Capacity factors

Top 10 emitters in Europe all coal power plants

EU Emissions Trading System, 2022

Power Plant	Owner	Fuel	Position	Emissions 202 (Mt CO2e)
Bełchatów	PGE	Lignite	1	35.0
Neurath	RWE	Lignite	2	24.22
Boxberg	EPH	Lignite	3 (▲2)	19.13
Niederaußem	RWE	Lignite	4 (▼1)	17
Kozienice	ENEA	Hard Coal	5 (▼1)	15.54
Jänschwalde	EPH	Lignite	6	15.31
Weisweiler	RWE	Lignite	7	14.93
Lippendorf	EPH/EnBW	Lignite	8 (▲1)	11.91
Turów	PGE	Lignite	9 (▲2)	11.22
Maritsa East 2	BEH	Lignite	10 (▲7)	10.93

Source: EU-ETS
Europe covers EU-27, Switzerland, Norway, Iceland and Liechtenstein.
EMBER

Figure 18. Top 10 emitters

6. The Economics of Nuclear Energy

Nuclear power plants are expensive and difficult to build. The question, however, is not whether they are expensive (which they are) but if they are overall beneficial from an economic perspective? A good description of nuclear power is "an expensive way to make cheap electricity, while most alternatives are cheap ways to make expensive electricity".[61]

We must distinguish between the costs and benefits of building new reactors compared to the decommissioning of functional reactors. While the former is an important and complex debate, the latter is not: shutting down fully functional nuclear power plants can never be an economic benefit, except for those companies who profit from a decline in energy and electricity supply. The French nuclear approach, for example, turned the country into the world's largest net exporter of electricity, creating an annual revenue of three billion Euros.[62] Using the Olkiluoto 3 plant in Finland as a reference point, even including cost overruns would mean that France could build a similar reactor every four years with the revenues from her electricity exports alone.

The supposed argument in favour of decommissioning operational nuclear power plants is that even a single catastrophic accident would come at such high costs that this risk alone outweighs any potential economic benefits. Such a view, however, rests on the mistaken belief that a nuclear reactor is indistinguishable from a nuclear bomb waiting to explode. As explained here, the safety record of nuclear power is exceptional, and even the most catastrophic incidents do not justify abandoning this technology. Yet this fear has led to an ever-tighter regulatory regime for the construction of nuclear power plants, and more regulation has meant higher construction costs and longer construction times.[63] Contrary to the idea that these problems are inherent, there is ample historical evidence that at the height of nuclear construction both costs and construction times were coming down.

A recent report on the growth of nuclear power in Canada demonstrated that not only was switching to nuclear energy crucial in staying on a path to decarbonisation, but that it was also practicable. Between the late 1960s and early 1990s Canada built 22 reactors in as many years, turning a grid with zero nuclear power to two thirds nuclear in record time, achieved through design standardisation and the streamlining of supply chains.[64] Under pro-nuclear political conditions, this can be repeated today, as the United Arab Emirates Barakah NPP has shown: although also initially quite expensive, the fourth unit was 50% cheaper than the first unit.[65]

> **"Safety concerns have been hijacked as an underhand tactic to avoid nuclear being built at all."**

It is once again important to put these observations into historical perspective. The first programmable pocket calculator (the HP-65) entered the market in 1974, following the first commercially available microprocessor (the Intel 4004) in 1971. At this time in Germany alone 25 nuclear reactors were either built or under construction, highlighting the fact that nuclear technology could be built effectively before the era of the microprocessor. The nuclear power plant Beznau in Switzerland, built between 1965 and 1969, is still producing electricity despite being older than the Apollo 11 mission that for the first time put a man on the moon on July 16, 1969.

It is hard to explain why a technology that is both durable and has been known for a long time should not see a reduction in construction costs, unless we take the growing regulatory requirements and political opposition into account.[66] During the construction of Olkiluoto 3 a rigorous safety regime was a significant driver of costs and time: "You test every single piece, if there is a deviation, it is rejected. It takes a while to make a new piece, so this causes a delay. Quality is more important than the schedule."[67] Whilst quality control is important, safety concerns have been hijacked as an underhand tactic to avoid nuclear being built at all. This much was brazenly, and shockingly, admitted by German former minister for the environment Jürgen Trittin: "It was clear to us that we could not prevent nuclear power by protesting in the streets alone. Therefore, once in government, […] we tried to make nuclear power plants unprofitable by increasing mandatory safety requirements."[68]

It remains one of the more puzzling aspects of the European debate that those who are supposedly most concerned about climate change and the environment are the ones who oppose the expansion of nuclear power at every turn. Also, as we will explore, most plans for decarbonisation rest on an expansion of electricity as a major source of energy, the driving idea behind the political push for electric vehicles or heat pumps and air conditioning. If one supports this approach, the question of where that electricity is supposed to come from becomes crucial. Once again, the German experience is instructive.

> ***"We could not prevent nuclear power by protesting in the streets … we tried to make nuclear power plants unprofitable by increasing mandatory safety requirements."***
>
> **Jürgen Trittin, German former minister for the environment**

Since 2000, Germany has spent an estimated 500 billion Euros on the 'energy transition'. This transition was characterised by replacing coal and nuclear with renewables (see Figure 19[69]) yet did not lead to any significant increase in overall electricity production (see Figure 20[70]). It did lead, however, to significant increases in electricity prices for both German households and industry (see Figure 21[71]).

In 2021 coal (both bituminous and lignite) was responsible for 28.1% of Germany's electricity production, and nuclear for 11.8%. By phasing out both coal and nuclear over the next 10 to 15 years, Germany will need to replace approximately 39.9% of electricity production by alternative sources simply to maintain current supply levels (some Green politicians are pushing for an even shorter transition by 2030). If Germany wants to shift quickly to EVs and replace heating via fossil fuels with heat pumps, the demand for electricity will increase significantly. By 2030 demand could increase by 20% compared to 2021 levels, according to the Federal Association of Energy and Hydroeconomics.[72]

The trend predicted for Germany also applies globally, and there is no reason to assume a decline in the need for electricity, on the contrary, electricity demand is expected to triple by 2050[73].

At this point it is not clear where this additional electricity is supposed to come from in a carbon neutral way – unless nuclear power is made a central part of future electricity production. If net-zero is to be achieved, nuclear power will have "to double or even triple by 2050"[74].

Based on the estimates presented in this report, there is no way to reach net-zero without the inclusion of nuclear on a significant scale. The only alternative would be to reduce energy and electricity consumption, but this would mean dramatically deteriorating living standards and it is unlikely that such an approach would be politically feasible. Demand from the developing world is also set to grow: "In 2020 the average annual per capita energy supply of about 40 percent of the world's population (3.1 billion people, which includes nearly all people in sub-Saharan Africa) was no higher than the rate achieved in both Germany and France in 1860."[75]

It is extremely unlikely that these 3.1 billion people will accept limited access to energy indefinitely. With the unavoidable industrialisation of the developing world, the need for all types of energy will increase. This is not a question of if, but of how fast.

6.1. Wind and solar: Genuine alternatives?

It is unlikely that it would be possible or even cheaper to meet this growing need through wind and solar alone, given the current state of the technology. Like hydropower, for wind and solar instalments to be efficient electricity producers, certain ideal conditions need to be present. As even a cursory investigation reveals those conditions do not exist everywhere to the same extent (readers are recommended to investigate the Global Wind and Solar Atlases to discover for themselves).[76]

Even under the best possible conditions wind and solar remain intermittent (i.e., non-continuous) providers of electricity, creating

The Economics of Nuclear Energy

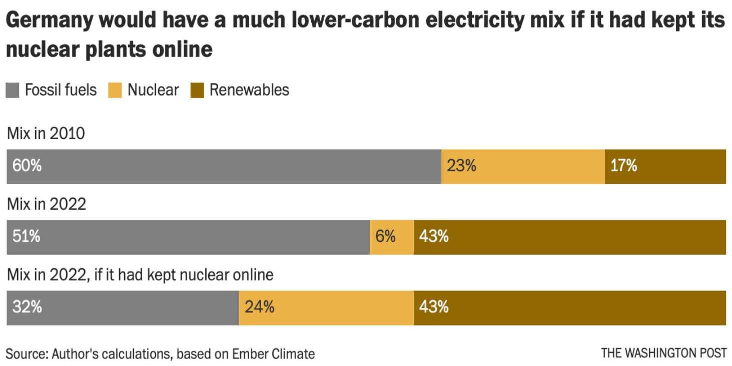

Figure 19. German energy mix

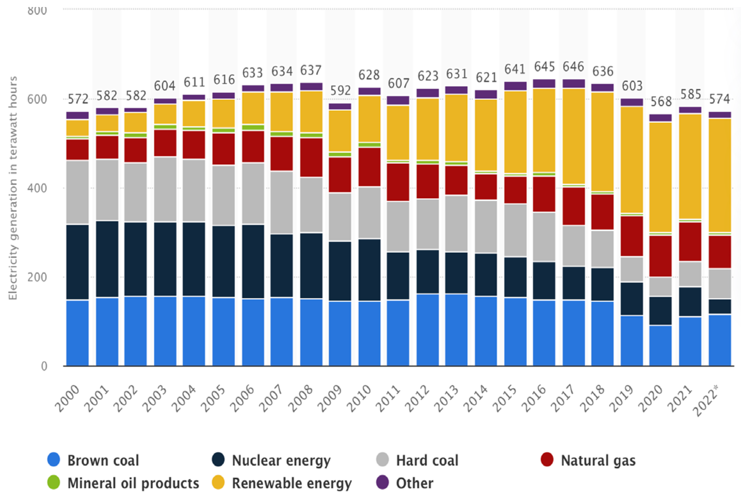

Figure 20. Gross electricity generation in Germany

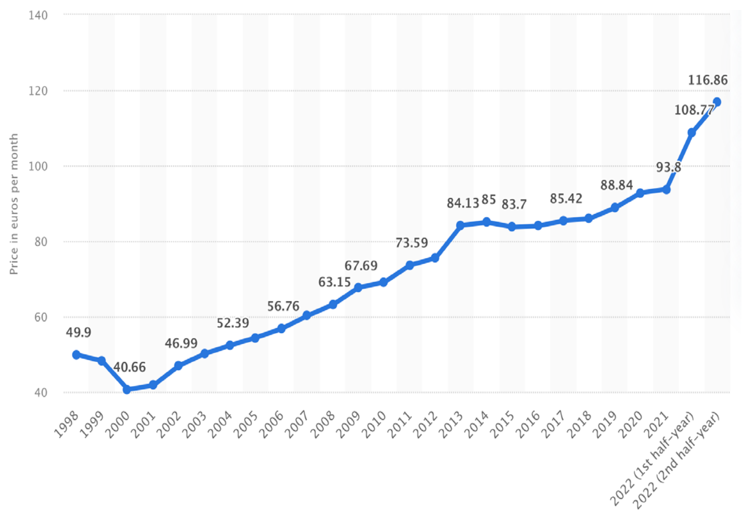

Figure 21. Average monthly electricity bill for a German three-person household

the need for backup systems on permanent stand-by. This impacts the price of electricity, since every addition of renewables to an electricity grid must be accompanied by a non-renewable backup system.

Imagine a country plans to replace all its existing train stations with brand-new, environmentally friendly, cheap energy railway stations. It seems logical at first, something that is better and cheaper should always be given priority. Alas, what seems too good to be true often is. As we plan our new train stations, we will soon find out that we cannot simply put them in place of the old ones (you cannot replace a coal, gas, or nuclear power plant at the exact same location with wind or solar) but have to build them far away from the city centres and the people who want to use the trains. So, it is not just that we need new stations, we also need new railways to connect them to the overall network (aka the electricity grid). But it gets worse.

Imagine that despite their incredible qualities, these new stations can only be operational between 11% (the capacity factor of solar in Germany) and 40% (the capacity factor of the best offshore wind farms) of the time – and you cannot even tell the exact days and times because these stations are weather dependent. This means that you must keep both the old stations and the existing railway network in place, as backup for the times the fancy new system does not work. In other words, instead of a cheaper railway system you get a duplicated one, making the price of train tickets go up, not down. Germany has electricity bills three times higher than the US, and German industry pays almost twice as much per mWh as their Chinese competitors.

This duplicated system consists of either nuclear, fossil fuels or hydropower – with the last subject to significant topographical limitations. Another factor that barely receives the attention it deserves is the problem renewables can create for grid stability.[77] For political reasons the backup system is currently neglected in Europe, and the question is not only about building new nuclear power plants, but replacing retiring ones:

"Nuclear fleets across the continent are ageing, and if they are not replaced, the grid will lose another 20 GW of supply by 2030. But if it takes 15 years to replace an ageing nuclear power station, we are too late already. Worse, by 2040, another 70 GW will have been retired. Replacing all this capacity with wind power is impossible; 18 GW of nuclear power equates on average to 3,146 15-GW offshore turbines. Solar is worse – in northern Europe, it is little more than a waste of precious mineral resources. Delivering a building programme on the scale required, and in the seven years remaining before the deadline, is an engineering and financial impossibility."[78]

There is not a single case study of a power grid running solely on wind and solar, and the only way to replace coal has been with hydro, nuclear, or natural gas – or a combination thereof. Behind closed doors even some members of the German government know that, otherwise it is hard to explain why they plan to double the regasification capacity of LNG by 2030. The 100% renewables-based grid is impossible unless other affordable, scalable, and long-term storage technologies have reached market maturity.

> **"There is not a single case study of a power grid running solely on wind and solar ... a renewables-based grid is impossible without technologies that do not yet exist."**

Many industry experts agree that we are a long way from grid-level battery storage even in an advanced economy such as the US:

"According to projections from industrial research firm Wood Mackenzie, the US is set to add 191.6 gigawatt hours (GWh) of battery backup systems across residential, non-residential, and grid-scale installations between 2022 and 2026. This sounds impressive until you realise the US produced 4,116,000 GWh of electricity on the grid in 2021 alone. By our math, the Wood Mackenzie projection amounts to a grand total of 24 minutes of total backup capacity added to the system over the quoted five-year period."[79]

The situation in Europe, according to Alexander Stahel, is not much different:

"There are just over 4 GW of grid-scale batteries worldwide. The Tesla Gigafactory (once completed) will produce enough batteries each year to store 30 GWh of electricity. This is a lot, but Europe consumes

3,300,000 GWh of electricity every year, so each Gigafactory would deliver only a few minutes of electricity storage."[80]

The economic question regarding nuclear cannot be answered by simply looking at the price tag, but by putting the costs (which are significant) in the context of the potential benefits (which are equally significant) and comparing it with alternatives. If the goal is to reduce carbon emissions and the use of fossil fuels without causing a decline in living standards, there is no way to avoid the expansion of nuclear power.

7. The Geopolitics of Nuclear Power

Modern societies depend on energy, but energy resources are not equally distributed around the globe, which is why trade in energy products can be so lucrative. Given its importance for the survival of an industrialised economy, securing energy supplies is a major obligation of any government.

Europe, despite its material wealth, is notoriously starved of energy, producing a very limited amount itself: "Using a variety of sources, we estimate the EU's global share of oil production to be less than 0.4%. For natural gas, the number checks in at only 2.3%. As for coal, the EU produced 309 Mt of the 8,057 Mt produced worldwide in 2021, for only 3.8% of the global production share. Of that share, 77% is produced by just three EU countries – Germany, Poland, and the Czech Republic."[81]

Unfortunately, the transition to clean energy will not solve the problem of dependency. As the International Energy agency has assessed, clean energy needs more minerals than other sources of energy production:

"Solar photovoltaic (PV) plants, wind farms and electric vehicles (EVs) generally require more minerals to build than their fossil fuel-based counterparts. A typical electric car requires six times the mineral inputs of a conventional car and an onshore wind plant requires nine times more mineral resources than a gas-fired plant. Since 2010 the average amount of minerals needed for a new unit of power generation capacity has increased by 50% as the share of renewables in new investment has risen."[82]

The war in Ukraine has highlighted that it matters who supplies your energy, which is why we have to ask who dominates the supply of critical minerals: "China's overall market share of energy transition minerals is double OPEC's share of oil markets."[83]

Figure 22 illustrates the different rare minerals which are required in various renewable energy technologies, which compares unfavourably with traditional energy sources.[84]

Switching from fossil fuels to clean energy will not create energy independence, but a renewed and intensified dependency on the People's Republic of China. Nuclear Power, by contrast, could play a role in decreasing dependency on both Russia and China. While it is true that Russia currently has a near-monopoly in the provision of fuel for nuclear power plants (especially processed Uranium), this problem could be addressed.[85] As outlined earlier, neglecting the nuclear industry also led to a neglect of crucial supply chains, but this does not mean that these supply chains cannot be replicated in Europe or the US.[86]

"Switching from fossil fuels to clean energy will not create energy independence, but a renewed and intensified dependency on the People's Republic of China."

Furthermore, new reactor designs (for example so called Small and Medium Reactors, or SMRs) are less fuel intense than older designs.[87] The strategic use of nuclear power could also decrease fossil fuel dependencies. Industrial and petrochemical processes often need high temperatures, that in the past could most efficiently be provided by using fossil fuels. This, however, could change using more advanced nuclear technology:

"While older generations of nuclear reactors were largely limited to producing steam with temperatures in the range of 300C, Generation IV advanced designs can reach temperatures between 500-1,000C, significantly expanding the utility of new nuclear-based co-generation facilities. At these temperatures, the steam requirements of many important petrochemical processes are suddenly in play, including the production of ammonia using the Haber Process. … 500-1,000C opens an attractive addressable market for industrial carbon abatement."[88]

In addition to the environmental benefits of nuclear power, there would be significant benefits in terms of geopolitics and energy security.

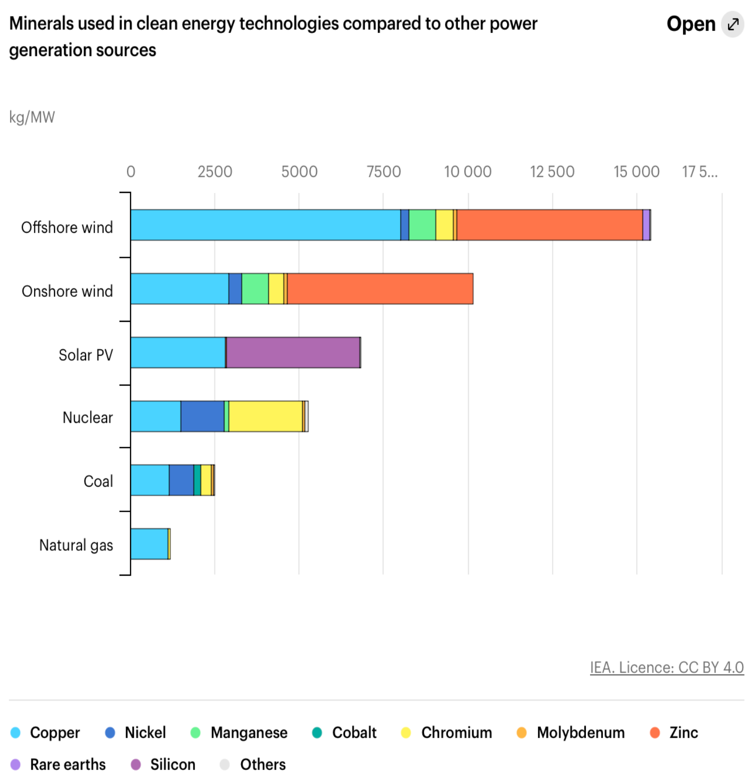

Figure 22. Mineral use in energy technologies

8. Conclusion

Neither energy independence nor any meaningful decarbonisation can be achieved without a renaissance of nuclear energy, unless we accept massive declines in prosperity and living standards. Although the most zealous environmentalists might be willing to accept this proposition, it is unlikely to be popular with most people in industrialised countries.

Some European countries seem to have come to a similar conclusion, despite years of promoting anti-nuclear propaganda (such as the supposed problem of nuclear waste). It is encouraging to see that in May 2023 France took the leadership of a group of European nations calling themselves the "Nuclear Alliance," actively promoting a renewed push for the use of nuclear energy in Europe.[89]

Their efforts, however, will continue to be an uphill battle unless all the issues mentioned in this report are addressed. To name but a few:

Proponents of nuclear power must start a more effective information campaign to make up for decades of misinformation by the well-organised anti-nuclear movement.

The entire regulatory framework surrounding nuclear energy needs to be overhauled to enable speedy and cost-efficient construction, thereby incentivising investments in the nuclear industry.

Universities need to encourage the training and education of future nuclear engineers and research into advanced reactor designs – especially those that could be used more widely in petrochemical and industrial processes.

If the potential of nuclear fission had been discovered yesterday, we would celebrate it as a world-saving miracle. Unfortunately, the circumstances that gave us access to nuclear power have tarnished the positive aspects and led to a history of fears and smears, co-mingling justified worries about nuclear weapons with the unjustified fear of nuclear power.

This report aims to shed some new light on the discussion and help create the conditions necessary for a nuclear renaissance.

9. About the Author

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Ralph is Assistant Professor in economics and political science at Webster University Vienna. His research focuses mainly on cultural factors of identity formation. He is a frequent contributor to the public debate on issues such as Europe's energy crisis. Ralph is the host of the podcast *The 1020* and writes for outlets including the *Jerusalem Post*, the *Washington Examiner*, *spiked* and *Unherd*.

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