NUCLEAR MONITOR

July 1, 2021 | Issue #894

A PUBLICATION OF WORLD INFORMATION SERVICE ON ENERGY (WISE) AND THE NUCLEAR INFORMATION & RESOURCE SERVICE (NIRS)

WISE / NIRS Nuclear Monitor

The World Information Service on Energy (WISE) was founded in 1978 and is based in the Netherlands.

The Nuclear Information & Resource Service (NIRS) was founded in the same year and is based in the U.S. WISE and NIRS joined forces in the year 2000 to produce Nuclear Monitor.

Nuclear Monitor is published in English, 15 times a year, in electronic (PDF) format only. Back issues are published on the WISE website two months after being sent to subscribers (www.wiseinternational.org/nuclear-monitor).

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ISSN: 2542-5439

CONTACTS

WISE

info@wiseinternational.org
www.wiseinternational.org

NIRS

nirs@nirs.org
www.nirs.org

Nuclear Monitor

monitor@wiseinternational.org
www.wiseinternational.org/nuclear-monitor

Monitored this issue:

CO_2 trap for Nuclear Power

J.W.Storm van Leeuwen, MSc, member of the Nuclear Consulting Group

Global perspective

Climate change by human-made CO_2 emissions is a global issue. Assessment of climate change by human activities requires a global perspective and a long time horizon.

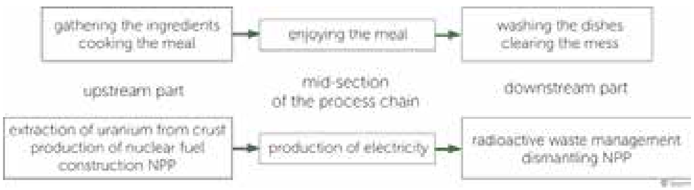
The nuclear contribution to the global energy supply was about 1.7% in 2019. Assumed that nuclear energy is free of emissions of CO_2 and other greenhouse gases (which it is not), the nuclear contribution to mitigation of the global emission would be about 1.7%. This share would decrease with time, if the global energy demand will rise. To keep the world nuclear capacity at the present level (370 GW), most of the present nuclear power plants have to be replaced by new ones, because many plants reach the end of their technical lifetime during the coming decades. Through 2050 each year 8 new nuclear power plants of 1GWe have to be connected to the grid.

A common fallacy

A nuclear power plant is not a stand-alone system. Commonly only the nuclear power plant itself, especially only the heat source of it (the nuclear reactor), is taken into account in CO_2 emission calculations.

A nuclear power plant is part of a system, a chain of specific processes without which nuclear power would be impossible. Without nuclear power these processes would not exist. The set-up of the nuclear process chain is comparable with the set-up of a daily domestic activity: having a meal.

Figure 1 Set-up of the nuclear processs chain and of a



daily domestic process chain.

All processes of the nuclear chain are industrial processes and emit CO_2, except the nuclear reactor. The nuclear process chain is a complex system, mainly because of the radioactivity of the involved materials.

Generation of “artificial“ radioactivity

A unique feature of nuclear power is the generation of human-made radioactivity. During the fission process in an operating nuclear reactor the radioactivity of the nuclear fuel and reactor increases inevitably with a factor of one billion, due to the generation of radioactive fission products and by neutron irradiation of non-radioactive materials. Each operating nuclear reactor produces each year an amount of human-made radioactivity equivalent to about 1,200 exploded Hiroshima atomic bombs.

The disasters of Chernobyl and Fukushima demonstrated the serious consequences of the unplanned release of a part of the annual radioactivity production into the environment. The chance of such disasters increases with time, due to the increasing amount of radioactive materials worldwide and the inevitable deterioration of the shielding materials.

This amount of human-made radioactivity gets distributed over a mass of various materials of about 60,000 tonnes. These radioactive materials should be isolated permanently from the biosphere and the human environment.

This comes on top of the materials which are contaminated with natural radioactivity with a mass of an estimated 6 million tonnes, mainly the mining waste. These materials too should be isolated from the biosphere permanently.

CO_2 emissions directly coupled to nuclear power

The nuclear reactor is the sole part of the process chain that does not emit CO_2, all other processes of the chain do emit CO_2. So it is important to draw a distinction between the CO_2 emission of nuclear power, involving the complete process chain, and the CO_2 emission of an operating nuclear power plant, involving just the nuclear reactor. The specific CO_2 emission of each process of the chain can be calculated on the basis of physical and chemical data.

Contemporary CO_2 emissions

The upstream processes, construction and the maintenance processes occur preceding or during the operating period of the nuclear power plant; these processes are contemporary with the generation of electricity by the nuclear power plant. Therefore their CO_2 emissions are called the contemporary CO_2 emissions of nuclear power.

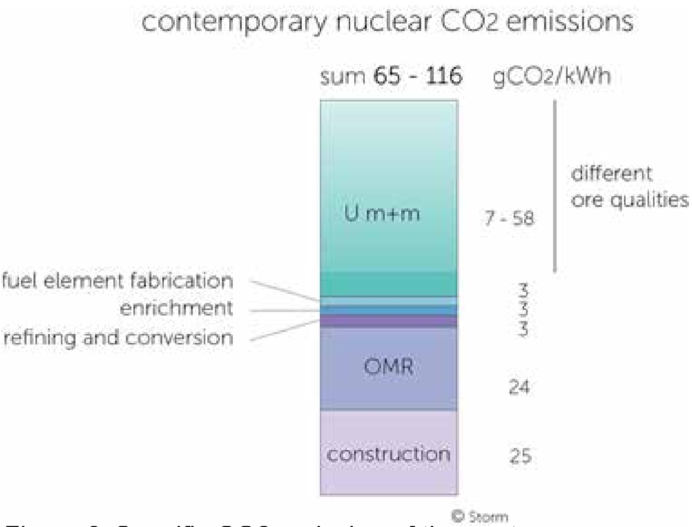


Figure 2, Specific CO2 emission of the contemporary processes of the nuclear process chain, at the present (2021) state of technology. U m+m means uranium mining + milling, OMR means operation + maintenance + refurbishments during the operational period of the nuclear power plant.

Figure 2 shows that the largest contributions come from construction of the nuclear power plant, from operation + maintenance + refurbishments (OMR) and from uranium mining + milling (U m+m). The contribution of U m+m exhibits a large uncertainty range because the currently exploited uranium ores vary widely in physical and chemical qualities. The CO2 emission of uranium mining + milling will rise with time, as is explained in the section 'CO2 trap'.

Thermodynamic analysis of uranium mining + milling proves that this first process of the nuclear processs chain is pivotal for the future of nuclear power based on the current nuclear technology. When the grade of the available uranium ores falls beneath a certain value, no net energy can produced from that uranium ore, as is explained in the section 'Energy cliff'.

Future CO2 emissions

How about the downstream processes? To speak metaphorically: the dishes and the mess are piling up in the kitchen and even in the dining room: not one nuclear chain has ever been completed. Human-made radioactive wastes since the 1940s are still waiting in vulnerable temporary storage facilities for definitive isolation from the biosphere, if not irretrievably dumped into the sea or landfills.

Ultimately all material streams containing natural radionuclides and human-made radionuclides are to be removed from the human environment and isolated from the biosphere for geologically long periods. This inevitability requires two main activities: the packaging of the wastes in durable containers and the construction of repositories deep in stable geological formations, such as granite. A geologic repository resembles an underground mine with galleries to dispose of the radioactive waste containers.

The CO2 emissions of these processes can be reliably estimated, because of analogy with conventional industrial processes. Figure 3 represents the estimated CO2 emissions of the downstream processes. These emissions would occur in the future, if and when the downstream processes actually would be realized.

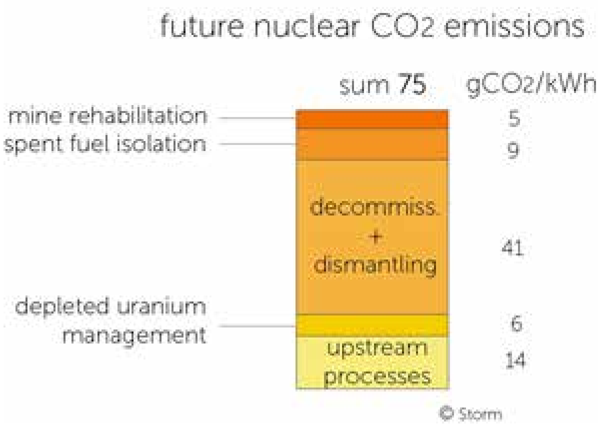


Figure 3, Specific CO2 emission of the future processes of the nuclear process chain, at the present (2021) state of technology.

A third inevitability is the decommissioning and dismantling of all nuclear power stations and other nuclear facilities, such as reprocessing plants, at the end of their technical life. For each nuclear power plant this process produces an estimated amount of 55,000 tonnes of radioactive waste. In many cases a large volume of radioactive contaminated soil has also to be removed from the site, because of leakages and small incidents during the operational life of the nuclear power plant or other nuclear facility.

Construction cost and construction time

Since the 1960s the construction costs and time of nuclear power plants per MW power are escalating, despite technological innovations. The current experiences with construction of nuclear power plants in Europe are not promising: the construction of the new plants in Olkiluoto (Finland), Flamanville (France) and Hinkley Point C (UK) are many times over budget and over time. Currently the construction of a new nuclear power plant, including prepararations, may take some 20 years.

How sustainable is nuclear power?

What do we mean when we name an energy source 'sustainable'? The following sections address several aspects of the sustainability of nuclear power:

- material consumption
- not all uranium resources are energy resources - energy cliff
- the specific CO2 emission of nuclear power rises with time - CO2 trap
- artificial radioactivity - safety

Material consumption

One aspect of sustainability is the specific material consumption. Materials are needed to construct the conversion equipment for all energy systems. Energy systems that are based on minerals from the earth's crust - fossil fuels and nuclear power - consume also materials to convert the primary energy input - the potential energy in the minerals - into electricity.

Nuclear power produces its delivered energy from uranium ore in the crust. So it depends on the availability of the mineral energy source and on the quality of it. One nuclear power plant with a power of 1 GW, operating longer than current the world average, consumes per kilowatthour delivered to the grid:

- 12 g/kWh processed materials, of which 5 g/kWh is recyclable
- more than 150 g/kWh fresh water, contaminated by radioactive materials
- about 47 g/kWh of other materials, of which 26 g/kWh of uranium ore

About 54 g/kWh of the materials input is lost forever due to contamination by radioactive materials; some of these lost materials are of strategic value.

Renewables based on wind and solar power need only materials for construction of the conversion equipment, the primary energy input is free. Solar energy has a constant quality, is inexhaustable and is available on any place on the world where the sun shines and the wind blows.

Example: an offshore wind park consumes per kilowatthour delivered to the grid: about 6 g/kWh of processed materials, largely recyclable.

Energy cliff

Uranium is the energy source of nuclear power plants. Nuclear power could contribute to the world net energy production as long as there are uranium resources available, right? However, there is a trap: called the energy cliff.

Uranium, a radioactive metal, occurs in many kinds of rocks in the Earth's crust, with grades varying from about 100 gram uranium per kg rock to less than 0,1 milligram per kg rock. The higher the uranium grade, the rarer such deposits in the Earth›s crust are and the smaller their total uranium content is. This is a common geologic phenomenon that applies to all metal ores. At present the world average grade of exploited uranium ore is about 1 g U per kg rock.

To extract uranium from a rock as found in nature a number of physical and chemical processes are needed. At lower grade more rock has to be mined and processed to obtain 1 kg of uranium. This 'dilution' effect is enhanced by a lower extraction efficiency as the uranium grade is lower, following from fundamental physical phenomena. An important consequence of both effects is the exponentially increasing energy consumption per extracted kg uranium when ores with lower grades are used. At a grade of about 0.1 g U/kg rock the energy used to obtain 1 kg uranium is as large as the energy amount that can be produced from 1 kg uranium in the nuclear system. Therefore, at a grade of about 0.1 g U/kg rock and below, uranium deposits cannot be considered energy sources. This phenomenon, that follows from fundamental physical laws and cannot be circumvented by advanced technology, is called the energy cliff of uranium occurrences.

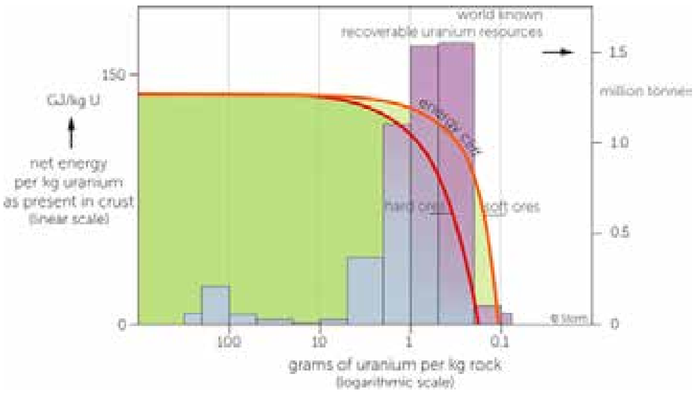


Figure 4, The energy cliff

The bar diagram represents the ore grade distribution of the world known uranium resources. At lower grades the uranium ores tend to be harder: harder to mine and more difficult to extract the uranium. This is indicated by the color of the bars: more violet means harder ore. During the past 3 decades no new significant uranium resources are discovered.

The bar diagram in Figure 4 represents the ore grade distribution of the world known uranium resources, with a total of more than 5 million tonnes. A modern nuclear power plant of 1GW needs each year about 175 tons of natural uranium. At present the world nuclear fleet is about 371 GW, so the current annual world consumption is about 65,000 tonnes of natural uranium. So the world has enough uranium for about 77 years at the current consumption rate?

It turns out to be not so simple. At lower grades the uranium ores tend to be harder: harder to mine and more difficult to extract the uranium. Figure 4 shows that a significant part of the world uranium resources approaches the energy cliff, because the poorer the ores are, the harder they are.

CO2 trap

Higher energy use per kg extracted uranium means more CO2 emission, because more materials and diesel are consumed per kg extracted uranium. Consequently more CO2 is emitted per generated kilowatthour by the nuclear power plant that depends on uranium from poorer ores. The richest available ores are mined first, because these offer the highest return on investment for the mining companies. The result is that the remaining uranium resources have lower grades and that the CO2 emission per kg extracted uranium increases over time. Consequently the specific emission of nuclear power increases over time and ultimately reaches values as high as those of fossil-fuelled power plants. This is called the CO2 trap: nuclear power will run around in the CO2 trap within the lifetime of new nuclear build.

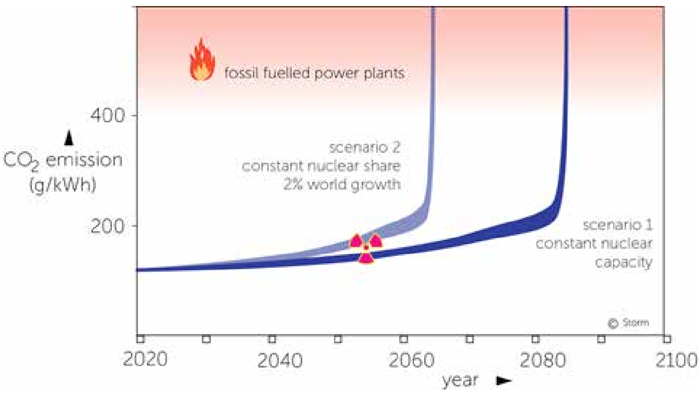


Figure 5, CO2 trap

This figure shows the specific CO2 emission of nuclear power as function of time in two scenarios: in scenario 1 the world nuclear capacity remains at the current level (370 GW), in scenario 2 the world nuclear capacity increases with 2% a year.

Conclusions

The energy source of nuclear power is a mineral from the earth's crust: uranium. An intricate system of industrial processes is required to convert the potential energy in this mineral into useful energy, and to manage the inevitable radioactive material wastes. During operation each nuclear power plant generates each year an amount of human-made radioactivty equivalent to about 1,200 exploded Hiroshima atomic bombs.

Without the process chain nuclear power would be inpossible, and without nuclear power these processes would not exist. The CO2 emission of these processes together form the specific CO2 emission inextricably coupled to nuclear power.

The thermodynamic quality of the available uranium resources declines with time, because the highest quality resources are always mined first, for these offer the highest return on investments for the mining companies. Declining thermodynamic quality of the resources results in an exponential rise of the specific energy and the coupled CO2 emission required to extract 1 kg of uranium from rock. At a given point the required extraction energy will equal the amount of useful energy that can be produced from 1 kg of uranium.

Within the lifetime of new nuclear build uranium resources cannot be considered energy resources anymore, if the world uranium consumption remains at the present level. Meanwhile the coupled specific CO2 emission will grow as large as fossil-fuelled power.

J.W.Storm van Leeuwen, MSc, member of the Nuclear Consulting Group

This paper is based on an elaborate study using data from the nuclear industry and from uranium mining companies. All references can be found on the website with the findings of the study: https://www.stormsmith.nl/reports.html

Nuclear energy in the EU Taxonomy

The Austrian Institute of Ecology presented its Critical Review of the EU Joint Research Centre's (JRC) Assessment for the EU Taxonomy Regulation, the first comprehensive review of the report commissioned by the European Commission.

Lead author Gabriele Mraz sums up her evaluation of the JRC paper: "We call upon the European Commission and both Euratom Art. 31 Group and SCHEER Committees which are tasked with evaluating the JRC Report by taking an evidence-based approach. The JRC assessment provides an insufficient basis for decision-taking. Our Critical Review highlights the consequences of nuclear energy use that the report ignored and should be considered. It is not acceptable to simply leave out facts about nuclear energy that do not support the desired narrative."

The facts that should be taken into account include:

- Severe accidents with catastrophic and long-term consequences have been downplayed by the JRC: the risk of chronic illness due to a severe accident, the risk of loss of agricultural areas due to severe contamination, and the disastrous social and economic impacts on people forced to live in contaminated territories. The JRC failed to include either of the major accidents – Chernobyl and Fukushima – in its comparison of fatality rates.
- After decades of research, there is still no final disposal for nuclear waste. The Swedish copper canister solution, which Finland also intends to use at its planned Onkalo disposal, has not yet been approved because copper appears to corrode under the expected underground conditions. There is currently no solution for the safe disposal of tons of high - level nuclear waste and spent fuel.
- JRC failed to discuss non-proliferation problems; the risk of more countries acquiring nuclear weapons via civil nuclear programs has been entirely omitted.
- JRC appears to believe that regulations alone will ensure nuclear safety, and that the achievable safety improvements identified during the EU stress tests have been implemented. The claim that the new Generation III+ reactors will guarantee safety are also incorrect; the only one (EPR) currently in operation is Taishan in China. Instead, the existing fleet of reactors will continue to operate beyond their planned lifespans, with outdated designs and increased risk associated with aging components.
- Nuclear energy significantly harms human health, even in the low dose range resulting from normal NPP operations and nuclear workplaces.

The JRC Report systematically downplays the risks and hazards specific to nuclear energy, omitting to mention many potential areas of danger. The residual risk of a severe accident at any plant, at any time, is ignored, although mankind has already experienced the outcomes of such events more than once. This is not only a serious omission, but also a clear failure to fulfil the task the JRC was set.

Patricia Lorenz, co-author of the Austrian Institute of Ecology's review: "The European Commission's choice of taxonomy as a tool to prepare for a sustainable future is a very valuable one. The process has started well and it should retain the trust it has built up thus far. We are aware of the nuclear industry's battle for survival, and that certain Member States are pressuring the EU Commission, urging them to overthrow the first assessment by the Technical Expert Group (TEG) and include nuclear in the taxonomy. However, this is an insidious approach: attempting to push nuclear energy in through the backdoor based on the JRC assessment whose authors remain anonymous, and involving two review committees who are neither transparent, nor obliged to consult on or even publish their statements. We ask for a fully transparent and public discussion and consultation on all the relevant documents and the EU Commission's upcoming legislative proposal in September."

The Critical Review of the Joint Research Centre's Assessment for the EU Taxonomy Regulation report can be downloaded here: http://www.ecology.at/files/pr922_1.pdf

For further information: patricia.lorenz@foeeurope.org

Should Nuclear Power have a future in Thailand?

By Tipakson Manpati

Thailand envisions nuclear power for electricity generation as it made several attempts to pursue this source of power, despite the fact that none of those plans have materialized yet. The first attempt to construct a nuclear power plant of 600 MW Boiling Water Reactor (BWR) was in 1966 in Aow Pai, Chonburi Province[1], but the project was scrapped due to public opposition [2], concerns over the financial cost [3] and the discovery of natural gas in the Gulf of Thailand in 1970s[4] that gave the country an alternative source of energy in 1970-1980. The agenda for nuclear power resurfaced in the 2000s.

It was the first time that 2,000 MW of nuclear power plant projects were included in the country Power Development Plan 2007 (PDP 2007). In May 2009, this plan was updated, indicating a "need for nuclear power plants in Thailand".[5]

PDPs are expected to change every three to four years. The PDP 2010 (2010-2030) also included the plan to start the construction of the first two nuclear power plants in 2020-2021, as government official source stated:

"Thailand's National Energy Policy Council commissioned a feasibility study for a nuclear power plant in the country and approved in 2007 a Power Development Plan for 2007-2021 including the construction of 4000 MWe of nuclear generating capacity starting in 2020-21. The new Power Development Plan 2010-2030, approved in 2010, envisages five 1000 MWe units starting in 2020-2028."[6]

All PDPs since 2007 covered plans for nuclear power plants. But they were removed from the latest PDP 2018 (Revision 1: 2018-2017).

Timeline of Thailand's nuclear power plant plans[7]

1966	• Thailand's first nuclear power plant project proposed by EGAT
1974	• Proposal of nuclear power plant project of 350-500 MW approved in Aow Pai, Chonburi province • The project shelved as natural gas costs drop
1977	• The project reproposed by EGAT and approved by the government • The project pressured by global and public opposition and later canceled
1993	• Nuclear research reactor (5-10 MW) in Ongkharak District, Nakhon Nayok province, proposed by Office of Atom for Peace (OAEP)
1993-2003	• Ongkharak plans halted multiple times due to safety and environmental problems. • The US-based General Atomics, contracted to build, threatening legal action for stall in plans
2007	• The 2007 National Power Development Plan (PDP 2007-2021) call for nuclear energy by 2020. • EGAT to invest six billion dollars to build 4,000 MW nuclear power plant • The revision of nuclear power plant to 2,000 MW in 2020 and 2021 (PDP 2007 revision 2)
2010	• PDP 2010 (2010-2030) covering 5,000 MW for nuclear power plant in its plan
2011	• On 11 March 2011, Fukushima nuclear accident raising global public concerned about nuclear safety issue. • In May 2011, the Thai cabinet approving PDP 2010 revision 2 • The revision of nuclear power plant to 4,000 MW in 2023-2024 and 2027-2028 • On 19 June 2012, the Thai cabinet approving PDP 2010 revision 3 • Nuclear power plant revised to 2,000 MW in 2026 and 2017
2015	• PDP 2015 (2015-2036) covering 2,000 MW of nuclear power plant in 2035 and 2036
2016	• Nuclear Energy for Peace Act B.E. 2559 (A.D. 2016) approved by National Council for Peace and Order (NCPO)
2018	• PDP 2018 (2018-2017) covering 2,000 MW of nuclear power plant in 2035 and 2036 • PDP 2018: Revision 1 (2018-2017) approved by the cabinet on 20 October 2020 • The removal of nuclear power plant plans for the latest PDP

[8, 9, 10]

Development of nuclear power in Thailand

Removal of nuclear power reflects the dynamic politics of formulating the PDP in Thailand. The plans to include nuclear power could be revived at any time in the future. The relevant agencies continue to work on the development of nuclear power in the country, especially to gain public acceptance and to create human resources specializing in nuclear technology.

According to INIR Mission (Integrated Nuclear Infrastructure Review in December 2010), Thailand can make a knowledgeable decision on the introduction of nuclear power.[11]

During 2008-2011, Thailand conducted preparation works to "go nuclear" including a pre-project phase and a feasibility study for the selection of preferred sites.[12] According to the feasibility study of the U.S. consulting company Burns and Roe Asia Ltd, there were 14 nuclear power plant sites in six provinces.[13] The $38 million fund for hiring the company to conduct the feasibility study was drawn from of the Energy Conservation Fund of Thailand and EGAT.[14] This did not include the full cycle of nuclear power plant set up, from preparation, construction, decommission and post-decommission that required the appropriate budget to ensure safety in the long term.

But the removal of plans for nuclear power caused disappointment among pro-nuclear groups.

Does nuclear power have a future in Thailand?

According to Santi Chokchaichamnankit of *Energy Watch*, there is no pressing need for nuclear in Thailand at present and it is unlikely to return to the national agenda in the coming years. There are several reasons for this. Firstly, the government does not pay much attention to nuclear technology because they prioritize other projects such as dams in Laos to diversify energy sources. In addition, in the past 4-5 years, Thailand has had a great supply of reserve energy – almost reaching 60% which means that it will be in use for the next 10 years. This is the undeniable fact that the Thai government has to accept that it will be a waste of time and efforts to prioritize in increasing national reserve energy which is already over supply.

Secondly, there is lack of public support for nuclear power. The budget and risks are not considered to be worth it. Also, in the context of political climate in Thailand, the government is creating an energy monopoly through pushing for private Independent Power Producers (IPPs) that are liquid natural gas (LNG) power plants. Thus, it does not pay attention on nuclear power nor care about over reserve margin.

Conclusion

In search for better energy sources other than nuclear power, Thailand must prioritize the de-monopolization of the power production structure and the promotion of energy conservation. The choice for clean energy and the decentralization of power structures, such as renewable energy, are more critical than ever before in combating the climate crisis and making it more effective and affordable for people in places not covered by the grid system.

Despite nuclear power being recently withdrawn from the Power Development Plan, it is important to keep an eye on the situation in Thailand and on a new potential momentum for nuclear power.

Tipakson Manpati is researcher who follows nuclear development issues in Southeast Asia.
Contact: tipakson.m@gmail.com

This article is a summarized version of a larger article on Thai nuclear developments. The full article is published by Heinrich Böll Stiftung Southeast Asia Regional Office in June 2021 and can be found at https://th.boell.org/en/2021/06/21/should-nuclear-power-have-future-thailand

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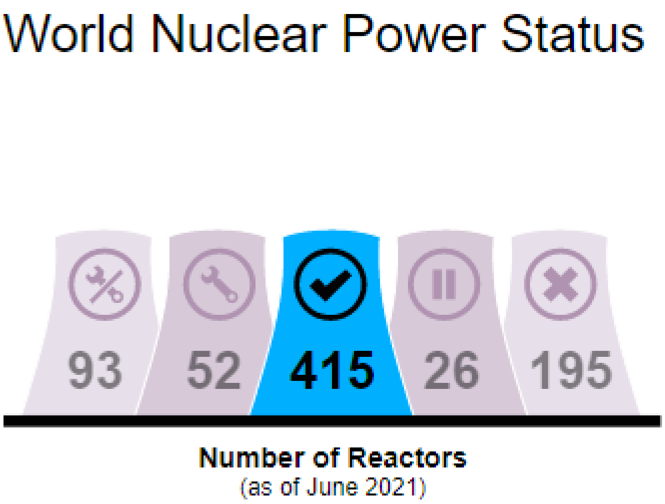

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UK.

Quite as a surprise two reactors at Dungeness were closed by its owner, EDF Energy. The reactors were already out of production for some time due to necessary repairs. The planning was however to reopen them in 2021 and then continue production until 2028. After a thorough analysis, the repairs turned out to be far too expensive.

Due to the closure of the two British reactors, the number of plants in long-term outage has fallen to 26 and the number of closed nuclear reactors has increased from 193 to 195.

ANTI-NUCLEAR NEWS

France.

In France there is growing resistance against plans to build 6 new EPR reactors. Despite the official position that a decision on this issue will not be made before the commissioning of Flamanville-3, scheduled for 2023, it seems that the state aid for this project has already been established. Sortir du Nucleaire started a petition on https://www.sortirdunucleaire.org/de-nouveaux-reacteurs-c-est-non