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Towards a clean and sustainable energy system: 26 criteria nuclear power does not meet

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About the Author

Jan Haverkamp (1959) graduated in biochemistry and environmental sciences with a side specialisation in nuclear energy. He has worked on the subject of nuclear energy since the 1980s, full-time since 1999. Between 1985 and 2017, he worked mainly in Central Europe and Brussels. As a senior expert on nuclear energy and energy policy, he currently works for the environmental organisations WISE and Greenpeace.

About WISE

WISE (World Information Service on Energy) was founded in 1978 in Amsterdam, the Netherlands. In 1978 revenues from sales of the Smiling Sun were used to start up the organisation, and for about 10 years partly to finance the work of WISE. From the very beginning, WISE has always published a magazine, meant to keep the global anti-nuclear movement updated on developments, arguments and campaigns. In the year 2000, the WISE News Communique merged with the NIRS Monitor into the current Nuclear Monitor. For many years, it has been the last magazine totally devoted to the fight against nukes.

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Introduction

Nuclear energy has been brought back into the European energy debate due to populist power. Currently, a complex debate is taking place within the EU about whether nuclear power should be part of the Taxonomy for Sustainable Activities. Nuclear energy does not meet a number of basic criteria that should be a requirement of technologies in a sustainable energy policy. It only became clear slowly after the introduction of the first nuclear power plants that nuclear energy does not meet these criteria. In the 1970s, however, this crystallised in a thorough nuclear energy critique on a technical, economic, social and political level. Over the last 50 years, the nuclear industry has not been able to overcome these problems. Certain ways of approaching them have changed, however: some risks have been counteracted by dint of expensive safety and security measures, so that the problem has shifted partly, but still not sufficiently, from risk to costs.

It is currently argued that we should keep existing nuclear power plants open longer to prevent a further exacerbation of the climate problem. It is also argued that we need to build new nuclear power plants to reduce greenhouse gas emissions. Work is currently underway on a few dozen new nuclear power plant designs that, according to protagonists of nuclear energy, should meet the criteria for a sustainable energy supply. However, these designs have not yet proven their worth in practice.

To determine whether nuclear energy can, or even should, play a role in future energy policy, it must fulfil basic criteria of sustainability.

Central to this analysis are concepts such as the "do no harm" principle (EU Green Deal, par. 2.2.5.),[1] the *precautionary principle* (Treaty on the Functioning of the European Union, art. 191),[2] and sustainability according to the definition of the Brundtland report: "*development which meets the needs of current generations without compromising the ability of future generations to meet their own needs*" (WCED, 1987).[3] On this basis, we have established a series of criteria that energy sources should meet in order to be able to carry the label "sustainable". If a source does not meet these requirements, it is not sustainable. The list of 26 criteria is not comprehensive, is set out in no particular order and does not indicate priority.

Nuclear energy does not currently meet any of these 26 criteria and it will almost certainly never fulfil the definition of sustainability in the future.

In the meantime, other clean energy technologies are expanding at an unprecedented rate. It can therefore be argued that nuclear energy has become superfluous and, certainly for the medium term, any attention to nuclear energy is a distraction from the political and economic priority that the introduction of truly clean technologies needs to be given so as to effectively counteract the climate emergency.

1 https://ec.europa.eu/info/sites/info/files/european-green-deal-communication _ en.pdf
2 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A12016E191
3 https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf

Sustainability criteria that nuclear energy does not meet

A. Technical criteria

a) Transparent and treatable raw material extraction
b) Sustainable resource exploitation
c) Low greenhouse gas emissions across the entire process chain
d) Exclusion of accidents with major consequences
e) Limitation of the consequences of accidents to an acceptable local level
f) Integration into a total-energy-system
g) No generation of waste for which there is no sustainable management
h) No possible dual use for military applications
i) Sufficient scalability to have a clear positive influence from the perspective of sustainability – contributing significantly towards countering the climate emergency

B. Economic criteria

j) Transparent cost and financing
k) Does not economically push out other, more effective measures
l) Contributes to a system that can function in a financially stable way in the long term
m) Does not lead to concentrations of financial power
n) Does not pass on financial burdens to future generations
o) Does not impose financial burdens on groups that do not benefit from the application
p) Contributes to a healthy development of the labour market at local, national and international level

C. Social and political criteria

q) Because of the urgency of the climate emergency, does not hinder the development of more effective technologies
r) Does not pass on burdens to future generations
s) Does not pass on burdens to groups, regions or countries that do not benefit
t) Democracy enhancing – does not lead to concentration of power
u) Democracy enhancing – does not increase the gap between rich and poor
v) Democracy enhancing – does not hamper increased public participation in decision-making
w) Does not contribute to military tensions
x) Reduction of dependence on resources, expertise and financing from abroad
y) Transparency throughout the entire implementation chain
z) Provides benefits that cannot be provided by other technologies

A. Technical criteria

a) Transparent and treatable raw material extraction

- **Existing nuclear power** – Uranium is mined in 24 countries in Africa, Australia, Asia, Europe and South and North America. On the one hand, mines are run by large companies (e.g. Cameco, Uranium One), large state-owned corporations (Rosatom in Russia, Kazatomprom in Kazakhstan, Eldorado in Canada), by foreign state-owned companies (Orano, France), or by small, largely uncontrollable mining companies (e.g. Wild Horse Energy, Australia – active in uranium exploration in Central Europe; Berkeley Energia, Australia – active in Spain). Europe purchases uranium jointly through the Euratom Treaty. Uranium enrichment and fuel production is in the hands of a small number of companies and countries (For Europe: Urenco, Netherlands/Germany/UK; Westinghouse, US/Sweden; Orano, France; TVEL/Rosatom, Russia; JNFL, Japan). The products from different companies are not always interchangeable.
- **New power stations based on existing designs** – See existing nuclear energy.
- **New designs** – Dependence on a limited number of countries and companies for the availability of uranium, thorium and manufactured fuel remains an important factor in the use of new designs.
- **The alternative** – Due to their decentralised application, most energy efficiency technologies and renewable energy sources and associated systems (transmission, storage) are less dependent on specific providers or countries. For a number of raw materials, there is dependence on a small number of suppliers – technical alternatives are being developed for this (for example for the large-scale use of lithium and cobalt).

b) Sustainable resource exploitation

- **Existing nuclear power** – Uranium mining has caused extensively documented major negative consequences for people and the environment.[4] This varies from large-scale poisoning of ground and surface water with mining tailings and the spread of radioactive material and contaminated materials within the human environment (Akokan, Niger, etc.) to large-scale human rights violations (Kazakhstan, Niger, Mali, USA, Canada, Australia, (former) East Germany, Czech Republic).

4 Biegert, Claus, Horst Hamm (eds.), *Uranium Atlas – Facts and Data about the Raw Material of the Atomic Age*, Berlin (2020), Rosa Luxemburg Stiftung, Nuclear Free Future Foundation, Beyond Nuclear, IPPNW; https://www.rosalux.de/fileadmin/rls _ uploads/pdfs/sonst _ publikationen/UraniumAtlas _ 2020.pdf

- **New power stations based on existing designs** – Uranium is a limited resource. Assuming the same use of nuclear energy as at present (approximately 400 GWe) without reuse in fast breeder reactors, the availability of recoverable reserves is approximately 90 years.[5] A new nuclear power plant is expected to be operational for 60 years. With a construction period of at least 10 years, this means that new power stations could have problems with adequacy of uranium supplies. Improvements concerning the negative effects of uranium mining will push availability down further.
- **New designs** – Fast breeder reactors and the use of thorium as a fuel could extend the availability of uranium by hundreds of years. However, this will not greatly improve the mining implications and dependence on a limited number of countries.
- **The alternative** – Mining is also needed for increased energy efficiency and the use of renewable energy sources. Some of this also releases radioactive and otherwise toxic substances into the environment, mining of several substances takes place in a small number of countries, and a number of substances also have limited availability. Recycling techniques exist for most of these substances and are less polluting than reprocessing used uranium and plutonium. Alternatives are being developed for other substances. Compared to alternative sources, uranium mining is not sustainable.

c) Low greenhouse gas emissions across the entire process chain

- **Existing nuclear power** – Estimates of nuclear emissions range from 3.7 to 110 gCO_2eq/kWh.[6] However, low estimates are usually based on non-transparent industry studies and the medial value of 12 gCO_2eq/kWh in the AR5 of the IPCC is therefore an underestimate. Most emissions occur during the construction of nuclear power plants, fuel production (mining, enrichment, fuel production) and the waste phase (reprocessing). When the uranium ore quality starts to decline, the emission values of nuclear energy increase.
- **New power stations based on existing designs** – See existing nuclear power plants.
- **New designs** – It is expected that the emissions of new designs of nuclear power plants will remain comparable to wind and solar energy.

5 https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/uranium-resources/supply-of-uranium.aspx

6 Schlömer Steffen e.a., *Annex III: Technology-specific cost and performance parameters. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, 2014 (Cambridge, UK and NY, USA) Cambridge University Press; https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc _ wg3 _ ar5 _ annex-iii.pdf – Table A.III.2, Emissions of selected electricity supply technologies.

- **The alternative** – Hydropower, wind energy and solar energy score comparably to nuclear energy assuming there is still uranium ore of reasonable quality available.

d) Exclusion of accidents with major consequences

- **Existing nuclear power** – The risk of accidents in ageing nuclear power plants increases with age, despite investments in improvements. Although the chance of a major accident in existing nuclear power plants is estimated to be very small (one meltdown per 10,000 reactor years), we have already experienced five meltdowns with a significant release of radioactive substances in the 70 years that nuclear energy has existed (Three Mile Island 2, USA 1979; Chernobyl 4, Soviet Union 1986; Fukushima 1,2,3 Japan 2011), and two dozen meltdown incidents without significant release into the environment of radioactive materials. In addition, severe accidents with a substantial spread of radioactive substances have occurred in reprocessing plants in Russia (Mayak, 1957) and England (Windscale/Sellafield, 1957). This has resulted in the evacuation of hundreds of thousands of local residents, huge social and health consequences and thousands of early deaths from radiation and social disruption. Safety measures and upgrades attempt to keep the likelihood of future accidents as low as possible, but these cannot be excluded.

- **New power stations based on existing designs** – At new generation III and III+ nuclear power plants, the theoretical chance of a major accident has been further reduced (less than once every 100,000 reactor years), but it still cannot be excluded. Moreover, these estimates are largely based on engineers' estimates, especially concerning non-technical factors (e.g. human behaviour). The likelihood of serious accidents due to malicious attacks (sabotage, terrorist attacks, acts of war) cannot be accurately estimated.

- **New designs** – Many of the proposed new nuclear reactor designs are smaller versions of existing ones and have similar risks of an accident that could lead to the release of significant quantities of radioactive substances into the environment. In that event, the quantity of these substances would be smaller than with large reactors. A number of other designs have ruled out the possibility of meltdown. However, the risk of other accidents in which concentrated high-level radioactive content could end up in the environment remains, such as those resulting from deliberate sabotage, terrorist attack or acts of war. Because these reactors are often smaller, the number of reactors worldwide would have to increase sharply to generate a comparable amount of electricity, which increases the possibility of such an accident.

- **The alternative** – Although accidents can also happen with renewable energy sources (such as a fire in a wind turbine, people falling when installing solar cells on a roof), these sources do not carry the risk of an accident resulting in mass evacuations and large-scale radiation exposure. Energy efficiency measures and renewable energy sources cannot cause very long-lasting (decades to centuries) negative environmental consequences when used. It is also easier to take measures to prevent accidents.

e) Limitation of the consequences of accidents to an acceptable local level

- **Existing nuclear power** – Many measures have been taken at nuclear power plants to prevent a major accident, and every time a serious incident occurs anywhere in the world at a nuclear power plant, this leads to additional measures at every comparable reactor. In addition, safety and security measures are regularly evaluated and improved. Most incidents therefore also have only small, often acceptable consequences for the environment. By the same token, however, safety and security considerations are one of the main factors behind the high cost of nuclear energy. In addition, there must be emergency plans at every nuclear power plant that are tested to an adequate level to limit the consequences in the event of a major accident. Recent research for the European Commission has shown that there are considerable challenges and shortcomings in this – on paper, everything seems fine, but in practice, it is virtually certain that a major accident will lead to an extremely chaotic reaction.[7]
- **New power stations based on existing designs** – See existing nuclear power.
- **New designs** – Because new nuclear power reactor designs have not been built yet (and are not expected on any scale in the next 20 years), little is known about the possible consequences of major accidents with these plants. There are plans to place small power plants closer to large densely populated areas (for district heating, for instance). This increases the risk of local consequences.
- **The alternative** – Existing planning measures prevent serious consequences from accidents involving renewable energy sources such as solar panels and wind turbines.

7 See among others: http://www.nuclear-transparency-watch.eu/wp-content/uploads/2015/12/NTW-EPR-position-12-2015-EN.pdf

f) Integration into a total-energy-system

- **Existing nuclear power** – The average age of nuclear power reactors is currently over 30 years. Ageing nuclear reactors mean that it is likely that we will see a gradual reduction in average load factor for nuclear power stations. With every unplanned outage, hundreds to over a thousand MW disappear from the network within minutes, which must be offset by other sources. With increasing use of variable energy sources in the electricity network, such as wind and solar, there will also be an increasing need to frequently curtail non-variable sources. As a result, the economic efficiency of nuclear power decreases even further. Load following furthermore has negative consequences for the safety margins of the reactor vessel.
- **New power stations based on existing designs** – In order to prevent catastrophic climate change, according to the Paris Agreement, temperature rise should be limited this century to no more than 1.5°C. Scenarios to achieve that aim require full decarbonisation of the energy sector by 2050.[8] Currently, nuclear energy provides 10% of the world's electricity and less than 4% of the world's energy need, with a clear downward trend. Scenarios doubling nuclear capacity in 2050, such as those proposed by the OECD-NEA or the World Nuclear Association, would need 37 new reactors of 1 GW brought on-line every single year for 30 years. This is physically impossible. But it would reduce greenhouse gas emissions only by less than 4% compared to business as usual. Any role of nuclear in climate action would therefore be marginal. New nuclear power plants have high investment costs against relatively low operational costs (albeit still much higher than for renewable sources). Various studies have already shown that such nuclear power plants cannot play an economic role under normal market conditions. This role becomes even more unsustainable if they do not have priority access to the network and can provide power 24/7 with the exception of scheduled fuel change and maintenance periods. While these designs are expected to have less unplanned downtime (load factors of over 90% predicted, where those of current nuclear power stations are between 80 and 85%), any unplanned outage will have a considerable effect on the network because of the high capacity of these power reactors of 1000 to 1658 MW each.
- **New designs** – Because they have similar costs to new reactors stations based on existing designs,[9] the integration of these power stations will unnecessarily push up the total costs of the electricity system. Even in the event that surplus

8 https://www.ipcc.ch/sr15/
9 OECD IEA, NEA, *Projected Costs of Generating Electricity – 2015 Edition, page 159: "In terms of generation costs, generation IV technologies aim to be at least as competitive as generation III technologies [...] though the additional complexity of these designs [...] will make this a challenging task."*

electricity is used for the production of hydrogen, which is already expensive, introducing expensive electricity into the mix means that the prices of this hydrogen will rise even further and make its applicability more difficult. Since new reactor designs will not come on stream until after 2035, by which time at least 70% or possibly even in excess of 90% of electricity will come from cheaper renewable sources in the developed countries in which they might have been introduced already, this cost aspect is even more pressing.

- **The alternative** – In the coming decades, the backbone of the European and world-wide power supply will be formed by variable power sources such as wind and solar energy. This is supplemented with solar thermal power and niche applications for other sources such as sustainable biomass, hydropower, geothermal and possibly tidal and other sea energy forms. The stability of the network will be guaranteed by overcapacity, import and export of electricity, various storage technologies, demand management and the use of sustainable biogas and smaller amounts of green hydrogen.[10]

g) No generation of waste for which there is no sustainable management

- **Existing nuclear power** – There are currently around 400,000 tons of high level radioactive waste stored world-wide. Every year, each nuclear power station produces 1.5 to 2.5 m^3 of high,1.5 to 3 m^3 of medium radioactive waste and 70 – 100 m^3 of low radioactive waste per year. There is no technology for high and medium level radioactive waste that can be guaranteed to keep it safe from the environment for hundreds of thousands of years. It has to be noted that high-level radioactive waste left over from reprocessing – i.e. vitrified waste – cannot be reused in any way, not even in possible future new reactor designs. Any useful uranium and plutonium have already been extracted from this waste. Reprocessing in La Hague (France), Sellafield (UK) and Mayak (Russia) produces large additional amounts of medium and low-level radioactive waste that remain in France, the UK and Russia respectively, as well as reprocessed uranium and plutonium. Only a fraction of the latter of this is currently used in MOX fuel, which cannot be further used with current reprocessing technology and will remain as unusable high-level radioactive waste. Shutting down existing nuclear power stations would freeze the amount of waste and provide the opportunity to develop a treatment facility that is acceptable, in one way or another.
- **New power stations based on existing designs** – Due to their larger size, these plants also produce larger quantities of radioactive waste.

10 See for instance: Teske, Sven (ed.), *Achieving the Paris Climate Agreement Goals – Global and Regional 100% Renewable Energy Scenarios with Non-energy GHG Pathways for +1.5°C and +2°C*, Sydney (2019) Springer; https://www.springer.com/gp/book/9783030058425

- **New designs** – Those new designs based on the current boiling and pressurised water reactors produce similar amounts of problematic radioactive waste. A number of other reactor designs result in smaller amounts of high-level radioactive waste and a greater amount of shorter-lived isotopes (which, however, still must be kept out of the environment for hundreds of years and are much more radioactive initially). A number of designs can use some, but not all (!), of the reprocessed uranium and plutonium as fuel and convert it into shorter-lived isotopes. However, high-level radioactive waste still continues to be formed and the necessary reprocessing processes before and after the fuel is used for these reactors produces enormous amounts of low-level radioactive waste that must also be kept out of the environment for several generations. New designs therefore fail to solve the radioactive waste problem qualitatively.
- **The alternative** – The production and decommissioning of renewable energy sources, storage systems and energy efficiency techniques also cause problems, especially toxic waste. However, reuse and recovery of these substances is a lot easier than reprocessing radioactive waste.

h) No possible dual use for military applications

- **Existing nuclear power** – Some countries (including France, the Netherlands, Russia, China, India and Turkey) have opted to reprocess spent nuclear fuel. For example, the plutonium that is produced in the Dutch Borssele nuclear power plant is extracted in France. This plutonium could theoretically be reused as a fuel in a nuclear power plant (mixed oxide fuel or MOX), but the vast majority currently remains in France pending further use or eventual storage in some form. This material can also be used for nuclear weapons. Uranium enrichment takes place in the Netherlands, the UK, Germany (by Urenco), France, the US (by Orano), Russia (by Rosatom TVEL), China, Pakistan, India and Iran. This enrichment technology (ultra-centrifuges) can also be used to enrich uranium to a level that can be used for nuclear weapons – Pakistan has produced uranium bombs with technological expertise from the Netherlands. Urenco and Orano also produce depleted uranium that until 2009 was shipped to Russia, where it was stored in open-air containers. Since 2017, Urenco's German facility in Gronau has resumed export of depleted uranium (DU) to Russia and Orano also restarted its exports there in 2020. Russia can use this depleted uranium for the production/breeding of plutonium in one of Russia's two fast breeder reactors. It can also be used as armour and for the production of so-called DU anti-armour weapons, using the highly dense and combustible uranium metal to penetrate steel and concrete.

- **New power stations based on existing designs** – See existing nuclear power.
- **New designs** – For new designs that are based on the existing boiling and pressurised water reactors, the same arguments apply as with existing nuclear power. For other designs, the proliferation risk is even higher. Because most designs require reprocessing technology (advanced chemistry) at or near the reactor to keep their fuel chain going, countries can acquire the technical skills to isolate various substances from the fuel themselves and are no longer dependent on outsiders. In a number of designs, this means that the technology to remove plutonium from the fuel falls into the hands of the country that owns the reactor. Thorium reactor technology offers the ability to isolate proactinium-233, which when purified decays into pure uranium-233 that can also be used for bombs.

  In addition, many of the new designs use HALEU fuel (High-Assay Low-Enriched Uranium, or around 20% enriched uranium). This uranium can probably already be used for nuclear weapons, but the threshold to a slightly higher enrichment for use in weapons (above 20%) is also lowered with access to this raw material.
- **The alternative** – A renewable energy system does not provide any new possibilities for military use than currently exist – indeed, armies also already use solar cells and wind turbines for electricity production. However, these cannot be used for mass annihilation.

i) Sufficient scalability to have a clear positive influence from the perspective of sustainability – contributing significantly towards countering the climate emergency

- **Existing nuclear power** – On a global scale, nuclear energy only supplies a marginal amount of electricity, less than 4%. Many ageing nuclear power stations are already running at a loss for their owners. Instead of filling that financial gap, as is now the case in countries like the US, Belgium, France and the Netherlands, it would be much more effective to close old reactors and spend the money on developing cheaper renewable energy systems. Nuclear phase-outs can be implemented without an excessive impact on greenhouse gas emissions.
- **New power stations based on existing designs** – Scenarios elaborated by the worldwide nuclear lobby organisation WNA and by the nuclear energy promotion arm of the OECD, the Nuclear Energy Agency (NEA), aim to double nuclear energy capacity (or more) by 2050. Such a doubling would lead to less than a 4% greenhouse gas reduction in the year in which we are supposed to have reduced by 100% already. In short, even in those scenarios, the contribution of nuclear energy is marginal. There are currently between three and ten new reactors coming on-line per year, mainly in China. For the above mentioned doubling of

capacity, around 35 new large nuclear power plants (of 1 GWe) would have to be brought to the grid every single year from now until 2050. That is technically absolutely impossible. Nor is it possible to increase the production capacity for the construction of nuclear power plants in such a way that we could, for example, produce 70 or more reactors in 20 years. This would require unparalleled capacity building for large reactor components that can only be compared to the change in industrial capacity in World War II. That does not even include the necessary increases in uranium mining, enrichment, reprocessing and waste storage. And all this for less than a 4% greenhouse gas emission reduction ...

- **New designs** – The issue of upscaling is even greater with new designs of nuclear power stations. For the time being, they exist only on paper. Before the first commercial reactors could appear on the market, it will be 2035 already. Because these are relatively small reactors (about a tenth to a third of the current reactors), thousands would have to be produced in the remaining 15 years to achieve a comparable reduction in greenhouse gas emissions of less than 4% by 2050.
- **The alternative** – The growth of renewable energy sources is showing an upward trend. By 2030, China expects to generate four times as much electricity from wind and solar energy as it does from nuclear. Scaling up renewable energy sources appears to exceed forecasts every year. Several countries are already sourcing more than half of their electricity from renewable sources and are adapting their systems to a 100% renewable system over the next two decades.

  Renewable projects also scale up faster than nuclear power and deliver energy within 3 years of the start of a project. Nuclear power plants take between 5 and 17 years.

B. Economic criteria

j) Transparent cost and financing

- **Existing nuclear power** – Regarding cost and funding, nuclear energy does not have a good reputation on transparency. The first generations of nuclear power plants were built in times when electricity supply was a state task, with state energy companies and state research budgets issued by state research institutes. Some nuclear energy research was also part of the military sector.[11] Because their investment costs were often carried by state budgets or have already been written off, the future role of existing nuclear power plants is mainly assessed on the basis of their ongoing organisation and management costs (O&M) and necessary upgrades for lifetime extension. Still, even in this situation, those costs often result in a non-competitive position on the electricity market. In the Netherlands, the Borssele nuclear power station makes a structural loss for its owners EPZ and RWE.[12] In the United States, nuclear power stations in states with a liberalised market are currently shut down because of their losses – despite having received permission to operate for 60 years. In states with regulated markets, they struggle to receive subsidies or other market advantages in order to survive financially.[13]

  In addition to these operational problems with transparency about financeability, there are also issues surrounding liability, plus decommissioning and radioactive waste management costs. Worldwide, liability costs for nuclear power stations are capped in total, in the form of limited prescribed financial reserves for liability or both.[14] The reserved amounts in the event of severe accidents are in the order of some tens of millions of euros up to a maximum of around 2.5 billion euros (Germany, Netherlands). This constitutes an indirect ongoing subsidy to

11 See among others the extensive analysis of the German Institute for Economic Research (Deutsches Institut für Wirtschaftsforschung DIW): Ben Wealer, Simon Bauer, Leonard Göke, Christian von Hirschhausen, Claudia Kemfert, *High-priced and dangerous: nuclear power is not an option for the climate-friendly energy mix*, Berlin (2019) DIW; https://www.diw.de/de/diw _ 01.c.670590.de/publikationen/weekly _ reports/high _ priced _ and _ dangerous _ nuclear _ power _ is _ not _ an _ option _ for _ the _ climate _ friendly _ energy _ mix.html

12 Brinkman, Gerard, *Hoe groot is het verlies van Borssele?*, Amsterdam (2020) WISE; https://wisenederland.nl/hoe-groot-is-het-verlies-van-borssele/

13 Schneider, Mycle, Antony Froggatt (eds.), *The World Nuclear Industry Status Report 2020*, Paris (2020) Mycle Schneider Consulting; pp 191-193; https://www.worldnuclearreport.org/-World-Nuclear-Industry-Status-Report-2020-.html

14 OECD-NEA, Nuclear Operators' Third Party Liability Amounts and Financial Security Limits (updated: October 2020), Paris (2020); https://www.oecd-nea.org/jcms/pl _ 31866/table-on-operator-liability-amounts-and-financial-security-limits-non-official-updated-october-2020 nuclear power, but also an uncertainty. By way of illustration: the first year after Fukushima, some 85 billion euros in cash flow was needed for compensation and measures.

As a result, some countries increased their liability caps after the Fukushima accidents, leading to higher costs for operators. Any severe nuclear accident, anywhere in world, will trigger further similar dynamics. In most countries, money to cover decommissioning and radioactive waste is set aside from operational income in special funds. However, the overviews of the European Commission under the 2011 Euratom Radioactive Waste Directive show that there is a structural lack of transparency about these funds, reserved funds are far too low and that there will be a need for a large amount of additional funds. These funds either have to come, under the polluter pays principle, from the operator (ultimately the rate payer/consumer), or from the state (the taxpayer). There is a tendency to shift liability for these costs from operators (which cannot be guaranteed to survive the long times involved – for most countries a century or more) to state entities.[15]

- **New power stations based on existing designs** – Financing new nuclear power plants is highly problematic. At the Olkiluoto 3 in Finland, currently under construction, scheduled for 2012 but potentially going on-line in 2022, most of the construction cost risks were transferred through a turn-key contract to Areva, France, while Finnish owner TVO has to cover a large part of the losses due to late delivery. At the time construction began, Areva was a state-owned company that went bankrupt due to, among other things, the losses in this project. The company was split into a profitable fuel and waste company (Orano) and the loss-making design and construction company Framatom was transferred to the state-owned EdF. A stripped-down Areva (consisting of Framatom and Siemens) remained responsible for Olkiluoto 3. It is therefore almost impossible to determine how much French and Finnish consumers will ultimately pay for power from this nuclear plant. In the case of the similarly delayed Flamanville 3 in France, EdF was the main constructor and owner, and liable for the losses incurred in the construction of this power station (cost increase from 3.1 billion euros to about 19 billion euros, according to the French National Court of Auditors). That is, they are borne by the French (and British, Polish and other) electricity consumers of EdF and the French taxpayer. Here again, it is completely unclear who carries which losses. The construction of the Mochovce 3 and 4 nuclear power plants in Slovakia also turned out to be very much more expensive than planned and

15 European Commission, *Report from the Commission to the Council and the European Parliament on progress of implementation of Council Directive 2011/70/EURATOM and an inventory of radioactive waste and spent fuel present in the Community's territory and the future prospects* – Second Report, Brussels (2019); https://ec.europa.eu/energy/topics/nuclear-energy/radioactive-waste-and-spent-fuel _ en#radioactive-waste-and-spent-fuel-management-directive those costs will have to be covered mainly by the Italian shareholder ENEL and, to a lesser extent, by the Czech EPH and the Slovak state. ENEL will withdraw from owner Slovenske Elektrarne (SE) six months after delivery of the nuclear power plant, leaving further risks with EPH and the Slovak state. In the UK, the financial risks of the construction of Hinkley Point C were covered by a fixed construction price (turn-key, risk borne by EdF), a guaranteed electricity supply price (CfD or cost for difference) of EUR 123/MWh[16] for a period of 35 years, and a loan guarantee from the UK government for a significant portion of the construction costs. The British state also assumed the full risk of loss should this project come to an early end on political grounds. However, the risks of this project, now estimated at £24 billion, are so great for all participants that this system has been abandoned for future projects in Sizewell, Bradwell, Angelsey/ Wylfa, Moorside and others. They are now looking at the possibility of partially recovering the costs from the electricity consumer before construction starts (the RAB system). In Hungary, the Paks II project is wholly owned by the state, which also bears the full risk. The Czech Republic, Poland, Romania and Bulgaria are looking for other financing mechanisms, but it appears virtually impossible to prevent the state from bearing the majority of the risk. The trend of increasing costs, taking account of the construction costs per installed megawatt of power, is increasing from Olkiluoto 3, to Flamanville 3, Voigtle (US) and Hinkley Point C, and there is no indication that this trend will be broken by Sizewell C (UK) or Paks II (HU). Uncertainty about the costs of liability, decommissioning and waste management will remain with these designs.

- **New designs** – These designs are promoted as cheap and suitable for the market, while serious analyses show that the costs will be comparable to those of the current generation III reactors under construction.[17] With the exception of the extremely expensive floating 2x35 MWe Russian nuclear power plant Akademik Lomonosov, there are no small reactors on the market yet.

- **The alternative** – The costs of renewable energy sources continue to fall, yielding LCOE results well below those of nuclear energy.[18] These costs include the waste

16 Calculated from £92.50 in 2012 prices with official inflation adjustment (15.22%) in February 2021 Euro.

17 OECD NEA, Projected Costs of Generating Electricity 2015 Edition, Paris (2015); https://www.oecd-nea.org/jcms/pl _ 14756/projected-costs-of-generating-electricity-2015-edition; page 159: *"In terms of generation costs, generation IV technologies aim to be at least as competitive as generation III technologies [...] though the additional complexity of these designs, the need to develop a specific supply chain for these reactors and the development of the associated fuel cycles will make this a challenging task."*

18 LCOE = Localised Cost of Electricity. See: Lazard, Lazard's Levelized Cost of Energy Analysis, Version 14.0, New York (2020); https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2020/

phase and there are few uncertainties about the input data. Integrating nuclear energy into a system based on renewable energy sources in all cases leads to higher costs.[19]

k) Does not economically push out other, more effective, measures

- **Existing nuclear power** – Countries that have made a clear choice in favour of their current fleet of nuclear power plants, such as France, Belgium, Finland, the Czech Republic and Slovakia, are lagging behind in the introduction of renewable energy sources and energy efficiency. Even with written-off nuclear power plants, it currently appears that the costs are increasingly too high to be able to keep up with the market. The reason for this can be found in low electricity purchase prices, which are determined by the marginal costs of the cheapest provider.
  In the US, cheap fracking gas has pushed nuclear plants out of the market, but it is increasingly the falling price of renewables that is undermining the business case of existing nuclear plants. In different states, therefore, nuclear power plants receive different forms of state support: direct subsidies, capacity market adjustments, regulated (high) prices with guaranteed sales. A proportion of the higher operating costs can be attributed to lower availability of aging nuclear power plants, partly also to the implementation of improvements to mitigate risks and continue to meet existing safety criteria. In a number of cases, for example in France, safety criteria are also being adapted to new insights into risks and aging nuclear power plants are expected to be made as safe as new ones before they are allowed to remain in operation for more than 40 years. By way of illustration: in the Netherlands, the argument for extending the lifespan of the Borssele nuclear power plant is currently being raised in discussions about the introduction of wind and solar energy. This fails to take into account the facts that the Borssele nuclear power plant is already losing its shareholders money, and that the risk of an ageing nuclear power plant will increase over time. The latter can be partially counteracted with more far-reaching technical measures, but these drive up costs further. Borssele's losses are partly caused by the approximately €100 million investments made in LTO (Long Term Operation) and partly in response to the Fukushima disaster. Borssele is currently running at a loss for its shareholders PZEM and RWE, who purchase electricity for a fixed price (the toll price) of around 45 euros/MWh, with which the owner EPZ covers the costs of the nuclear

19 See for instance the case of the Netherands: Kerkhoven, John, Rob Terwel, Tuuli Tiihonen, *Systeemeffecten van nucleaire centrales*, in Klimaatneutrale Energiescenario's 2050; Rotterdam (2020) Kalavasta/Berenschot; https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/rapporten/2020/03/09/systeemeffecten-van-nucleaire-centrales-in-klimaatneutrale-energiescenarios-2050/Systeemeffecten+van+nucleaire+centrales.pdf power plant with a slight shortfall (it also makes a profit from wind and solar energy). The losses of PZEM and RWE, which have to sell this electricity on a market at an average price of around 40 Euro/MWh, amount to tens of millions per year. This loss financing distracts from investing in cheaper and better alternatives.

- **New power stations based on existing designs** – In Finland, France and Slovakia, it is clear that the delayed construction of Olkiluoto 3, Flamanville 3 and Mochovce 3,4 respectively is hindering the development of an energy strategy based on ultimately 100% renewable sources. In these three countries, investors have long been wary of the renewables market in view of the entry into the market of the large capacity of these new nuclear power plants. It is also clear that in countries with comparatively serious discussions about new nuclear power, such as the Netherlands, Poland and the Czech Republic, new nuclear is contrasted with the development of renewable sources, while building myths around nuclear energy. In the Netherlands, the construction of new nuclear power plants is actively used, often through municipalities and provinces, in discussions about Regional Energy Strategies (RES) to slow down investments in wind and solar energy – often based on NIMBY argumentation (Not In My Back Yard). In the Czech Republic, the religious adherence to nuclear power is preventing the government from assessing and taking into account nuclear phase-out scenarios in their energy strategy development.
- **New designs** – Small modular reactor designs (SMRs) and, in particular, molten salt thorium reactors (MSTRs) are used as arguments to put a brake on the development of wind and solar energy in the RES in Dutch provinces such as Overijssel, North Brabant, North Holland and Utrecht. SMRs play a large role in the discussion about energy strategy in Poland, possibly enabling a longer life for loss-bringing coal mining and burning into the next decades.
- **The alternative** – During the early years of modern renewable energy sources in the 1990s and the first decade of this century, the speed of development was strongly underestimated – certainly by renowned institutions such as the OECD (and its energy advisory arm IEA) and the EU. The initially high investments and subsidies in countries such as Denmark, Germany, Spain and the Czech Republic were cited as a suppression of cheaper solutions. It is now clear that due to the rapid fall in costs of these energy sources, fossil fuels are not being displaced by, for example, nuclear energy, but rather by renewable sources. For the time being, this applies to a slightly lesser extent also to energy efficiency, but the increasing electrification of the economy is causing a similar trend there as well, as do various forms of energy storage, such as (mega) batteries. An interesting but as yet unclear role could be played by hydrogen as a flexible energy carrier, in addition to sustainable biomass based on the use of waste material from the economy, agriculture and forestry.

l) Contributing to a system that can function in a financially stable way in the long term

- **Existing nuclear power** – Many of the periods of great instability in the energy sector over the past century show that concentrations of financial power play a major role. Recently, this has been the case, for example, with the brakes that the five biggest German energy companies tried to put on the Energiewende in 2010, in order to open the door to the further development of (then already expensive) nuclear energy. The Fukushima catastrophe thwarted these attempts. Chernobyl and Fukushima nearly caused not only nuclear disasters, but also financial ones. A single power plant accident proved to have severe consequences for all economies around the world with nuclear power plants due to the need for controls, temporary shutdowns and upgrades.
- **New power stations based on existing designs** – Although a higher safety level of these plants reduces the chance of disruption due to accidents, this possibility is still not completely excluded. Underestimating the risk (chance times impact) of possible accidents and the necessary preparations for them increases potential impact. The higher costs of nuclear energy also require greater concentration of capital in the energy sector, with all the possible disruption that this can cause.
- **New designs** – It is at present difficult to predict how new designs should be funded and whether this could lead to potential problems, but it is likely that this will be comparable to nuclear power plants of existing designs.
- **The alternative** – Although there are also renewable energy sources that require large concentrations of capital, such as offshore wind, the whole range of renewable energy sources is relatively decentralised and therefore also requires a relatively decentralised financing system. As a result, risks are better spread and an incident in one energy source does not immediately lead to major financial instability.

m) Does not lead to concentrations of financial power

- **Existing nuclear power** – After the privatisation wave of the industrial sector in the fourth quarter of the last century, nuclear power plants either remained in the hands of government players (e.g. France, Hungary, Czech Republic, Romania, Bulgaria, initially Slovakia) or fell into the hands of large market players (Belgium, Germany, Finland, Spain, Sweden, Switzerland and, later, Slovakia).

- **New power stations based on existing designs** – In the UK, it was not possible for new nuclear power plants to be built by British energy companies. Only major international players were able to take the necessary financial risk: the French state-owned company EdF (also the largest market player in the UK), the Chinese state-owned companies CNG and CNNC. Initially, the German E.On and RWE, the Spanish Iberdrola and the Japanese Hitachi also tried to gain a foothold, but these companies have all since bowed out because of the financial risks involved. In Hungary, it is only possible to build a new nuclear power plant with a new state-owned company. No interested parties for new nuclear energy have yet been found in Poland and the Czech Republic, but when they do come forward, they will either consist of large foreign groups or become state-owned companies.
- **New designs** – Here, it is still early to predict developments. The earning model is built on factory line production of power stations, and for that there will have to be a very financially strong carrier. Large-scale consolidation is expected in this branch of industry until only a small number of providers remain.
- **The alternative** – Developments in renewable energy sources are also showing consolidation here and there, especially in the off-shore wind sector, which is capital-intensive. With solar energy, on-shore wind energy, the development of storage, sustainable biomass and other sustainable forms of energy, large industrial conglomerates-are clearly lagging behind. They are too inflexible to adapt to the local demands of these more decentralised forms of energy. Although the initially fast-growing PV market in Germany collapsed when China set up cheaper production, this disruption has been partly offset by the emergence of a solar installation and maintenance market. The wind sector has seen fewer such problems. For example, Polish concerns of major political influence from German wind energy firms appear to be false and largely political, while at the same time the ailing Gdansk shipyards received an economic boost as a hub for wind turbine assembly and offshore wind support.

n) Does not pass on financial burdens to future generations

- **Existing nuclear power** – There are three main categories of financial burden that nuclear energy transfers to subsequent generations:

  Decommissioning costs: At the moment, for most nuclear power plants, decommissioning reserves are collected via the electricity bill in a special fund (sometimes together with the reserves for waste management).

In its 2017 and 2019 implementation reports on the Euratom radioactive waste directive, which covers both decommissioning and waste management, the European Commission warned that reserves for both categories are falling far behind what will ultimately be required.[20] In practical terms, this means that at European level, billions of euros of liabilities for decommissioning are being passed on at least one generation beyond the one receiving the benefit of the operation of nuclear power plants.

Waste costs: At most nuclear power stations, these are also channelled from electricity income into special funds. The European Commission estimates on the basis of national reports that a total of 566 billion euros will be needed for waste processing, but admits that there is not enough data to make a firm estimate. Storage costs for low- and medium-level radioactive waste will weigh on the economy for another 10 generations. For highly radioactive waste, possibly many hundreds more generations.

Costs due to accidents: Three Mile Island (Harrisburg), Chernobyl and Fukushima have shown that for decades to come, costs continue to accrue for post-accident measures. The new safe enclosure in Chernobyl was installed in 2019 at a cost of 2.3 billion euros. This will allow work to remove the old sarcophagus to begin, and then the heavily radioactive molten fuel. This will cost billions more, which have not yet been covered. Also at Fukushima, billions of euros of costs will arise for decades to come. In both cases, this means a burden for at least two generations. It should be borne in mind that the maximum legal financial coverage for liability is only a small fraction of these costs and future costs will have to be covered by those future generations.

- **New power stations based on existing designs** – see existing nuclear power plants, with the understanding that the quantities of waste are larger.
- **New designs** – The situation here is still very unclear, although it will not differ much from existing nuclear power plants. Differences can be seen in types and quantities of radioactive waste. In all cases, however, large costs are passed on to future generations.
- **The alternative** – The costs for decommissioning, the waste phase (including recycling) of renewable energy sources are paid for chiefly by the user generation, and a small part by one next generation.

20 https://ec.europa.eu/energy/topics/nuclear-energy/radioactive-waste-and-spent-fuel _ en

o) Does not impose financial burdens on groups that do not benefit from the application

- **Existing nuclear power** – The groups that bear the burden of existing nuclear power plants without benefiting from them include residents around most uranium mining areas, future generations dealing with nuclear decommissioning and waste and victims of nuclear disasters such as Chernobyl and Fukushima, as well as victims of the disasters in the Windscale (now Sellafield) and Mayak reprocessing factories.
- **New power stations based on existing designs** – These nuclear power plants are designed for an operating life of 60 years and there are claims that they will be in operation for up to 100 years. This means that in addition to those already mentioned for existing nuclear power plants, the second generation after the one responsible for construction, even though it may still reap some benefit from a nuclear power plant, will be responsible for its entire decommissioning, disproportionally to the potential benefit.
- **New designs** – This is likely to be comparable to new nuclear power plants based on existing designs.
- **The alternative** – Energy efficiency technologies and renewables are currently growing rapidly, and in order to meet climate targets, they will account for the vast majority of energy production by 2050. The group of people who suffer from resource extraction for renewable energy sources, storage technologies and energy efficiency technologies is in absolute terms larger than that who suffer from uranium and raw material mining for nuclear power plants. However, the former group will enjoy the benefits of such a sustainable energy system, which is not the case with nuclear energy.

p) Contributes to a healthy development of the labour market at local, national and international level

- **Existing nuclear power** – An existing nuclear power plant provides about 500 to 750 highly qualified jobs. These jobs are usually located in economically relatively marginal areas, so that a nuclear power plant has a substantial impact on that local labour market. At the national and international level, the number of jobs is relatively small. A sufficient inflow of temporary professionals is required for maintenance. By way of example, in France, this often takes the form of subcontractors, and these skilled workers live under relatively difficult conditions ("nuclear nomads"[21]). Many older nuclear power plants, especially those that will soon be closed, are struggling with a shortage of young skilled workers. Nuclear power has not been a sexy field of study for several decades and neither is much of the work that needs to be done now (waste management, decommissioning, etc.).

- **New power stations based on existing designs** – The construction of a new nuclear power plant will provide 2,000 to 5,000 temporary jobs. These generally have to be fairly highly qualified, so that this market is very international. For example, at Olkiluoto 3, Polish welders may have worked through a subcontractor under a Portuguese supervisor. A major problem here is adequate qualification.

  After commissioning of a new nuclear power plant, its staff consists generally of highly educated and young people (young families) who age with the power plant. There have been complaints for years about a shortage of skilled nuclear workers for new construction projects, but at Hinkley Point C in the UK this does not seem to be an insurmountable problem.

- **New designs** – It is still unclear what the impact of small and new designs will be on the economy. This will likely be comparable to existing designs.

- **The alternative** – Renewable energy sources are in the long run likely to require a higher number of workers than nuclear energy, but with a profile that better fits the average national work profile: medium to higher educated, with more general qualifications. Due to the decentralised use of renewable sources, storage and efficiency techniques, these are also more geographically distributed.

21 See for instance the documentary *"Rien à signaler/Nothing to report"* of the Belgian documentarist Alain de Halleux – https://dafilms.com/film/9734-nuclear-nothing-to-report

C. Social and political criteria

q) Because of the urgency of the climate emergency, does not hinder the development of more effective technologies

- **Existing nuclear power** – Existing nuclear power plants hinder the development of more effective technologies (as described above) in several ways:

€ Political attention: In countries with a high penetration of nuclear energy, less attention generally is given to the development and implementation of energy efficiency and renewable energies. In Finland, the development of wind energy lagged almost 10 years behind the rest of Europe; in the Czech Republic, Slovakia, Hungary and Poland, there have been active campaigns against renewable energy sources; in France, the penetration of renewable energy sources is slower than the EU average. A major exception is the UK, where, despite the political focus on nuclear energy, the renewable energy market, especially off-shore wind, is developing very quickly – but there, too, it could be faster if less attention was paid to nuclear energy and there was a clear focus on efficiency and renewable resources. In the Netherlands and Belgium, the attention to the possible extension of the lifespan of nuclear power plants is distracting from policies to speed up the implementation of energy efficiency and renewable energy measures.

€ Costs and financing: The loss financing already mentioned under economic criteria distracts from investments in cheaper and better alternatives.

€ Waste: The radioactive waste problem distracts both attention and capital from better alternatives.

€ Accidents: Fukushima has shown that when an accident occurs anywhere in the world, a large number of nuclear power plants must be temporarily or permanently shut down for an inventory of risks. Because a quick alternative had to be found, we saw in many countries an initial increase in the use of fossil fuels. In Japan this was initially gas, later also coal. The urgency of providing security of supply pushed the slow development of renewable resources into the background, despite the enormous public support for using renewables as an alternative. The situation was similar in Central Europe. In countries like Germany and France, the Fukushima disaster led to more attention being paid to a clean energy system.

- **New power stations based on existing designs** – The discussion about new nuclear energy is brought to the table by parties and groups that have not traditionally been overly enthusiastic about addressing the climate emergency in the past. We often see the discussion being conducted hand in hand with NIMBY argumentation against wind and solar energy. Within the nuclear sector, there are attempts to counteract this ("we need everything"), but there the cost discourse is subsequently undermined with disinformation, so that the contrast between nuclear energy and renewable energy is put back on the table. The latest attempts revolve around so-called system costs. Where the reasoning for a policy towards a 100% renewable, efficient energy system is based on extensive scenario studies, which include all system costs, this is taken out as a special issue in the political debate and all necessary system changes are fully moved towards the cost price of renewable sources, while the necessary system adaptation costs related to building relatively inflexible capacity in the new system are not allocated to nuclear energy. Scenario studies, such as those by Kalavasta/Berenschot, but also a number from the IPCC SR1.5, clearly show that adding nuclear energy to an otherwise sustainable renewable system increases costs, and also slows down the necessary early reduction in greenhouse gas emissions.

- **New designs** – Because new nuclear energy designs will not be on the market before roughly 2040, the forward-looking effect of these discussions is a fundamental problem for urgent climate action. These designs have not yet been proven, the costs seem to be comparable to existing nuclear designs, advantages may at best lie in the amount of waste produced, but not in the qualitative waste problem (the need to keep waste out of the environment for hundreds to many hundreds of thousands of years) and new disadvantages (proliferation, more complicated waste flows, security) are on the horizon. By diverting the discussion about urgent implementation of climate action into theoretical technical discussions, many people think that urgent climate action is unnecessary and there may be an alternative in a distant future. To be clear: by the time new nuclear energy designs turn out to work and are not unacceptably expensive (both a big "if"), it will be at least 2040. By then, 90% of the European electricity system will already run on renewable sources and, theoretically, 100% after 2050. Since renewable sources are cheaper, there is little reason to introduce a non-sustainable, expensive alternative after that date.

- **The alternative** – Various scenarios, including recent scenario studies from the University of Sydney, Melbourne and the German DLR, and others, show that a 100% renewable electricity system by 2050 is feasible within a greenhouse gas neutral energy system. But these scenarios require action and policy implementation now.

r) Does not pass on burdens to future generations

- **Existing nuclear power** – Burdens that are passed on to future generations: waste (final storage will be passed on for at least two to five generations; monitoring and control from several hundred to thousands of generations (mainly due to the presence of plutonium)), decommissioning (takes 10 to 60 years), accidents (the aftermath of Chernobyl, apart from waste treatment, will last at least another 50 years, that of Fukushima 60).
- **New power stations based on existing designs** – The most important burden passed on to future generations is that of postponed urgent climate action. Because every focus on new nuclear energy translates into a delay in decreases in emissions (after all, they have to replace greenhouse gas-emitting plants that must continue running until they are hooked up to the grid), it is becoming increasingly difficult for the young people of today and the generation after that to keep global temperature rises below 1.5°C. In addition, these reactors require operating lives of 60 to 80 years to keep costs under control. This means that the responsibility for decommissioning and dismantling a plant falls into the hands of two to three generations after the one that decided to build it. And then there is the waste problem.
- **New designs** – The same arguments apply here as those mentioned above, plus the effects of a wider geographical spread of nuclear technology, substances, risks and waste. Plus a greater risk of nuclear proliferation, which will have to be contained by future generations.
- **The alternative** – Also here, certain burdens are passed on to future generations. An important one is establishing a circular economy for the raw materials used in modern renewable energy sources and efficiency technologies. Unlike nuclear energy, however, this is largely achievable with already known technologies within two to three generations.

s) Does not pass on burdens to groups, regions and countries that do not benefit

- **Nuclear energy (existing, new and future designs)** – For all nuclear energy, burdens are placed on the populations of resource-mining areas – US, Kazakhstan, Canada, Australia, Niger, Namibia, India, China, etc. – often indigenous peoples. Concerning radioactive waste, there is currently much discussion concerning the organisation of international depositories for high-level radioactive waste and an increasing internationalisation of the treatment of waste fractions (export of depleted uranium to Russia, radioactive material for treatment in Slovakia and Sweden, reprocessing of spent nuclear fuel in France, England and Russia, etc.). Proliferation increases the likelihood of nuclear war with far-reaching consequences.

- **The alternative** – Resource mining is an ongoing problem that requires close attention. This also applies to the recycling of materials.

t) Democracy enhancing – does not lead to concentration of power

- **Existing nuclear power** – The nuclear lobby has a large influence in countries like Germany (which, under pressure from that lobby, reversed its nuclear phase-out in 2010), Belgium (pressure to reverse its nuclear phase-out), South Korea and Taiwan (ditto), the Czech Republic and Hungary (government financial and political lock-in). But this is particularly true in countries that have both a civil and military nuclear programme: France, Great Britain, the US, Russia, China, Israel, India and Pakistan. Here, the interdependence of these programmes appears to have a clear influence on political decision-making. Something similar can also be seen in discussions around radioactive waste policy: in almost all countries where attempts have been made to involve the population in decision-making, this has stalled: England, France, and the Czech Republic. Recently, the German attempt also seems to have come under fire from an intransigent industry lobby. The need for a high degree of security should also be mentioned here, amongst other things due to the risks of malicious attacks on nuclear power plants. The Austrian philosopher Robert Jungk already described in 1977 the need for an "Atomstaat" (an atomic state).[22] Anyone who sees how far the security measures around nuclear energy extend today can only conclude that Jungk was largely right. Employees in the nuclear industry, as well as critics, are widely watched by security forces - of course, in some countries more intensively than in others.
- **New power stations based on existing designs** – It is no coincidence that in democratic countries (US, France, Japan, South Korea), companies building new nuclear power plants have run into problems. Transparency is an important driving factor in trying to control the risks of nuclear energy. We can see here that these problems put enormous pressure on the governments in these countries: France is doing everything in its power to prevent the bankruptcy of its national utility EDF and has already bought out Areva; the Trump administration tried to keep Westinghouse afloat with an aggressive export policy; Hitachi has (unsuccessfully) done everything to entice the UK to give unprecedented subsidies for a new nuclear power project. In Russia, Rosatom has become a state within the state, and the position of CNNC and CNG in China is also very strong.

22 Jungk, Robert, *Der Atomstaat – Vom Fortschritt in die Unmenschlichkeit*, München (1977) Kindler Verlag GmbH; a summary can be found here: https://jungk-bibliothek.org/robert-jungks-stand-against-nuclear-energy/

- **New designs** – Many new nuclear power plant designs are currently being developed by relatively small start-up companies. This resembles a democratisation of the sector. However, the more advanced projects are from companies that have more to lose, such as Rolls Royce and GE, and are using new design development to access new government funding streams while keeping a foot in the lobby door. Smaller companies such as NuScale or Fermi Energia are already getting into financial problems and are trying to embrace major financiers. In Russia and China, it is the large state-owned companies that work on these designs. In Belgium, the Czech Republic, Hungary and Poland, all eyes are on Europe, with associated aggressive lobbying activities. Additionally, new designs can only survive in a centralisation of power – financial power and political power.
- **The alternative** – Although certain forms of renewable energy sources, such as offshore wind and the large-scale grid connections, also need centralised large, capital-rich companies and strong government regulation, the majority of a 100% sustainable, renewable, efficient energy supply can be managed in a much more decentralised way than the current system, including nuclear energy. In 2019 in Germany, 95% of new installed renewable capacity was not in the hands of large energy companies. Nor does such a system lend itself to a concentration of military power.

u) Democracy enhancing – does not increase the gap between rich and poor

- **Nuclear energy (existing, new and future designs)** – There are no poor countries with nuclear power plants. Both Bangladesh and Belarus are now building nuclear power plants with Russian money and technology and are beholden to Russia for the 12 billion euro loan they each received from Russia. Nuclear energy was traditionally, and still is, a toy for the rich and those who have, or aspire to have, nuclear weapons. Nuclear power plants supply large amounts of power and are therefore not suitable for countries with a small electricity network. This also makes integration into emerging economies difficult and where plans exist, it is likely to widen the poverty gap between rural and urban areas.
- **New designs** – Although new designs are usually smaller, they are still very expensive. In contrast to the designs currently used, they can be used in remote areas with a smaller network. They need, however, even more highly qualified staff.
- **The alternative** – Decentralised renewable energy sources are ideally suited to bridge the poverty gap. They are cheap and can be developed bottom-up in exponentially larger networks, which are also becoming increasingly reliable (security of supply). They also need decentralised management with an intermediate staff training level and hence benefit a larger part of the local population.

v) Democracy enhancing – does not hamper increased public participation in decision-making

- **Nuclear energy (existing, new and future designs)** – Nuclear energy is, as the Aarhus Convention Implementation Commission (on transparency, public participation and access to justice in environmental matters) formulated, an activity with a potentially ultra-high impact (an ultra-hazardous activity). This means that for optimal transparency, a large number of people must be involved in decision-making about nuclear power plants. Of course, this costs money and effort, and the nuclear industry is doing everything to limit this. The industry refuses to conduct environmental impact assessments for decisions on how to extend the life of nuclear power plants (for example in Europe), information is in many cases declared confidential (Slovakia, Romania, Belgium), citizens and NGOs are banned from advisory bodies (Czech Republic, Slovakia), citizen advisory bodies are pushed aside (UK, Czech Republic) or opponents threatened (Bulgaria, Belarus, Russia). The Aarhus Convention has inspired all kinds of initiatives for greater transparency in the nuclear sector in, in particular, Europe, South Africa, Taiwan and South Korea.

- **The alternative** – There is a risk that the need to expand renewable energy sources could also lead to restrictions on public participation in decision-making. However, experience shows this is always counterproductive. Successful renewable energy projects are always based on early and comprehensive public participation in project development.

w) Does not contribute to military tensions

- **Existing nuclear power** – Nuclear power stations are extremely risky installations from a military point of view. This became evident during the tensions between Azerbaijan and Armenia, the war in Iraq, as well as attacks on oil installations in Iraq, Libya and by Yemeni Houthi rebels in Saudi Arabia. Assassination attempts, sabotage and cyber-attacks (US, Israel) on Iranian nuclear scientists and installations are putting pressure on the entire Middle East. South Korea's nuclear power fleet poses a huge risk should the never-officially-ended Korean war flare up again.

- **New power stations based on existing designs** – Although nuclear energy does not directly supply nuclear weapons, it is noticeable that many countries interested in new nuclear power plants also occasionally show an interest in nuclear weapons. That certainly applies to countries such as Egypt, Saudi Arabia and Turkey, but even in a country like Poland, there were ultra-right wing voices that said Poland needed nuclear energy to be able in a distant future to use nuclear weapons to reclaim lost territory in the East. The nuclear energy ambitions of Iraq and Iran have shown how those have aroused military tensions and even led to Israeli military action against Iraq.

- **New designs** – In order to make a meaningful contribution to tackling the climate emergency, small nuclear power plants would have to be very widely distributed. Most of these designs depend on the reprocessing of their nuclear fuel, and the delivery of local (chemical) reprocessing technology would therefore also have to be included in many cases. This means, in the first place, that the number of objects at risk of military attacks would increase (with a potential nuclear disaster as a result), but also that it would be much easier for malicious governments or non-government groups to obtain nuclear weapons material. This can be based on plutonium, use or further enrichment of HALEU (around 20% enriched uranium), or, in thorium reactors, use of uranium-233. Proliferation is therefore a major problem for most new designs.
- **The alternative** – Because renewable sources come in small decentralised units compared to nuclear, it would be far more difficult to wipe out a large capacity with one blow. The most vulnerable aspect is the switching structure in the electricity network. Renewable energy sources themselves do not pose a danger in a military conflict. In addition, the ownership structure of renewable energy sources can be designed in such a way that there is no concentration of power and associated interests.

x) Reduction of dependence on resources, expertise and financing from abroad

- **Nuclear energy** (existing, new and future designs) – Uranium may be extracted in a fairly large number of countries, but nuclear fuel production requires highly specialised industrial capacity and therefore takes place in a limited number of countries: the US, Canada, France, Russia, Sweden, India, Japan and China, and small capacities in Romania and Iran. There is a limited number of countries with sufficient know-how to build large nuclear power plants: the US, Canada, France, Russia, Japan, China and South Korea. New nuclear power plant designs require highly specialised knowledge available in only a few countries. This means that most countries starting with nuclear energy become politically and strategically dependent on the country or countries of origin of the technology. Because new nuclear power is so difficult to finance, we see that new plans usually go hand in hand with a financing agreement, with the technology's country of origin contributing some or all of the capital for the nuclear power plant. Examples include Bangladesh (Roopur – Russia), Hungary (Paks II – Russia), Turkey (Akkuyu – Russia), Belarus (Astravetz – Russia), Finland (Hanhikivi – Russia), the UK (Hinkley Point C – France; Bradwell – China).

- **The alternative** – Renewable energy sources, storage methods (including batteries) and efficiency technologies depend on a number of raw materials that are only found in a small number of countries. Some of these can be replaced by more widely available raw materials through innovation, but some of this dependence will remain and even grow.

y) Transparency throughout the entire implementation chain

- **Nuclear energy (existing, new and future designs)** – there are a number of relevant issues that put pressure on transparency around nuclear energy:

  <u>Security</u>: Since a malicious attack on a nuclear power plant can have enormous consequences, security-sensitive information must be kept confidential. There is also the risk of misuse of nuclear fuel for terrorist or military purposes. As a result, nuclear energy has always been shrouded in secrecy. This has changed somewhat in the last three decades, but some countries are still trying to withhold a lot of information from the public.

  <u>Large commercial interests</u>: The nuclear industry consists of very large companies with an enormous number of very small subcontractors. Much information is therefore seen as commercially confidential.

  <u>International security and diplomacy</u>: Due to the high risks posed by nuclear energy, as well as reputational concerns, many countries find it problematic to share information about accidents and shortcomings. Because the importance of sharing such information to improve safety is so great, a system of confidentiality has been established in which the IAEA plays a central role. The IAEA for that reason does not have an official transparency policy. Information may only be released with the consent of the country of origin. This has recently led to the absurd situation in which the whole world knew that measured Ru-106 in the atmosphere, a very rare human-made isotope, could only have come from an incident at the Mayak reprocessing plant in Russia, but Russia flatly denies it to this day.

Nuclear energy and transparency appear to be in many cases incompatible.

- **The alternative –** The biggest problems with transparency in the renewable energy sector are related to trade secrets and public participation in project planning. Badly planned projects in most cases meet with (often justified) NIMBY reactions from local residents. Greater transparency at an early stage, together with a large audience participation in the implementation and operation of such projects, can prevent many problems.

z) Provides benefits that cannot be provided by other technologies

- **Nuclear energy (existing, new and future designs)** – The nuclear industry likes to point out the contribution it makes to the medical use of nuclear knowledge and technology. Certainly, countries with nuclear power plants have an edge in the training of nuclear experts. For energy production, nuclear energy has no advantages over any other technology that can produce electricity and/or heat. Hydrogen production, desalination and high-temperature supply can all also be done with renewable, sustainable alternatives. Medical isotopes can also be produced with particle accelerators, resulting in much less waste. A very small number of medical and research isotopes can only be produced in a nuclear reactor – but just a handful of specialised ones can meet that demand worldwide. Another advantage that is sometimes cited for nuclear energy is the small (surface) footprint compared to other energy sources (also called a high energy density). The footprint of uranium mining, reprocessing and waste treatment is often forgotten, but it is true that put together, the required surface area remains smaller than that of all other energy technologies. The only question is whether that is a problem in itself. Even if all energy worldwide in 2050, at an equal, high level of prosperity for all people, comes from renewable energy sources, the land area used would only be in single digit percentage points and not much higher than it is now. This is partly due to a leap in user efficiency.
- **The alternative** – The greatest benefits of renewables, storage and energy efficiency are cost, decentralised generation, and the ability to use these resources in closed resource cycles. The latter in particular is a crucial advantage compared to fossil fuels or nuclear energy, which always leaves waste that exerts pressure on the biosphere for current and future generations.

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