ENERGIAKLUB
CLIMATE POLICY INSTITUTE
APPLIED COMMUNICATIONS

OPERATIONAL ANOMALIES OF NUCLEAR ENERGY

OPERATIONAL ANOMALIES OF NUCLEAR ENERGY

Contributing authors:

Béla Munkácsy, PhD

Teacher, MSc in Environmental Management, PhD in Energy Geography. Assistant Professor at the Department of Environmental and Landscape Geography, Eötvös Loránd University; Consultant at Energiaklub, Member of the Board of the International Network for Sustainable Energy. He studied sustainable energy planning at the University of Oslo.

Dorottya Egres

Certified expert of communication and media. She is an assistant lecturer at the Department of Philosophy and History of Science at the Budapest University of Technology and Economics, project manager at Energiaklub. Her main field of research and the topic of her doctoral dissertation is the Hungarian discourse about nuclear energy. She is a member of the European Network for Argumentation and Public Policy Analysis.

Professional reviewer:

Martina Méhes

Managing and Policy Director of Energiaklub. Certified agricultural environmental management engineer, specialized in renewable energy. She studied nuclear energy engineering at the Technical Department of Szent Istvan University.

Translation:

Zsuzsanna Lestál

ISBN 978-615-5052-15-6

The study can also be downloaded from the website of Energiaklub Climate Policy Institute and Applied Communications Association: www.energiaklub.hu.

ENERGIAKLUB
SZAKPOLITIKAI INTÉZET
MÓDSZERTANI KÖZPONT

Published by ENERGIAKLUB in 2021

CONTENTS

LIST OF FIGURES

"(…) with the construction and operation of nuclear power plants, one is already pushing the limits of one's abilities, so it would be better to stop in time. But this is known by professionals and insiders as well … I think the risk is too high and comparison with any other risk is useless. Due to the danger of radiation, nuclear energy is so insidious that you should not play with this fire any longer. This is too serious a game ... I think it is necessary to mention that I am not talking about the topic as a football booster, I see it from the professional side, and I have also gained personal experience. Responsibility makes me speak. Of course, the nuclear lobby, led by the nuclear energy agency, will certainly see it differently. Their existence is also at stake."

by Ernő Petz, director of the Paks Nuclear Power Plant between 1991-1994

EXECUTIVE SUMMARY

Nuclear power accounts for barely 2% of global final energy consumption and it is not part of the energy mix in 84% of the world's countries. Its importance in developed economies is rapidly declining, and the capacities that are still operating are being liquidated. Capacity expansion is typically observed in developing countries where the political system is not functioning democratically.

The 70-year journey of nuclear power has been lined with 17 particularly serious accidents. The security expectations that can be traced back to these are constantly getting more and more rigorous, which has resulted in dramatic price increases over the last three decades. This fact and the fall in the price of the competing renewable energy technologies mean that new nuclear power plants can no longer be built on a market basis. The costs of the planned investment in Paks in Hungary will also be paid by the taxpayers, while they will not be able to form an opinion in a referendum on the project which has a final cost of HUF 10,000-20,000 billion (i.e. HUF 1-2 million for each Hungarian citizen). Because of the enormous costs, nuclear energy is a hotbed of corruption, of which there are deterrent examples around the world.

Not only do nuclear power plants operate with poor energy efficiency of around 33%, but - according to international life-cycle research, taking into account the energy needs of mining and waste management for hundreds of thousands of years - it is possible that the operation will have a negative result, i.e. energy loss.

More and more system operators are reporting that the power generated by nuclear power plants (and coal-fuelled power plants) is causing them operational difficulties. These "obsolete" facilities, due to their inflexible production, pose an increasing threat to the security of energy supply to consumers year after year due to their inability to support fast-growing and very low-cost wind turbines and solar systems.
Based on the operating experience so far, nuclear energy is therefore not cheap, not safe and not in the least clean. Furthermore, the expansion of the Paks Nuclear Power Plant cannot be called transparent, as there has been no proper expert debate or social dialogue. In contrast, the last decade has been marked by data request lawsuits, data request denials and data encryptions, thus depriving the wider scientific community and society of the opportunity to form well-founded opinions and excluding them from decision-making processes.

1. INTRODUCTION

The government's statement that "nuclear energy has no alternative" has been voiced many times in Hungary, but has never been scientifically substantiated. In comparison, 84% of countries worldwide do not operate nuclear power plants, of which only a few major European states are Austria, Denmark, Portugal, Italy and Poland. Moreover, based on government decisions, it can be stated that the range of non-nuclear energy countries will expand in a few years. This is because it has been clearly demonstrated that this technology has not lived up to its promise, generated a number of serious problems in recent decades. Moreover, realistic alternatives have emerged, leading to a radical change in the direction of many nuclear-powered countries. Belgium, for example, which currently provides 5,930 MWe of nuclear power with half of its electricity, has decided to decommission nuclear power plants completely, within four years, by 2025.[1] Germany, where the share of nuclear power in electricity generation[2] was still around 30% in 2000, plans to complete the withdrawal of 8,545 MWe[3] of capacity from the six nuclear power plants still in operation by 2022. In Spain, the total capacity of 7,121 MWe will also be decommissioned by 2035.[4] The citizens of Switzerland have also voted for a nuclear-free future, so the 35% electricity fleet must be dismantled there as well. But other developed European economies have also moved towards nuclear cutback. France, cited as eminent in the area, for example, also plans to significantly reduce overall capacity, to shut down 14 reactors by 2035 and to reduce the share of nuclear power in electricity generation from 75 to 50%. In connection with domestic opportunities, among other things, the software research of ELTE[5] proved that a serious regulatory turn and the related complex intervention could make it possible to achieve up to 100% renewable energy share in Hungary.

The aim of our publication is to outline the background and causes of this worldwide phenomenon, to present the operational anomalies of nuclear energy - all in accordance

---

[1] *The Brussels Times*. 2019. "Belgium closes down its nuclear plants by 2025." 29 October, 2019 https://www.brusselstimes.com/belgium/76210/no-clarity-on-alternatives-for-belgian-nuclear-plants/

[2] EIA. 2019. "Germany announces proposal to phase out coal by 2038, further changing its generation mix." 29 May, 20219 https://www.eia.gov/todayinenergy/detail.php?id=39652

[3] KernD.de. d.n. "Nuclear Power Plants in Germany." https://www.kernd.de/kernd-en/nuclear-power/npps-germany/

[4] *Reuters*. 2019. "Spain plans to close all nuclear plants by 2035." 13 February, 2019 https://www.reuters.com/article/us-spain-energy-idUSKCN1Q212W

[5] Munkácsy, Béla (ed.) 2011. "Erre van előre - Egy fenntartható energiarendszer keretei Magyarországon." https://edit.elte.hu/xmlui/handle/10831/51512

with 21st century expectations, on a scientific basis, taking into account the complexity of the problem, to present the entire life cycle. Given the multitude and severity of the challenges, we dedicate a separate publication to present waste issues as well, which will be published at about the same time as this document.

It makes it difficult to see the topic clearly, when in addition to independent scientific studies, antipropaganda products appear - typically with many years of delay - to tangle the threads, which portray the technology in a better colour than it actually is. Such detachment from reality is often quite obvious, but in many cases, it is not easy to see through the sieve, to recognize the real connections. Getting informed is almost impossible for an ordinary person - this is what the nuclear lobby takes advantages of - as the independent scientific literature is not always available to the public, and its comprehension requires extensive and in-depth background knowledge. Reflecting on this, our publication serves the purpose of helping you find your way around, based on objective, scientific literature and facts and statistics. This is much needed in a situation where the objectivity of "public service" information has ceased. The nuclear lobby - in Hungary alone - spends billions every year to misinform the widest possible circle of society, by distorting or concealing the facts.
The experts of Energiaklub have been working for decades to at least alleviate this distorted situation, to promote the correct provision of information to the Hungarian population, and to provide professional support for the transition to a sustainable energy system in general. The following is a non-exhaustive list of some important milestones in this work through a list of publications specifically on nuclear energy published by Energiaklub:

'Reaktorta' - Nuclear power plants and our environment (2001)
https://energiaklub.hu/files/brochure/reaktorta.pdf
Nuclear energy: the other side of the coin (2007)
https://energiaklub.hu/dl/kiadvanyok/Atomenergia_%20Az_erem_masik_oldala_Energia_Klub.pdf
Corruption risks of nuclear power plant investments: what can we expect in the case of Paks II? (2014)
https://energiaklub.hu/files/study/korrupcios_kockazatok_paks.pdf
The world without Paks II - The energy vision of Energiaklub for 2030 using EnergyPLAN software (2015)
https://energiaklub.hu/files/study/paksii_nelkul_a_vilag_web.pdf

The authors of this publication are active participants of the scientific discourse, they take part in research specifically about energy management and related fields. The complex approach they (also) represent is essential to understanding and solving the huge problems accumulated by the operation of the energy system in recent decades. Fortunately, more and more experts working on energy issues are recognizing the importance and need for this radical change of attitude. Perhaps the time is not far, when the Hungarian engineering community will stand united against nuclear energy, and for the full expansion of renewable energy sources like in Denmark, for example, where - thanks to the Danish Society of Engineers -, it has been the norm for decades.[6]

[6] IDA. 2006. "The Danish Society of Engineers' Energy Plan 2030."
http://www.fritnorden.dk/NF2007/Energyplan2030.pdf

IDA. 2015. "IDA's energy vision 2050. A Smart Energy System strategy for 100% renewable Denmark."
https://vbn.aau.dk/ws/portalfiles/portal/222230514/Main_Report_IDAs_Energy_Vision_2050.pdf

2. STATISTICS - ABOUT THE NUCLEAR ENERGY SITUATION IN BRIEF

Nuclear power accounts for ~2% of global final energy consumption, and its share is declining year by year.[7] Some organizations, such as the International Energy Agency (IEA), also report higher values, but in these cases only consumption that takes place through some official channel, typically a bill, contract or similar document, is taken into account. These therefore do not include the energy consumption of the approximately three billion inhabitants of developing areas who procure the energy resources - such as firewood or dried manure - they need directly from nature. But IEA statistics also do not show a wide (and growing) range of consumers in the industrialized world, such as those who consume heat and electricity generated by household solar applications without being included in any statistics.

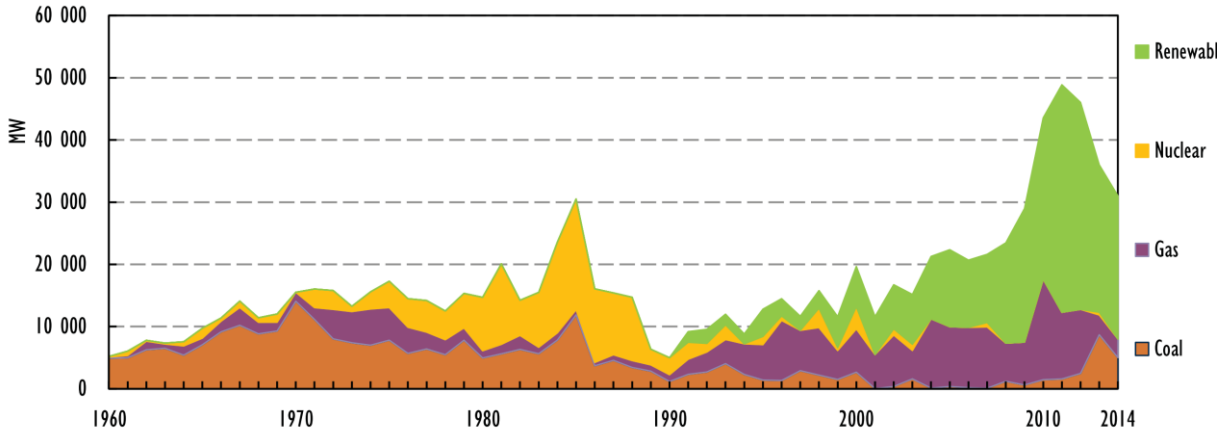

Figure 1: Entry of new power plant capacities into the system in European OECD countries in the period between 1960 and 2014, broken down by year.[8] The data clearly show the consequences of the Chernobyl tragedy, which first resulted in the dominance of natural gas-fuelled technology, and, from 2005, renewable energy-based technologies in new power generation capacities. Every year since 2018, more than 90% of new capacity in the European Union has fallen into this category - while nuclear power plant capacity has been declining steadily for a long time.[9]

The first energy-purpose nuclear power plant began production in 1954. The technology fitted well into the centralized energy system of the 20th century, so built-in capacity grew

[7] REN21.2020. "Renewables 2020 Global Status Report." https://www.ren21.net/wp-content/uploads/2019/05/gsr_2020_full_report_en.pdf

[8] IEA. 2016. "Re-powering Markets." https://www.iea.org/reports/re-powering-markets

[9] Schneider, Mycle et al. 2020. "World Nuclear Industry Status Report." https://www.worldnuclearreport.org/

very rapidly across richer countries around the world. This required another factor, namely to silence the real nature of nuclear energy, to cover up the recurring serious accidents and their consequences. Today's generally accepted figures show that before the 1986 Chernobyl tragedy, there were at least 14 very serious accidents that resulted in radioactive contamination in the environment, to a greater or lesser extent - most of which also claimed fatalities.[10] Directly or indirectly, but most of all as a result of these events, the importance of nuclear energy is also declining globally - and in developed economies it has shrunk downright and now seems to be completely disappearing.

[10] *The Guardian*. 2011. "Nuclear power plant accidents: listed and ranked since 1952." 14 March, 2011. https://www.theguardian.com/news/datablog/2011/mar/14/nuclear-power-plant-accidents-list-rank

3. NUCLEAR ENERGY IN THE LIGHT OF ACCIDENTS

The nuclear fuel cycle is thus bordered by far more tragedies than we might think, which is due, among other things, to the fact that a significant part of them have been hidden for decades. Also in connection with the Chernobyl accident, the well-proven secrecy was a central element of the scenario, but as a result of the huge amount of pollutants entering the atmosphere and the development of instrumental measurement technology, this attempt has already failed. At that time, the world was really faced with the risks of using nuclear energy. The statistics clearly show the consequence of this, namely the halt in the growth of nuclear power plant capacity and, following the Fukushima accident in 2011, its decline.

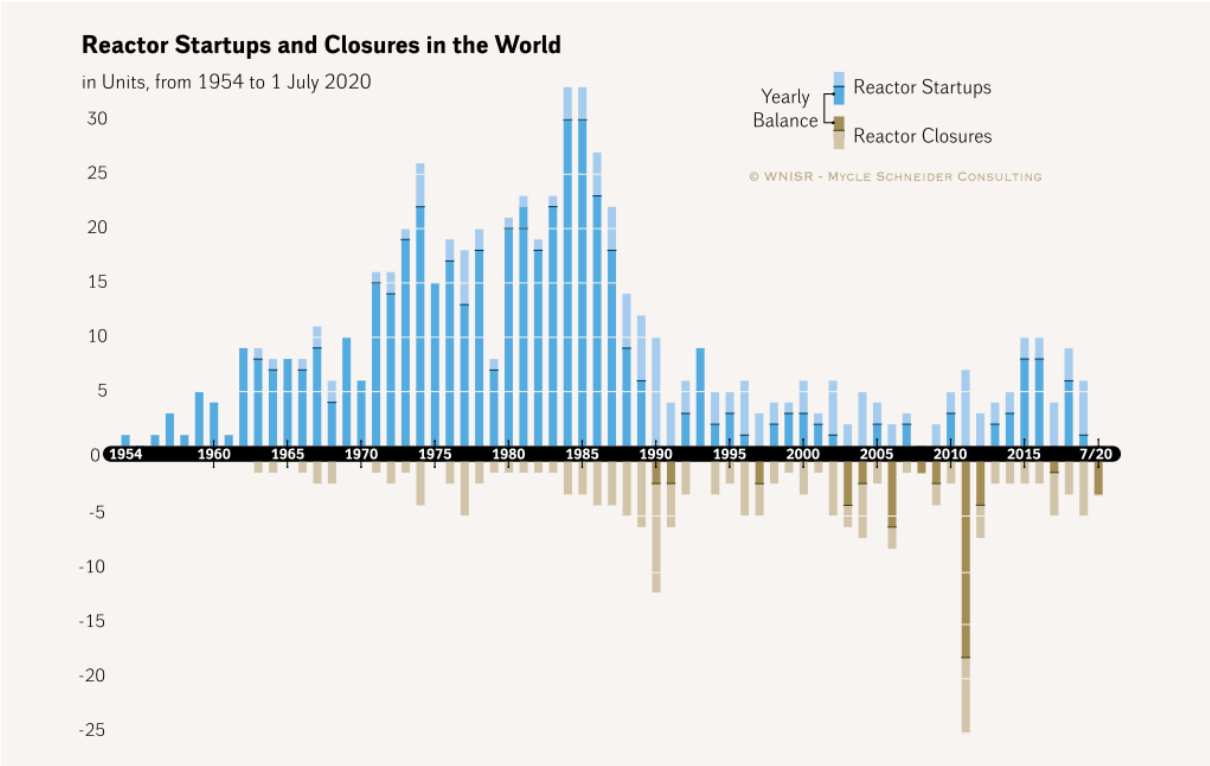

Figure 2: Commissioning and decommissioning of nuclear power plant capacities between 1954 and 2020 on a global scale.[11] The data set clearly illustrates the radical change of direction following the Chernobyl (1986) and Fukushima (2011) accidents, the significant decline in new nuclear-based electricity generation capacities.

[11] Schneider, Mycle et al. 2020. "World Nuclear Industry Status Report." https://www.worldnuclearreport.org/

Of the many accidents, the number of human victims of the Chernobyl tragedy is believed to be the largest. The UN links about 4,000 deaths directly to this accident. However, according to records from the National Radiological Research Centre in Kiev, there may be about five million people in the former Soviet Union alone who have suffered minor or major health damage as a result of this single nuclear power plant accident. In addition, the consequences will have to be borne by future generations, as the incidence of diseases due to various genetic disorders is very high among the children of parents exposed to radioactive contamination.[12]

Compared to the value calculated at the Chernobyl accident, the amount of radioactive contamination released in connection with the Kistim tragedy[13] in 1957 may have been twice as high. There are no exact data on the number of fatalities in the blast accident, but due to the low population density of the affected area, this is presumably a lower value than the data published in connection with the Chernobyl accident. On the other hand, the consequences were compounded by nuclear power generation and waste processing technology, which ignored the basic principles of environmental protection for decades. As a result, the living waters of the area have been completely polluted with radioactive waste, causing severe health damage (e.g., lymph node tumors) and frequent premature deaths among those living in the area. As the affected settlements vegetated in an almost hermetically sealed zone, isolated within the Soviet Union, any information about these events, and the terrible conditions there did not reach abroad until decades later.[14]

There have been more serious nuclear power plant accidents not only in the countries of the Eastern Bloc, but essentially in all the countries where such facilities operate. Even with the highest level of technology, such a tragedy cannot be ruled out.

Fatalities are to be counted with not only as a result of accidents but also as a result of normal operation. Workers mining uranium face the greatest health risk. According to a

---

[12] Gray, Richard. 2019. "The true toll of the Chernobyl disaster." *BBC*. 26 July, 2019 https://www.bbc.com/future/article/20190725-will-we-ever-know-chernobyls-true-death-toll

[13] The accident is also often referred to as the Mayak tragedy, as it occurred during the operation of a plant for the production and reprocessing of nuclear fuel called the Mayan Production Association.

[14] Lewis, Robert. d.n. "Kyshtym disaster." *Britannica.com*. https://www.britannica.com/event/Kyshtym-disaster

wide-ranging and long-term survey by the U.S. Department of Occupational Health, lung cancer is six times more likely to occur among uranium miners of European descent, pneumoconiosis (a chronic lung disease known as "black lung") 24 times, and tuberculosis four times more often than the general population.[15]

[15] Centers for Disease Control and Prevention. 2000. "Worker Health Summaries." https://www.cdc.gov/niosh/pgms/worknotify/uranium.html

4. NUCLEAR ENERGY = 100% IMPORT DEPENDENCE AND TOTAL VULNERABILITY

First of all, it is worth disproving the most frequently voiced argument of the Hungarian government, that says nuclear energy helps to achieve energy sovereignty (i.e. import independence), and to reduce vulnerability in the strategically important field of electricity generation. At the same time, from time to time, a strongly and erroneously generalized argument against renewable energy generation appears in the government-controlled "public service" press, drawing attention to its weather dependence and the resulting energy imports.

The reality is more nuanced on the one hand, but we can even say that it is quite different. If we talk about imports in connection with the energy sector, there has been only one area for decades where the dependence on foreign resources of Hungary is 100%, and that is nuclear energy. We are forced to source both nuclear power plant technology and fuel from Russia, in addition. As a reminder: this is the same country that is now occupying the territory of a neighbouring sovereign country by military force[16], where members of the political opposition are being killed by the secret service through murders[17], where the trampling of human rights takes place on an institutionalized level[18]. Getting into a vulnerable position from Russia for another 50-60 years in a strategically important area of the national economy is not a wise concept at all.

Renewable energy sources offer an outbreak of Hungary's current vulnerable situation, as they are domestic energy sources, triggering all kWh of energy produced with their help. Due to their decentralized nature, these technologies create jobs in the most remote settlements of the country, generate local tax revenues, thus resolving vulnerabilities, so their widespread use would obviously be a key issue for the survival of the depopulated Hungarian countryside.

---

[16] Council on Foreign Relations. d.n. "Conflict in Ukraine." https://www.cfr.org/global-conflict-tracker/conflict/conflict-ukraine

[17] Coelho, Carlos, and Kristina Foltynova. 2020. "Everything You Need To Know About Novichok." 23 November, 2020. https://www.rferl.org/a/everything-you-need-to-know-about-novichok/30964840.html

[18] Human Rights Watch. 2020. "Russia. Events of 2019." https://www.hrw.org/world-report/2020/country-chapters/russia#

5. POOR ENERGY EFFICIENCY

Losses must always be taken into account during energy conversion processes. This is less important when it comes to the use of renewable energy sources, which are available in huge quantities such as sun or wind - although the role of this factor is obviously not negligible even then. However, energy efficiency is a key issue in the use of decreasing resources. This category includes nuclear energy, in connection with which one often comes across the false claim that it is an efficient energy solution. But this statement can be refuted in several ways with the tools of science. Efficiency can be examined from several points of view, and at the same time an important question is: where to draw the boundaries of the examined system? The simplest way is to look at the values on the input and output side for a given fleet of a given power plant, that is, only on a short time scale and only within the "fence." In the case of nuclear power plants, only the electrical capacity is usually given (in the case of the Paks NPP it is ~2000 MW), the data on the triplicate figure of the thermal power can be found only with a more thorough investigation (in the case of the Paks NPP it is 5940 MW). The explanation for the large difference is to be found in the poor efficiency of steam turbines, which is why the traditionally interpreted energy efficiency index of nuclear power plants is very low, barely 33-34%[19]. Thus, at the cost of high environmental impact, most of the energy extracted from nuclear fuel (about two-thirds) comes out of the energy system in the form of waste heat, because it cannot be utilized substantially due to the extremely large amount of hot water. This also means that getting into nature as a heat load it causes ecological problems.

This low efficiency explains the very significant vision of growth in primary energy use for the next ten years, as outlined in the National Energy and Climate Plan - which has not been experienced for a long time in advanced economies: "*We will see a significant increase in primary energy use in the late 2020s. Significant growth is expected for both the WEM and WAM*[20] *scenarios. This is mainly due to the entry of new Paks units that increase transformation losses (...) The value of primary energy consumption in the case of the*

[19] Pór, Gábor. 2012. *Basics of Nuclear energy*. Edutus College. https://regi.tankonyvtar.hu/hu/tartalom/tamop412A/2010-0017_61_atomenergetikai_alapismeretek/ch04.html

[20] WEM = with existing measures; WAM = with additional measures

implementation of new policy measures in 2030 may be 30664 ktoe (approximately 1284 PJ), which is 29.2% higher value than in 2016".[21]

However, in a more serious, truly scientific analysis, we need to push the boundaries of the system further - in line with reality -, as in the 21st century it is appropriate to analyze and take into account efficiency throughout the life cycle. So the starting point is the energy content of the primary energy source used, in this case the energy content of the uranium ore extracted from the mines. Taking this into account, according to a benchmark Swedish study, a fraction of the energy content of the ore (1.25-1.7%)[22], is converted into electricity and only part of it is utilized[23], as significant losses are to be expected in the subsequent stages of the energy chain. The former is a staggeringly low value due to the fact that the spent fuel coming out of a nuclear power plant still contains a huge amount of energy, but it gets into the environment unused. The spent fuel units in Paks are cooled with water for five years[24] and then with air for 50 years[25], so this energy is lost. There will certainly be some - but not yet planned - geological storage as the next station, where we will have to count with continuous heat production again. In reality, therefore, nuclear energy is inefficient even compared to fossil fuels, which are considered to be extremely obsolete, as there is at least no such loss, and the energy content of fuels is much more utilized.

---

[21] Ministry of Innovation and Technology. 2020. "National Energy and Climate Plan 2020." https://ec.europa.eu/energy/sites/ener/files/documents/hu_final_necp_main_hu.pdf

[22] Eriksson, Ola. 2017. "Nuclear Power and Resource Efficiency—A Proposal for a Revised Primary Energy Factor." *Sustainability* 9, no. 6:1063. https://doi.org/10.3390/su9061063

[23] Adapt Consulting AS. 2013. "Conversion Factors for Electricity in Energy Policy." 15 February, 2013. https://www.energinorge.no/contentassets/e86a4dc8771845dfb03fee35c1d0f45d/2013-02-15--conversion-factors-for-electricity.pdf

[24] Nuclear power plant. d.n. Temporary storage http://www.atomeromu.hu/hu/Documents/Ideiglenes_tarolastol_a_vegleges_elhelyezesig.pdf

[25] National Atom Energy Agency. d.n. "A clear summary of the modification of the operating license for the Interim Spent Fuel Storage Facility."

http://www.haea.gov.hu/web/v3/oahportal.nsf/B6A5660AF889CD35C1257CBE002A41ED/$FILE/KK%C3%81T%20RHK%20%C3%B6sszefoglal%C3%B3.pdf

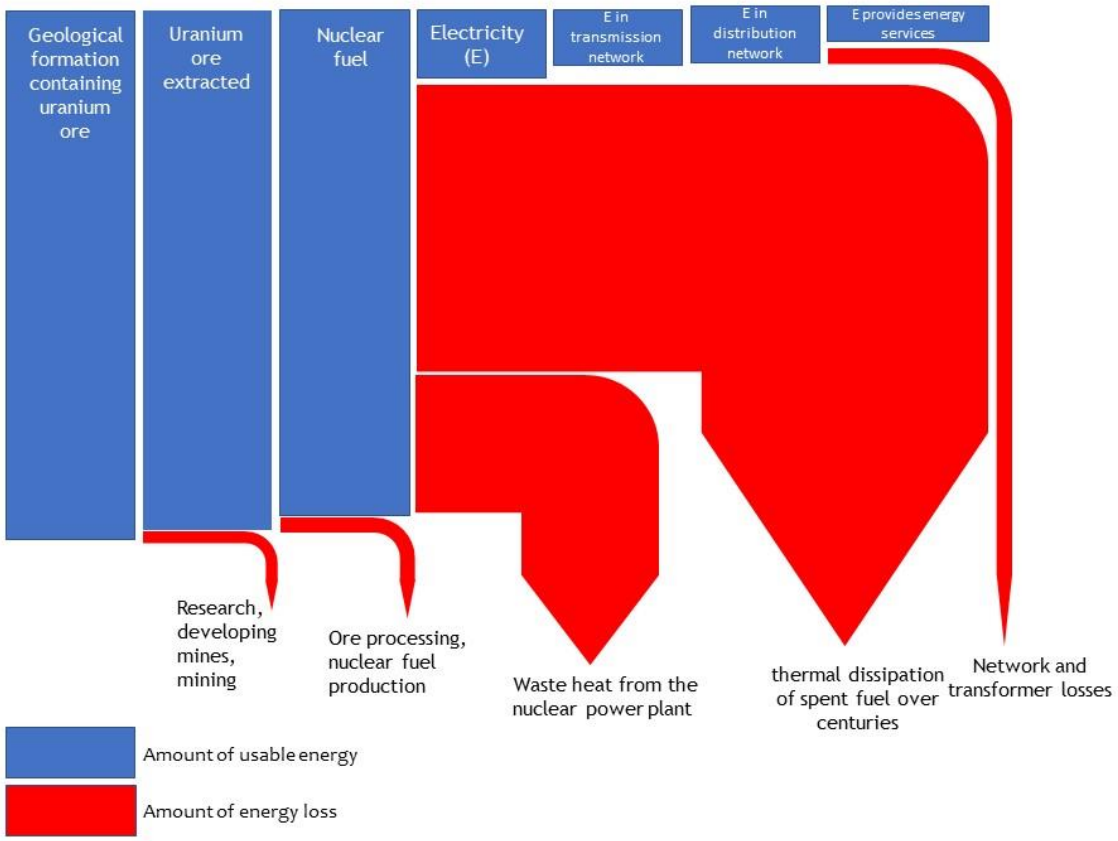

Figure 3: Energy chain losses from the nuclear power plant to the electricity consumer[26]. A significant part of the energy available in the form of a primary energy source is lost. It is not advisable to give specific values because different results are obtained for each power plant. The present figure depicts more modest than actual losses in order to keep the amount of energy actually used visible at the end of the energy chain. For the same reason, the additional losses in the final steps are no longer shown in the figure, because they can be very significant, and very large differences are possible in this respect, depending on the consumer equipment.

However, this does not end the series of aspects that must be taken into account when assessing the efficiency of nuclear energy, as there are other problems and methodological approaches that reflect them. If we remain with uranium ore as a problem, one characteristic should be highlighted, the very low uranium oxide concentration. On a global average, this is around 0.1% on average, so in the case of conventional mining, the amount of rock needed to be extracted, moved, processed and disposed of is ten thousand times more than that. It is also thought-provoking that the uranium concentration in the mined ore is deteriorating year by year, as mining obviously always targets better quality

[26] Eriksson, Ola. 2017. "Nuclear Power and Resource Efficiency — A Proposal for a Revised Primary Energy Factor." Sustainability 9, no. 6:1063. https://doi.org/10.3390/su9061063

resources.[27] Extraction therefore requires more and more resources as reserves decrease, and nevertheless results in poorer quality uranium ore. This includes information that the Hungarian Mining and Geological Service (MBFSZ) still registers 31,000 tons of uranium ore with a uranium content of 0.117% in the area of the former Kővágószőlős mine. However, extraction has become so uneconomical since the 1980s, that mining was finished in 1996.

The Oxford Research Group calculates that at uranium concentration below 0.02%, more energy must be invested to operate the process at a foreseeable stage of the life cycle than recoverable energy, meaning that the activity loses its meaning[28] in energy terms. This regularity is described in the international literature by the concept of ***energy cliff***. It also follows form this, that the extraction and processing of rock bodies with ever lower uranium concentrations results in significant additional energy requirements, which sooner or later results in a level of CO_2 emissions that causes higher and higher emissions per unit of electricity.

[27] Strom van Leeuwen, Jan Willem. 2006. "Secure energy: options for a safer world - Energy security and uranium reserves." https://www.files.ethz.ch/isn/91713/06-07%20Factsheet%204.pdf
[28] Strom van Leeuwen, Jan Willem. 2016. "Nuclear power in its Global Context." Geographical Locality Studies 4, no. 1:726-87. https://www.stormsmith.nl/Resources/TYPESET_GLS4_Paper-1.pdf

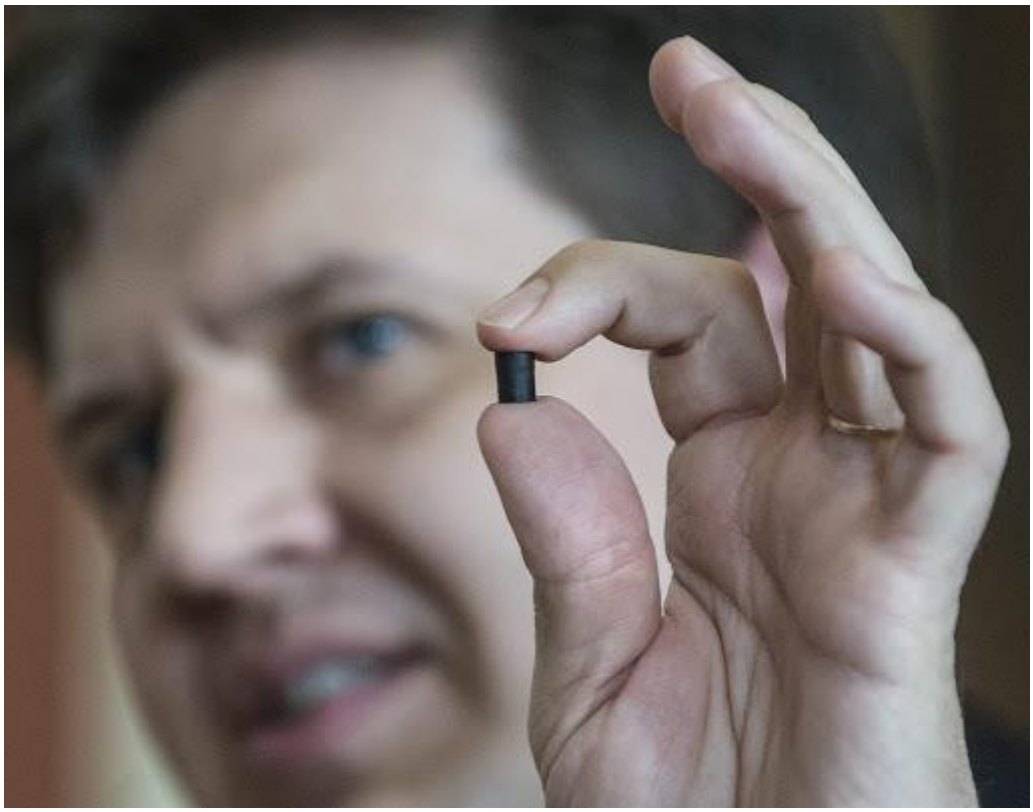

Figure 4: Nuclear fuel pellet. To produce such a product, 22,500 times the amount of rock from the mine has to be picked up, moved and processed, while generating the same amount of different hazardous and radioactive waste (since all the materials entering the process sooner or later become waste).[29]
Source of the image: Sándor Ujvári / MTI

With regard to extraction, it should be mentioned that in recent decades, traditional mining activities have been significantly replaced by the in situ leaching technology. Switching is advantageous in some respects, as it can cause severe health damage to miners, for example, but this process generates new problems, such as the huge demand for water and the resulting heavy metal-laden wastewater production.

After the above detour, returning to the energy cycle of the entire life cycle, it is worth getting acquainted with the results of studies conducted by researchers from Louisiana State University and the University of Oklahoma. In their work in the late 1980s, they sought to take a wide range of factors into account: not only the construction of nuclear power plants, but also the resource requirements and environmental impacts of establishing, operating

[29] Thomson, Jonathan. 2020. „Nuclear power is clean – if you ignore all the waste. Compare the annual waste produced by a coal-burning power plant and a nuclear generating station." High Country News. 1 January, 2020. https://www.hcn.org/issues/52.1/nuclear-energy-nuclear-power-is-emissions-free-but-at-what-cost-waste

and dismantling transmission and distribution networks and energy storage infrastructure, as well as government and economic background work. These independent research papers claim that the net energy yield of nuclear power under adverse conditions can be negligible or even negative[30]. This is particularly thought-provoking in light of the fact that researchers have not taken sufficient account of one aspect (as there is no operational experience anywhere in the world), namely the hundreds of thousands of years[31] of waste disposal and the associated additional energy requirements.

In the early 1980s, Charles Hall, a researcher at New York State University, sought to incorporate the laws of the science of ecology into the world of energy management. He began his research by exploring the connections between the oil industry and then expanded it to other energy sources and technologies, including nuclear energy. Its concept focuses on energy extracted and invested throughout the life cycle (Energy Return On Energy Invested - EROEI or, according to other sources, Energy Returns on Investment - EROI). Its logical proposition is that the application of a technology makes sense in theory, if the amount of energy extracted is greater than the amount of energy invested (1:1), but in practice it is no longer fortunate, if the indicator falls below 5:1[32] - that is, five units of energy can be obtained from one unit of energy invested. It is interesting that in his writings he does not meet the topic of radioactive waste management and its energy demand, as if these were not included in the calculations on the merits. On the other hand, if the calculations of Tyner and his colleagues on nuclear energy published in the prestigious scientific journal "Energy" - mentioned in the previous paragraph - are placed in this system of relations, they write about 1:1 or even below of that.[33]

---

[30] Tyner, Gene, Robert Costanza, and Richard G. Fowler. 1988. "The net-energy yield of nuclear power." Energy 13, no. 1: 73–81. https://doi.org/10.1016/0360-5442(88)90080-1

[31] Kautsky, Ulrik, Peter Saetre, Sten Berglund, Ben Jaeschke, Sara Nordén, Jenny Brandefelt, Sven Keesmann, Jens-Ove Näslund, and Eva Andersson. 2016. "The impact of low and intermediate-level radioactive waste on humans and the environment over the next one hundred thousand years." Journal of Environmental Radioactivity 151, no. 2: 395–403. https://doi.org/10.1016/j.jenvrad.2015.06.025

[32] Hall, Charles A. S., Stephen Balogh, and David J.R. Murphy. 2009. "What is the Minimum EROI that a Sustainable Society Must Have?" Energies 2, no. 1: 25–47. https://doi.org/10.3390/en20100025

[33] Tyner, Gene, Robert Costanza, and Richard G. Fowler. 1988. "The net-energy yield of nuclear power." Energy 13, no. 1: 73–81. https://doi.org/10.1016/0360-5442(88)90080-1

The University of Sydney calculates that the EROI is around 5:1[34], disregarding the multi-million dollar waste disposal tasks and associated energy needs. What is important, however, is that researchers say, it is steadily deteriorating[35]. An interesting development is that many years later, some researchers published EROI values of around 60-70:1, which is much better than the results of independent research reports[36].

However, it quickly becomes clear that these only appear in the writings of organizations closely related to the nuclear energy sector, so their objectivity is at least questionable.

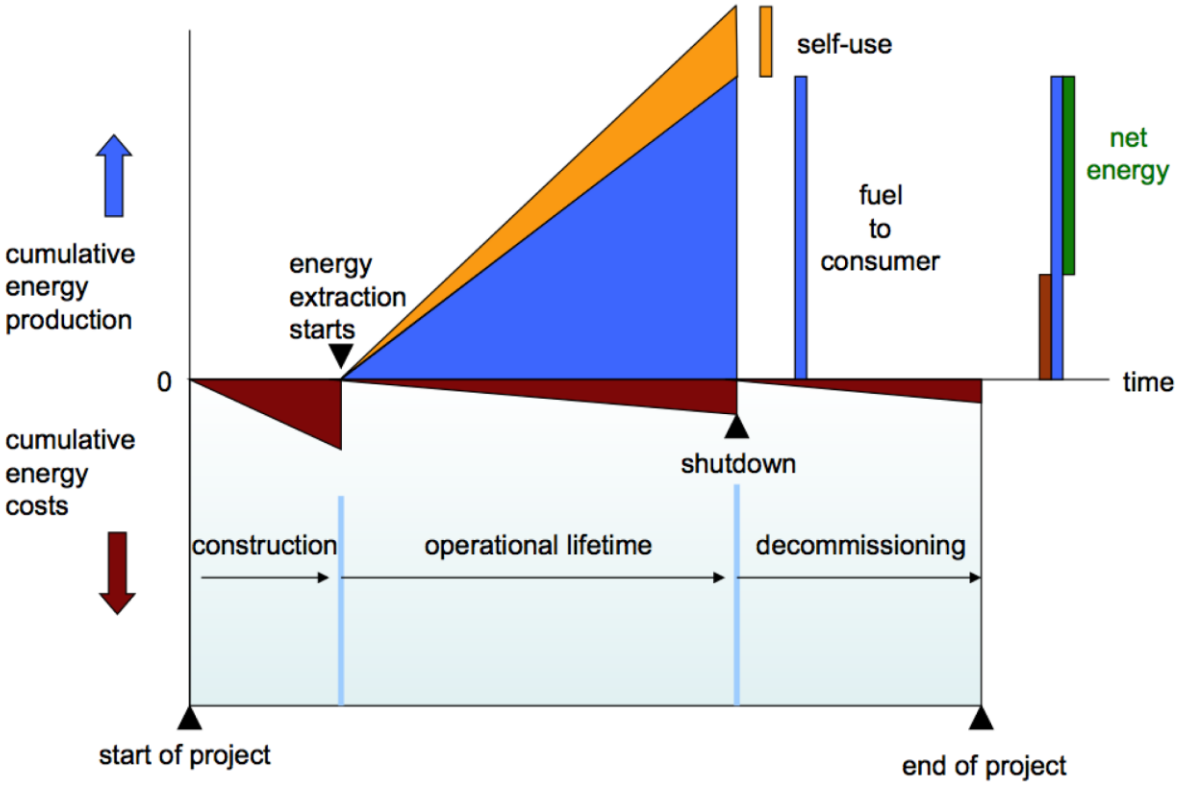

Figure 5: Calculation logic of the energy return indicator (EROI). The calculation must take into account all energy used and produced over the entire life cycle.[37]

[34] Lenzen, Manfred. 2008. "Life cycle energy and greenhouse gas emissions of nuclear energy: A review." Energy Conversion and Management 49, no. 8: 2178–99. https://doi.org/10.1016/j.enconman.2008.01.033

[35] Strom van Leeuwen, Jan Willem. 2006. "Secure energy: options for a safer world - Energy security and uranium reserves." https://www.files.ethz.ch/isn/91713/06-07%20Factsheet%204.pdf

[36] Weißbach, D., Ruprecht, G., Huke, A., Czerski, K., Gottlieb, S., & Hussein, A. 2013. "Energy intensities, EROIs (energy returned on invested), and energy payback times of electricity generating power plants." Energy 52: 210–221. https://doi.org/10.1016/j.energy.2013.01.029

[37] Cleveland, Cutler J., and Peter O'Connor. 2011. "Energy Return on Investment (EROI) of Oil Shale." Sustainability 3, no. 11: 2307–22. https://doi.org/10.3390/su3112307

6. THE OUTDATED NUCLEAR POWER PLANT PRODUCTION

> *"The idea of large power stations for baseload is outdated."*
>
> Steve Holliday, CEO, National Grid

Steve Holliday, director of electricity systems in the UK and New England, found it important in an interview to share his opinion[38] by saying that large base plants producing baseload power are now obsolete, because their inflexibility is a growing problem for the 21st century electricity system in which environmentally friendly weather-dependent generation plays a strenghtened role.

Different technologies work with different uses depending on the regulatory philosophy and natural endowments. The 20th century system management required high utilization for base power plants and low utilization for peak power plants. This is particularly evident in the case of nuclear energy, where values around 70-80% are typical, and, in the case of natural gas combustion (30-40%), which is mostly used to meet peak demand. Wind turbines and solar systems generate electricity depending on weather, as a result of technological development more and more efficiently.

The question may arise whether a higher capacity factor can be interpreted as a higher quality or a better indicator. Certainly not. A very high indicator shows much more inflexibility, which is a bigger problem in the energy system of the 21st century, than hindering the integration of cheap and clean weather-dependent technologies into the system, making it difficult to adapt to the ever-changing consumer demand. At the same time, the remarkably low value raises questions about financial and energy returns (see EROI).

---

[38] Beckman, Karel. 2015. "Steve Holliday, CEO National Grid: "The idea of large power stations for baseload is outdated." Energypost.eu, 11 September, 2015. https://energypost.eu/interview-steve-holliday-ceo-national-grid-idea-large-power-stations-baseload-power-outdated/

> *"The centralised model of power production is dying, to be replaced by local solar and wind, supplemented by batteries and intelligent management of supply and demand."*
>
> Mark Boillot, Vice-president of EDF

According to the vice-president of the French multinational electricity company[39], which operates 19 nuclear power plants, the centralized energy system can no longer be maintained for long. The future lies in decentralized generation based on solar and wind energy, where flexibility is provided by batteries and demand-side regulation based on information and communication technologies.

The centralized energy system is problematic from several aspects. On the one hand, the unexpected outage of a larger production unit can easily cause supply difficulties. In July and August 2020, 1,250 MW of nuclear power plant capacity was dropped from the Hungarian domestic production in three steps (Figure 6.), and the lost energy had to be replaced by imports.

In the case of decentralized production, the technical failure of units with a capacity of a few kW (or possibly MW) does not substantially cause a perceptible change in supply. In Denmark, where centralized generation has essentially ceased, with only medium-sized power plants operating at most, the best quality service on the European continent is provided to electricity consumers.

[39] electricity info. environmental news & information about the UK electricity supply industry. 2017. EDF. 20th February, 2017. https://electricityinfo.org/news/edf-20-2-17-2/

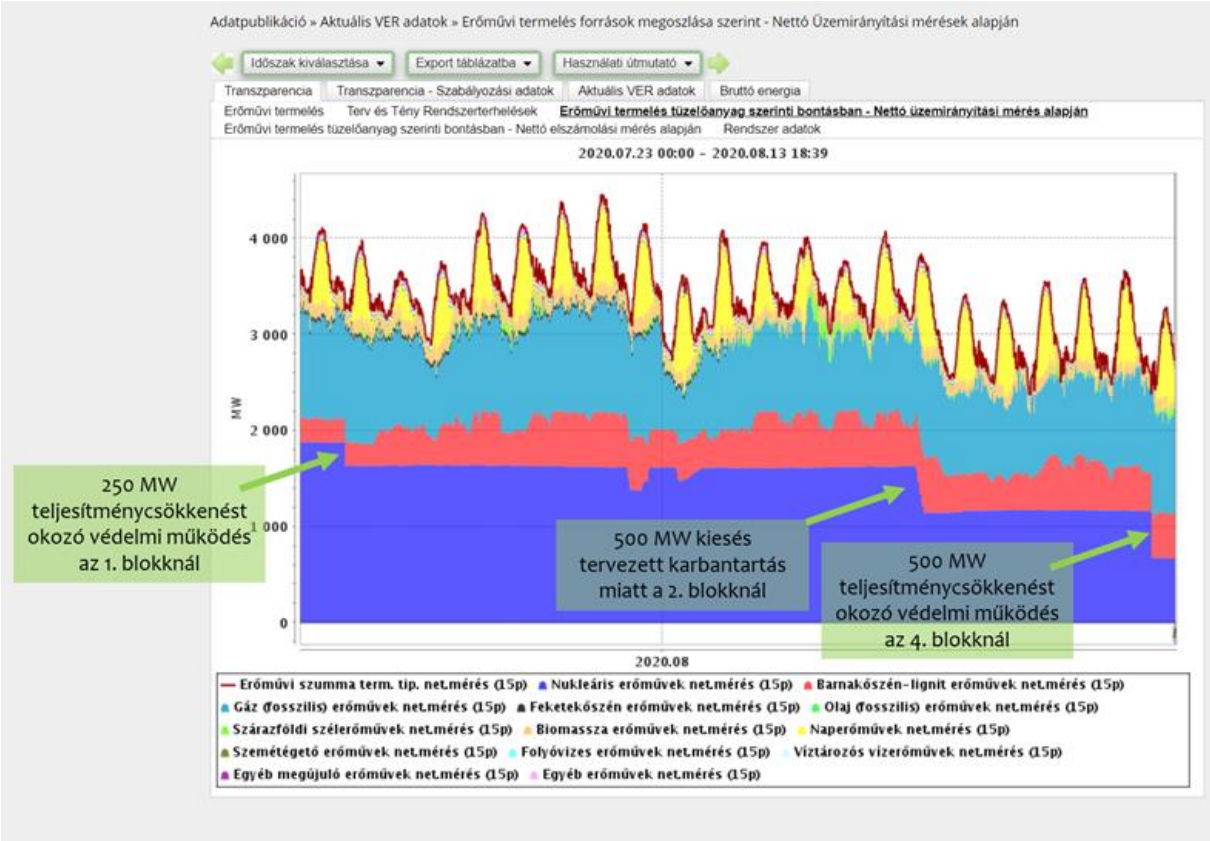

Figure 6: Distribution of domestic power plant production by sources between 23 July and 13 August 2020[40]. The unexpected outage of large nuclear power plant units is already causing great difficulties for the electricity system operator. Increasing the maximum output per unit to 240% - as planned in case of the Paks II entry - this problem will grow much worse.

On the other hand there is that the planned new Paks nuclear power plant units will no longer have an electrical capacity of 500 MW, but 1,200 MW, which will cause significantly greater problems in the supply of electricity to consumers in the event of a technical failure. Significantly increasing reactor capacity is also a concern from another related aspect. According to the Union for the Co-ordination of Transmission of Electricity (UCTE), the fast-start reserve power capacity of the electricity system must reach or exceed the capacity of the largest block in each member state.[41] If the Paks II project is implemented, this mandatory reserve will also increase to 1,200 MW, so such a fast-start power plant capacity will have to be created and operated. Its additional costs will be obviously passed on to the consumers or taxpayers.

---

[40] The figure was created using the MAVIR database. https://mavir.hu/web/mavir/eromuvi-termeles-forrasok-megoszlasa-szerint-netto-uzemiranyitasi-meresek-alapjan

[41] MVM gter. d.n. "Gas turbine power plants." http://www.gter.hu/bemutatkozas/tevekenyseg/gazturbinas-eromuvek/

Another problem is the significant transmission (network) and conversion (transformer) losses associated with the centralized system. The value of transmission loss (4,141 GWh) is equivalent to the power production of one of the reactors of the Paks nuclear power station (4,025 GWh).[42] Decentralization can radically reduce this problem. For example, the electricity generated by a household solar system typically does not travel huge distances with significant losses, in most cases it does not even gets till the end of the street or till the garden gate.

The worldwide decline of nuclear power is less noticeable in some countries, most notably in China and Russia. It is interesting that scientific literature[43] refers to these countries as centrally managed countries, directed by centrally planned instructions. This approach is contrasted with what the literature calls energy democracy, which means that energy production is decentralized, using environmentally friendly technologies, profit interests are secondary or irrelevant, and network usage rights are controlled by municipal energy providers, while social dialogue and the reconciliation of interests are also exercised[44]. Where economic rationality and the contribution of taxpayers are important factors, construction of nuclear power plants has stopped since the Chernobyl accident. At the same time, prosumer status is becoming more widespread, meaning that the proportion of consumers who are also connected to the electricity grid as a producer is growing rapidly. According to a scientific analysis[45], by 2030, 11 million families in Germany alone will be in this fortunate position, thus fully decentralizing electricity generation. If energy democracy could spread to a similar extent in other countries of the European Union, it would mean the involvement of some 50 million households as producers over a ten-year period.

The involvement of households in the field of energy storage also offers huge prospects, which is proved by nothing more than the fact that half of German solar customers also buy battery storage capacity as part of the system. Today, their average size is 8.2 kWh each. At the moment, ~200 thousand German families have such a system, which now means a

---

[42] MAVIR. 2017. 2017 data of the Hungarian electricity system (VER). https://erranet.org/wp-content/uploads/2016/11/Hungarian_Electricity_System_2017.pdf

[43] Mudd, Gavin M. 2014. "The future of Yellowcake: A global assessment of uranium resources and mining." Science of The Total Environment 472: 590–607. https://doi:10.1016/j.scitotenv.2013.11.070

[44] Antal, Attila: 2016. Environmental Democracy in Hungary. Doctoral dissertation. https://edit.elte.hu/xmlui/bitstream/handle/10831/33755/Disszertacio_Antal%20Attila.pdf?sequence=1

[45] Flaute, Markus, Anett Großmann, Christian Lutz, and Anne Nieters. 2017. "Macroeconomic Effects of Prosumer Households in Germany." International Journal of Energy Economics and Policy 7, no. 1: 146-55.

considerable storage capacity of ~1600 MWh[46]. This represents a significant income for German families in the long run and a very significant added value for society.

> *"Nuclear energy is hierarchical and anti-democratic by its very nature. The exact opposite holds true for sources of renewable energy, like the sun and the wind. Users of energy produced by a nuclear power plant have their electricity cut off if they fail to pay their bills. This cannot happen to people using electricity generated by the solar panels installed on the roofs of their houses. Solar energy makes people independent."*
>
> Ulrich Beck, sociologist

Ulrich Beck, the sociologist who created the concept of 'risk society'[47], says nuclear energy is hierarchical and anti-democratic by nature. The sharp opposite is true of renewable energies, such as the sun and wind. The user getting electricity from a nuclear power plant can be disconnected from the system at any time, if one does not pay the bill. This cannot happen to those who put solar panels on the roof of their house. Solar energy makes people independent.

Technological developments can affect our lives not only at the level of everyday life, but also affect the organization of society. Centralized and decentralized energy production systems can be thought of not only as technology, but as elements embedded in socio-technical systems, where infrastructure, producers and consumers are parts of the system. Although energy production methods do not determine social structures, so it is not clear and necessary what social structure the centralized and decentralized systems create, they interact with each other. Jeremy Rifkin[48] argues that energy regimes shape the nature of

---

[46] Colthorpe, Andy. 2020. *"Germany: Growth in home and industrial sectors but large-scale battery storage slowed down in 2019."* Energy Storage News. 7 December, 2020. https://www.energy-storage.news/news/germany-growth-in-home-and-industrial-sectors-but-large-scale-battery-stora

[47] Beck, Ulrich. 2011. *"Germany Is Right To Opt out of Nuclear Power."* Dissent Magazine. 30 July, 2011. https://www.dissentmagazine.org/online_articles/germany-is-right-to-opt-out-of-nuclear-power

[48] Rifkin, Jeremy. 2011. *The Third Industrial Revolution: How lateral power is transforming energy, the economy, and the world.* New York, NY: Palgrave Macmillan.

civilization — how people organize, how they exercise political power, how they shape social relationships.

According to Laurence Raineau[49], renewable energies are more than alternative energy sources: they are new social, economic, political projects. If energy supply is provided locally instead of a small number of central systems, we can get closer to self-sufficiency and move away from dependence on the system. Renewable energy sources can also have a centralizing effect, but their use really opens up the possibility of independence at the level of local communities, even in families. These projects provide an opportunity, and even encourage citizens to get organized at the local level and build relationships for their own energy supply.[50]

[49] Raineau, Laurence. 2011. "Vers une transition énergétique?" Natures Sciences Sociétés 19: 133-43. https://www.cairn.info/revue-natures-sciences-societes-2011-2-page-133.htm
[50] Yannick, Rumpala. 2018. "Alternative Forms of Energy Production and Political Reconfigurations: Exploring Alternative Energies as Potentialities of Collective Reorganization." Bulletin of Science, Technology & Society 37, no 2. https://doi.org/10.1177/0270467618766995

7. COSTS AND FINANCIAL RISKS OF NUCLEAR ENERGY

"Nuclear power is ridiculously expensive."

Nobuo Tanaka, former President of the International Energy Agency

The above quote appeared in 2018 in one of Japan's most renowned dailies, The Asahi Shimbun. In the article, the expert reports that nuclear energy is not financially able to compete with solar energy. They refer to a presentation by the former president of IEA, in which he described the construction and expansion of nuclear power plants as "amazingly uncompetitive"[51]. Tanaka's resolution is noteworthy because he is known to have been a board member of a company called Japan Atomic Industrial Forum for years as a supporter of the nuclear industry.

Of course, Tanaka's remark is not the only evidence of the decline of the nuclear industry. Companies that manufacture and operate nuclear reactors around the world have accumulated huge debts, filed for bankruptcy, or have just withdrawn from the nuclear industry citing cost-effectiveness considerations.

The German industrial giant, Siemens, played a significant role in the rise of nuclear power in the 1970s and 1980s. Siemens supplied all the reactors in Germany, but also exported them to Argentina, the Netherlands, Switzerland and Spain. However, after the Fukushima nuclear disaster, it decided to withdraw from the industry[52].

The US company Westinghouse filed for bankruptcy in 2017, which, in addition to the difficulties of the Japanese parent company, Toshiba, significantly overshadowed the vision of the nuclear industry. Westinghouse's financial problems can be originated partly from unprofitable deals, but partly also from general trends in energy, with the growing demand

---

[51] Fukushima-is-still-news.com. 2018. „Straight from the horse's mouth." 1 August, 2018. https://www.fukushima-is-still-news.com/2018/08/straight-from-the-horse-s-mouth/

[52] World Nuclear News. 2011. Siemens quits the nuclear game. 19 September, 2011. https://world-nuclear-news.org/Articles/Siemens-quits-the-nuclear-game

for alternative energy sources due to the more and more expensive nuclear energy. With the fall of Westinghouse, the number of manufacturing companies fell even further. As General Electric has reduced the number of its nuclear-related businesses, France's Areva has undergone a huge corporate restructuring. The rearrangements between the players in the nuclear industry may favor for the nuclear power 'sovereign', China, which also has a significant influence, but this raises security issues due to the country's political system[53].

In 2018, U.S. Vice President of Exelon said he sees no chance of building new nuclear reactors in the United States, because of their outstanding investment and operating costs. He also suggested that the units currently in operation could be converted to store energy coming from renewable sources, so there would be no need to build new ones. Nuclear energy would thus be just a bridge on the road to the carbon-neutral future. This is particularly notable in light of the fact that Exelon currently operates more than 20 reactors around the world[54].

---

[53] Cardwell, Diane, and Jonathan Soble. 2017. "Westinghouse Files for Bankruptcy, in Blow to Nuclear Power." The New York Times. 29th March, 2017. https://www.nytimes.com/2017/03/29/business/westinghouse-toshiba-nuclear-bankruptcy.html

[54] Lardieri, Alexa. 2018. "Exelon Official: No New Nuclear Plants To Be Built in the U.S." U.S. News. 16 April, 2018. https://www.usnews.com/news/national-news/articles/2018-04-16/exelon-official-no-new-nuclear-plants-to-be-built-in-the-us

Jandó, Zoltán. 2018. "It's too expensive, so no more nuclear power plants are being built in the world's largest nuclear power plant." G7. 19 April, 2018. https://g7.hu/vallalat/20180419/tul-draga-ezert-nem-epul-tobb-atomeromu-a-vilag-legnagyobb-atomhatalmaban/

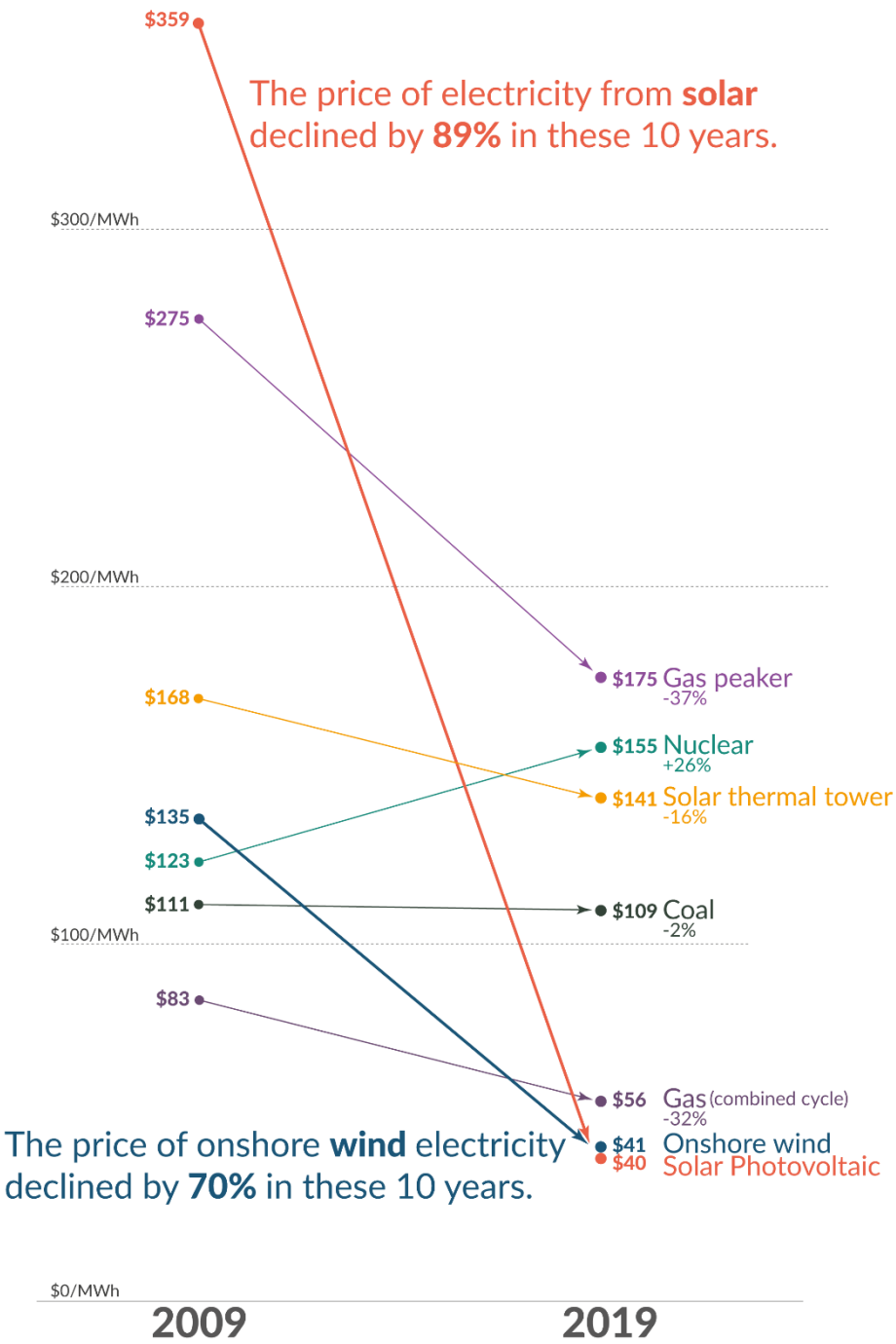

Figure 7: Change in the cost of electricity generation (LCOE) between 2009 and 2019[55]. The largest decreases (89%) are in solar cells and wind turbines (70%), which have become the cheapest production technologies in the world by now. Meanwhile, nowadays nuclear power has become essentially unaffordable.

[55] Roser, Max. 2020. "Why did renewables become so cheap so fast? And what can we do to use this global opportunity for green growth?" *Our World in Data*. 1 December, 2020. https://ourworldindata.org/cheap-renewables-growth

One of the main challenges related to the construction of a nuclear power plant is financing. The primary reason for this is the outstanding capital requirements, which affect all nuclear power plants, regardless of the mechanism and source of the investment. Other reasons include the long duration, as the construction of nuclear power plants is not a short process in itself, but it is necessary to calculate even higher costs due to the delays typical of the industry – as it can be seen in the case of Paks II.

In addition, account must be taken of the growing competitiveness of other forms of energy production available on the market, with which nuclear energy must compete on the deregulated electricity market. The Fukushima nuclear disaster brought with it one of the most significant declines in the nuclear industry, just as the more and more rigorous safety regulations have resulted in rising investment costs.

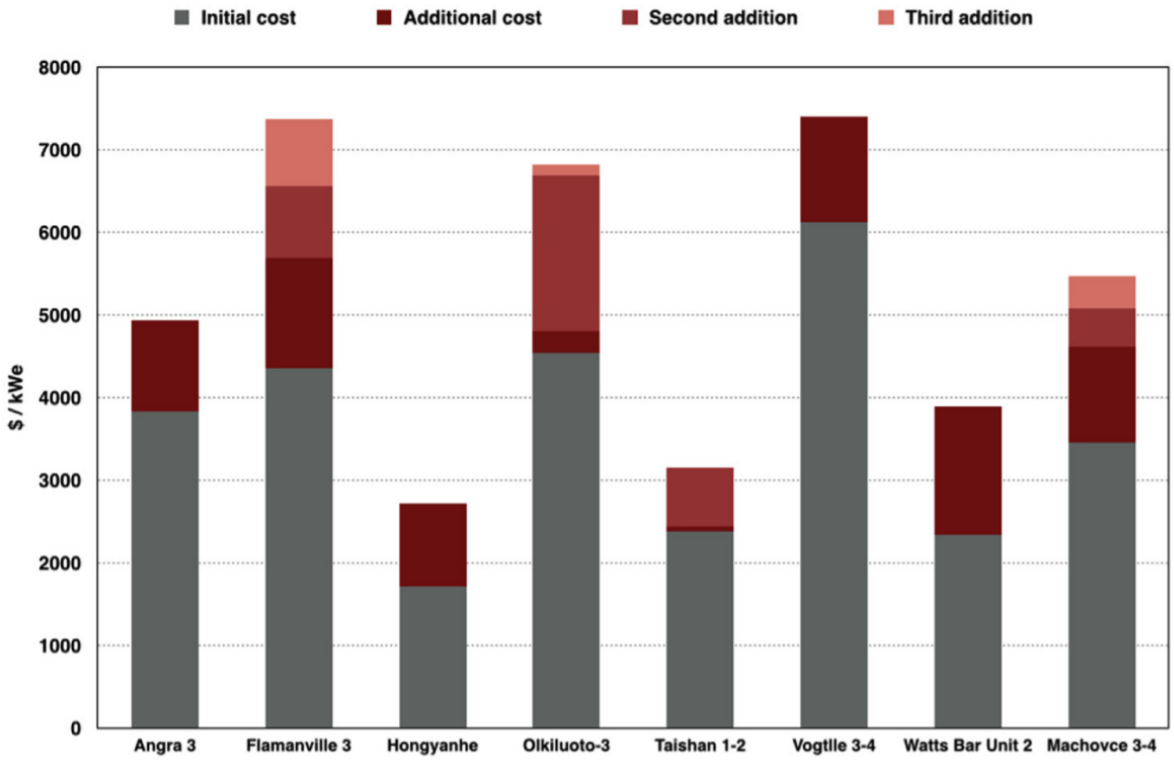

Figure 8: Rising costs of nuclear power plant investments.[56]

[56] Barkatullah, Nadira, and Ali Ahmad. 2017. "Current status and emerging trends in financing nuclear power projects." *Energy Strategy Reviews* 18: 127-40. https://doi.org/10.1016/j.esr.2017.09.015

The costs of nuclear power are usually broken down into capital costs and operating costs. Capital costs include site preparation, costs of permitting procedures, engineering work, manufacturing, construction, and commissioning. Operating costs include fuel costs (from uranium mining to fuel production), maintenance, decommissioning, and waste disposal. The capital costs of a nuclear power plant are much higher than that of other energy sources. The annual cost of repaying the initial investment is significantly higher than the annual operating cost.[57] In the case of the new Paks units, it is worth considering the costs in such a way that the only significant revenue from the project comes from the sale of electricity.[58] The basis for the debate on the returns on the project is the high price at which the electricity generated by Paks II is expected to be sold on the market and the level of utilization of the nuclear power plant. In government communication, we constantly come across the mantra of "cheap electricity" and the magic utilization of over 90%, which is usually refuted by domestic and international expert analyses and forecasts.

In the case of a nuclear power plant, three phases can be distinguished: the construction phase, the operation phase and the closing phase. In these three phases, different risks have to be considered.

Risks during the construction phase include delayed construction time, compliance with increasingly stringent legislation, modifications due to official and regulatory intervention, lack of construction routine, and contractor availability. Factors influencing returns can also be identified in the operational phase. These include risks related to operating and market sales, which are affected by the capacity utilization of the nuclear power plant and the sales opportunities of electricity. During the closing phase, there is a risk of decommissioning and disposing of spent fuel and other radioactive waste. The generation of the necessary amount for decommissioning and the financing of subsequent expenses are endangered by the possible bankruptcy of the power plant, a financial crisis or even the underestimation of the relevant expenses.[59]

---

[57] Iurshina, Daria, Nikita Karpov, Marie Kirkegaard, and Evgeny Semenov. "Why nuclear power plants cost so much—and what can be done about it." *Bulletin of Atomic Scientists*. 20June, 2019. https://thebulletin.org/2019/06/why-nuclear-power-plants-cost-so-much-and-what-can-be-done-about-it/

[58] Romhányi, Balázs. 2014. "Fiscal implications of the Paks II investment." https://energiaklub.hu/sites/default/files/a_paks_ii_beruhazas_koltsegvetes-politikai_kovetkezmenyei.pdf

[59] Regional Energy Economics Research Center. 2013. "Business models of nuclear power plant investments and their expected return." Workshop study. https://rekk.hu/downloads/projects/rekk_atom_megterules.pdf

If the nuclear power plant under construction is classified as FOAK (*first of a kind*), it means higher risk and therefore more expensive financing for investors. These risks are reduced when the nuclear technology used in a given nuclear power plant reaches the NOAK (*n^{th} of a kind*) rating, so more have already been built from that type. In the case of the 3+ generation nuclear reactors, which are also planned for Paks II, we can only talk about the FOAK indicator for the time being.

There are significant delays in Hungary compared to the official planned schedule. Despite the fact that in the government communication[60] the application for the establishment permit was scheduled for 2017, it was only in 2020 that Paks II Limited Liability Company submitted it to the National Nuclear Energy Agency,[61] which company is struggling with labour shortages. Furthermore, according to the Hungarian-Russian intergovernmental loan agreement, an availability fee must be paid for the undrawn amount, which also means a significant cost overrun.

They try to manage the risks of nuclear projects using different business models. The business model is a different combination of the ownership structure, financing method, contractual structure of the project and the related regulatory solutions. In some countries, state involvement can also be considered significant. There are several variations of each element of the different business models: we can talk about a concentrated or multi-stakeholder ownership structure, financing can take the form of corporate or project financing, public involvement can be reluctant or actively supportive, and the regulatory environment can be a fully liberalized or highly regulated market.[62]

Traditionally, policymakers have planned to finance the construction of nuclear power plants using public funds. However, the recent trend shows that governments around the world are increasingly looking for a solution in private investment, open to new financing approaches

---

[60] Aszódi, Attila. 2015. "Current status of the Paks investment." Lecture. Sustainable Development Committee, 13 May 2015, Budapest. https://www.parlament.hu/documents/129646/229814/Asz%C3%B3di+el%C5%91ad%C3%A1s/d7f414be-df0a-46d0-b4fa-6a259529fd24

[61] *portfolio.hu*. 2021. "Not enough people to license Paks II, wages are not competitive." 21 January, 2021 https://www.portfolio.hu/gazdasag/20210121/nincs-eleg-ember-paks-ii-engedelyezesehez-nem-versenykepes-a-berezes-466256

[62] Regional Energy Economics Research Center. 2013. "Business models of nuclear power plant investments and their expected return." Workshop study. https://rekk.hu/downloads/projects/rekk_atom_megterules.pdf

with different risk and ownership structures. The aim of this is to mitigate the huge and multi-layered financial risks and dangers associated with the establishment.[63]

Policy makers are increasingly seeking the private sector to co-finance new infrastructure investments, including large capital-intensive assets such as nuclear power plants. But why?

First of all, governments recognize (or should recognize) the need to prioritize social sector programs such as health and education. Thus, public resources are not sufficient for capital-intensive nuclear power plant investments. Secondly, governments recognize (or should recognize) that project beneficiaries must pay, not just taxpayers. Thirdly, governments recognize (or should recognize) that the private sector has the potential to generate greater incentives for innovation, design, construction, and operational efficiency and for the expertise based on market demand. This can be traced back to the principle that the "best value for money" prevails in the private sector.[64]

Balázs Felsmann, senior researcher at the Regional Energy Economics Research Center, said in connection with Paks II that "the risks are not primarily borne by the power plant, but by the taxpayers".[65] The reason for this is that the implementation of the Paks expansion is fully financed by the Hungarian state. The returns on the project depend in part on the price at which the energy produced by Paks II can be sold. If the free market price remains below the cost of production of Paks II, the resulting loss must be borne by the power plant, the Hungarian Electrical Works (Magyar Villamos Művek, MVM, the state-owned electricity trader and power producer) or the government. However, as both the Power Plant and MVM are state-owned and the loan for the project is taken up by the state itself, the ultimate risk bearer is entirely the taxpayer.

Under the intergovernmental loan agreement, Russia will provide Hungary with a state loan of EUR 10 billion to finance the expansion of the Paks Nuclear Power Plant. The loan can only be used for the design, construction and commissioning of the two new reactor units.

---

[63] Barkatullah, Nadira, and Ali Ahmad. 2017. "Current status and emerging trends in financing nuclear power projects." Energy Strategy Reviews, 18: 127-40. https://doi.org/10.1016/j.esr.2017.09.015
[64] Barkatullah, Nadira, and Ali Ahmad. 2017. "Current status and emerging trends in financing nuclear power projects." Energy Strategy Reviews 18: 127-40. https://doi.org/10.1016/j.esr.2017.09.015
[65] Atombusiness. 2017. "Opponents and supporters of the investment debated the issues of Paks enlargement." 16 November, 2017. http://atombusiness.hu/hirek/a-paksi-bovites-kerdeseirol-vitaztak-a-beruhazas-ellenzoi-es-tamogatoi

The loan agreement stipulates that Hungary will use the loan to finance 80% of the value of the works, services and equipment contract (EPC contract), while Hungary will cover 20% of the total amount of the EPC contract. The government has been arguing for years that the project does not involve state aid, but the European Commission's ruling that the project does involve state aid has not been challenged, but the government rather argued with a favorable loan structure. Energy management experts, on the other hand, criticized both the business model, more specifically state support, and the unfavourable terms of the loan agreement. The repayment period is 21 years, of which 25% in the first seven years, 35% in the second seven years and 40% in the third seven years must be paid at a steady rate of the total amount initially withdrawn. The interest rate is 3.95% until the investment is commissioned, but no later than 2026, and then 4.5%, 4.8% and 4.95% in seven-year cycles. Furthermore, the repayment of the loan must start when the power plant is put into production, but no later than in 2026, which could be a serious financial burden for Hungary due to the delays created in the project.[66]

Finally, from the point of view of the financing structure, the social support of the different technologies cannot be ignored either, as people would rather publically finance those that are less controversial. In many cases, it can also be observed that less social acceptance is compensated by corruption by the affected lobby group. In the case of nuclear energy, this is no different.

[66] Romhányi, Balázs. 2014. "Fiscal policy implications of the Paks II investment." https://energiaklub.hu/sites/default/files/a_paks_ii_beruhazas_koltsegvetes-politikai_kovetkezmenyei.pdf

> *"Gross corruption is evident in nuclear technology exporting countries such as Russia, China, and the United States, and in a number of nuclear technology importing countries... Widespread corruption of the nuclear industry has profound social and political consequences resulting from the corrosion of public trust in companies, governments, and energy systems themselves."*
>
> Richard Tanter, Professor at the University of Melbourne

In his writing, Richard Tanter, a Nobel Peace Prize-winning professor, states[67] that widespread corruption is well felt in countries that export nuclear technology, but also in many importing countries. The nuclear industry has long been unable to compete fairly in the energy sector with fair means, and has been using illegal solutions for decades. However, widespread corruption has serious social and political consequences. According to the study, one of the causes of the Fukushima tragedy was the intertwining relations between the authority and the industry players.

Last year also enters the history of nuclear power in black letters, due to an unprecendented corruption scandal uncovered in the United States. The bribery case over huge sums of money proved the involvement of high-ranking Republican politicians who, in exchange for bribes, helped weak projects by illegal means in nuclear power plant licensing procedures. The case provoked serious resentment in society that, according to analysts, led to the Democratic Party's victory in the concerned state (Ohio).

As one of the publications of Energiaklub reveals, Paks II investment also carries a high risk of corruption. According to the analysis carried out by the Corruption Research Center in Budapest, the nature of the project's large investment creates opaque systems of relations, which means higher corruption opportunities for the parties. This is compounded by the fact that almost all the essential elements of the project is made encrypted, which can also be interpreted as a reference to the appearance of corruption. According to domestic experience, the rate of the bribe can be set at 13-16% of the cost of investments made

---

[67] Tanter, Richard. 2013. „After Fukushima: A Survey of Corruption in the Global Nuclear Power Industry." Asian Perspective 37, no. 4: 475-500. http://www.jstor.org/stable/42704842

through corruption. In the case of the Paks project, this would mean a taxpayer loss of several hundred billion Hungarian forints.[68]

[68] Fazekas, Mihály - Főző, Zsolt – Tóth, István János. 2014. "Corruption Risks in Nuclear Power Plant Investments: What to Expect in the Case of Paks II?" https://energiaklub.hu/files/study/korrupcios_kockazatok_paksii.pdf

8. NUCLEAR ENERGY AS THE LAUNGE OF NUCLEAR ARMS RACE

> *"Every dollar spent on nuclear is one less dollar spent on clean, renewable energy and one more dollar spent on making the world a comparatively dirtier and a more dangerous place because nuclear power and nuclear weapons go hand in hand."*
>
> Mark Z. Jacobson, Professor at Stanford University

Stanford University's director of the Atmosphere and Energy Program draws attention[69] to the need to subsidize the use of renewable energy sources instead of subsidizing nuclear energy, as this would not only bring environmental benefits but also dispel the threat of nuclear war.

Nuclear energy is the antecedent of nuclear disarmament and the destructive nuclear war, as it is a precondition for the production of nuclear weapons. According to documented sources, humanity has drifted fifteen times to the immediate vicinity of a nuclear war[70]. But nuclear power plants are also linked to military conflicts in other ways. The power plant itself and its related infrastructure can become a target during military conflicts, which can also have unpredictable consequences. There have been at least eight such air strikes or other military attacks in the last three decades, mainly in the Middle East[71]. The underlying logic is obvious, as a successful offensive can have a number of benefits: on the one hand, obstructing the production of nuclear weapons; on the other hand, in a centralized energy system, paralyzing the supply of strategic electricity; and thirdly, the generation of radioactive contamination with serious consequences in the territory of the opponent's country. To prevent the above, countries with nuclear power plants are making significant efforts to protect the nuclear power plant facilities, which again raises the question from a

---

[69] Jacobson, Mark Z. 2010. "Nuclear power is too risky." CNN. 22 February, 2010. https://edition.cnn.com/2010/OPINION/02/22/jacobson.nuclear.power.con/index.html

[70] Tertrais, Bruno. 2017. "On The Brink"— Really? Revisiting Nuclear Close Calls Since 1945." The Washington Quarterly 40, no. 2: 51–66. https://doi.org/10.1080/0163660x.2017.1328922

[71] Sovacool, Benjamin K. 2011. Contesting the Future of Nuclear Power: A Critical Global Assessment of Atomic Energy. World Scientific Publishing Company. https://doi.org/10.1142/7895

taxpayer's point of view why power plants with such risks are needed, if the necessary electricity can be generated in other ways.

The relevance of all this in the case of Hungary is that the government intends to buy ground-to-air missiles in the near future, which, for example, would be installed next to the Paks nuclear power plant to ensure its protection.[72] The need to maintain the military air fleet can also be justified by the vulnerability of the Paks power plant.[73]

In addition to the possibility of a military attack, the growing problem of terrorism also highlights the fact that the centralized energy system, and one of its potential central elements, the nuclear power plant, is becoming less and less in line with security policy expectations. It is no coincidence that the governments of the countries that operate nuclear power plants are forced to spend huge sums on defense tasks in this regard - the bill, of course, once again paid by the taxpayers[74].

In connection with the 2001 American terrorist attack, it was revealed that the possibility and danger of the collision of large aircrafts had not yet been taken into account in the design of the Paks nuclear power plant[75]. Yet terrorist attacks, whether by armed means or in the form of similarly dangerous cyber-attacks, are becoming more frequent. In addition, the toolbox of attacks is constantly expanding, most notably in the last decade with the widespread use of drones. In the fall of 2014, drones flew over French nuclear facilities more than 30 times without identifying their owners. There were 57 similar intrusions[76] in the United States between 2015 and 2019, and further incidents were reported in late 2020[77]. In these cases, it is not only the drones themselves that are a cause for concern, but rather the

---

[72] hirado.hu. 2019. "State-of-the-art equipment makes up the new air defense system." 6 May, 2019. https://hirado.hu/belfold/belpolitika/cikk/2019/05/06/a-legkorszerubb-eszkozok-alkotjak-az-uj-legvedelmi-rendszert

[73] Horváth Csaba László. 2018. "Army fighters were alerted to the Paks nuclear power plant." 24.hu. 20 July, 2018. https://24.hu/belfold/2018/07/20/a-paksi-atomeromuhoz-riasztottak-a-honvedseg-vadaszgepeit/

[74] Parliamentary Office of Science and Technology. 2004. „Assessing the risk of terrorist attacks on nuclear facilities." https://www.parliament.uk/globalassets/documents/post/postpr222.pdf

[75] index.hu. 2001 "Paks' defenses have been strengthened." 10 October, 2001. https://index.hu/kulfold/pakseros/

[76] liteye.com. 2020. „Dozens More Mystery Drone Incursions Over U.S. Nuclear Power Plants Revealed." 8 September, 2020. https://liteye.com/dozens-more-mystery-drone-incursions-over-u-s-nuclear-power-plants-revealed/

[77] Hambling, David. 2020. „'Drone Swarm' Invaded Palo Verde Nuclear Power Plant Last September — Twice." forbes.com. 30 July, 2020. https://www.forbes.com/sites/davidhambling/2020/07/30/drone-swarm-invaded-palo-verde-nuclear-power-plant/?sh=6b071f8b43de

fact that the authorities responsible for safety have not been able to explain these cases or prevent flights.

However, this is not the most worrying phenomenon. Over a ten-year period, most of the thousands of attacks were aimed at obtaining radioactive materials, the consequences and dangers of which are very difficult to assess in the event of a terrorist attack.[78]

[78] Bunn, Matthew. 2010. „Securing the Bomb 2010." https://media.nti.org/pdfs/Securing_The_Bomb_2010.pdf

9. CLASSIFICATION AND MAKING DEBATES IMPOSSIBLE

„It is a fact that signing the extraordinary contract came as a surprise not only to the Hungarian people, but also to the Hungarian energy industry and even the government. It is also a fact that not only the preparation took place in secret, but all the data that would be needed to make a responsible judgment of the decision were encrypted for ten years."

László Sólyom, former President of the Republic of Hungary

The use of nuclear energy has always been the subject of heated debates, be they political, professional or social. However, in the case of the Paks expansion, the discussions were somewhat made impossible by the encryption of the data, as László Sólyom (former President of Hungary) points out in the above quote[79]. The debates can be traced back in part to the fact that the subject of these debates is both nuclear technology as a way of energy production and as a specific investment in a nuclear power plant. So the clash of different positions does not only take place in the professional circles, but in front of the public, with its involvement.

It is a misconception to see the issue of expansion as a purely technical decision. The use of nuclear energy clearly has environmental, economic, political and social implications, among other things. The use of nuclear energy in the energy mix does not help us to have a more sustainable future, it has huge investment costs, and it also endangers Hungary's future politically. Its impact on society is not negligible either, as we would be committed to a mode of energy production for at least half a century, thus narrowing our opportunities both on individual and collective levels. With all this in mind, we cannot leave the decision to a small circle of politicians or engineers, there must be a real social dialogue about it. Nevertheless, there are regular attempts by the Hungarian government to depoliticise, as they narrow down the number of participants in the decision-making and make essential pieces of information inaccessible. In the series of decisions related to the expansion of

[79] hvg.hu. 2014. „Sólyom raged against the government." 18 February, 2014. https://hvg.hu/gazdasag/20140218_Solyom_kemenyen_kikelt_a_hatalom_ellen

Paks, neither political nor professional deliberation, nor even the participation of society can be considered adequate.

Criticisms of the quality of decision-making processes can be partly attributed to the fact that, from the basic research to the Hungarian-Russian treaties, their content is not available to the public. So the citizen cannot get to know how decisions are made that have such diverse and serious consequences and implications. This fact makes it impossible to take an informed decision, even for those who would be more able to take into account the complexity of the issue due to their expertise or interest.

Politicians and organizations have filed a number of lawsuits since the 2000s seeking data. The court proceedings were based on the refusal to publish and disclose data and information of public interest. The courts must conduct these lawsuits out of turn and the data controller must prove the lawfulness of the refusal. However, these two principles have been regularly violated in recent decades. Clairvoyance is also made more difficult by the fact that the required data takes several years to litigate, so that they may no longer be relevant by then. This was the case, for example, after the 2003 accident at the Paks nuclear power plant, which was considered serious by international standards.

Restrictions on the disclosure of data began with the Teller project, launched in 2007, and the Lévai project, established in 2009, to assess the need for and various effects of the expansion. Even in the case of these projects, it took several years of litigation to access the information, and the court had to repeatedly call on MVM to release the data in its possession. However, on the basis of the published parts, not only were the inconsistencies not clarified, but the need to increase the capacity of the nuclear power plant was not substantiated.

In connection with the expansion of the Paks Nuclear Power Plant, it is not only the unavailability of information that makes informed decision-making impossible. The vote of the Parliament's provisional acceptance in 2009, despite the overwhelming majority of votes, provoked resentment from some deputies, such as “neither the Turks nor the Tatars will drive us on this issue. There could have been time for a correct analysis and calculation of what kind of energy we want to use, to what extent and at what price, and not to fool MPs with the ‘cheap nuclear power’ blah-blah. The provisional acceptance of the National Assembly consists of only one paragraph, and there was unusually little time to discuss it. The MPs who took part in the vote did not even know how many reactors the decision was

made about (would it be possible to expand the nuclear power plant with reactors 5 or 6?), and who was the beneficiary. It was not even made clear whether they give permission for the preparation for the expansion or for the expansion itself. Concerning the controversial political support for expansion and the unnecessary nature of political debates, we have heard regularly from the government in recent years that the 2009 provisional acceptanc laid the foundations for the “Paks Pact”.

The refusal to disclose data continued with the Hungarian-Russian agreements concluded in 2014. These included the construction of two new reactors by the state-owned company Rosatom and the provision of a EUR 10 billion Russian state loan. The January agreement came as a surprise to oliticiansp, experts and citizens alike, as neither parliamentary deliberation nor a tender preceeded the signing of Lászlóné Németh's (the Minister of Development) contract in Moscow. Imre Mártha, the former CEO of MVM, said that "the contract, to put it mildly, was decided over a coffee."[80]

In order to make the details of the treaties public, several politicians took the fight to justice, with limited success. The so-called ’Project Act’, also known as the ’Paks Secrecy Act’, was passed by the Parliament in 2015, according to which the Paks II project-related data were encrypted for thirty years. It has been stated that data the disclosure of which would infringe a national security interest or an intellectual property right in the course of a request for data in the public interest may be encrypted for a period of thirty years from the date of their creation. A quarter of the MPs turned to the Hungarian Constitutional Court after the enactment of the Secrecy Act, proposing an ex-post norm control. They requested that the Constitutional Court examine whether the thirty-year restriction on access to “technical and business data related to the investment and the data used to substantiate related decisions” was compatible with Hungary's Constitution for reasons of national security. The Constitutional Court made its decision six years later and stated that the protection of national security interests and intellectual property rights could justify restricting the disclosure of public interest data, encrypting it for thirty years. The partial failure of the legal struggles means that today information about the expansion of Paks is still unknown in Hungary, so there is still no opportunity for society to form well-founded opinions and decisions.

---

[80] Ökopolisz Alapítvány. 2017. „Paks II – The business of the century – but for whom?” Ökopódium, Budapest. 16 November, 2017.
https://www.youtube.com/watch?v=6zOX40eTs4U&ab_channel=%C3%96kopoliszAlap%C3%ADtv%C3%A1ny

The government's depoliticization of the issue of Paks expansion also implies that society does not really need the opportunity for informed decision-making. Although, in accordance with the Espoo Convention, the government held local and international public hearings, neither the county seats nor the capital considered it necessary to involve local citizens to hear their questions and objections. The decision to use nuclear energy through a referendum is also rejected with the reason that society is unable to form an opinion on such a complex technical-technological issue.

It is true that nuclear power plant investments cannot be decided only through a referendum, yet we can see examples of this type of decision-making around the world. In Italy, nuclear energy was rejected in several referendums: first after the Chernobyl nuclear disaster, and in 2011 for the second time. Switzerland also ruled in a referendum to ban the extension of the life of existing nuclear reactors, and also their National Energy Strategy to 2050 stated that the country would not invest in additional reactors. Spain, Sweden, Bulgaria and Lithuania also asked society about nuclear power generation, and Poland rejected the admission of a new facility in a local referendum as well.[81]

[81] Sarlós, Gábor. 2014, „Miért kell, ha lehet nem is?" Magyar Narancs. 11 October, 2014. https://magyarnarancs.hu/publicisztika/miert-kell-ha-nem-lehet-is-91666

10. CLOSING THOUGHTS

Since the advent of the Industrial Revolution, the world has been constantly in the fever of "energy transition," that is, the transformation of the energy system. As an element of this, the source structure of energy consumption changes from time to time. In the 1700s, the dominance of animal and human muscle power was taken over by wood burning. The 1800s were characterized by an increasingly pronounced appearance of coal-fired power, and then by the end of the century its dominance. In the first half of the 1900s, an increase in the use of crude oil and in the second half, a rise in the use of natural gas was observed. In the 1950s, however, many felt or realized that the centuries-long transformation had come to a standstill as nuclear power emerged, which some claimed would be so cheaply available that it would not even be necessary to install meters. However, the 70-year history of nuclear power has come as another surprise. It has been shown that this technology, as opposed to the generally observed regularity, is not becoming cheaper and more accessible; moreover, on the contrary, it produces at an unaffordable price today, so as things stand, it will disappear in the depths of the history of energy management within a few decades.

If we look for the causes, we must first of all mention the astonishingly irresponsible practices of the last decades, which have been observed in connection with radioactivity in general, but radioactive waste in particular. Construction and operating costs, for example, could be slashed by saving a good portion of the cooling system.
Indeed, in the Soviet Union, without caring about the consequences, the river water was discharged directly into the reactor core, and then the cooling water that had become radioactive was simply discharged back into the river or the nearby lake. But at least as shocking is the practice of disposing of waste as tossing barrels full of spent fuel into the sea - as was the general practice around the world until 1993.

By fully neglecting the environmental, health and ecological aspects, it was of course possible to produce electricity cheaply, but only in the short term. Sooner or later but someone has to bear the costs and damages. In the 21st century, the population of developed economies will no longer accept the former irresponsible attitudes and practices. However, the drive for safe and environmentally friendly production has raised the cost of nuclear power generation beyond imagination - all at a time when an army of increasingly cheap renewable energy technologies has emerged on the stage. Thus, the process of energy transition has not stopped, European statistics of recent years clearly show the direction of change, as the share of renewable generation units, mainly solar and wind power, in new capacities has been above 90% for several years now. Of course, this will require other

radical changes to ensure the reliable operation of the energy system. Above all, there is a need for a change of approach: in addition to the technical aspects, the social and environmental aspects, as well as the disciplines that represent them, must also play a role in energy planning and energy management. But even within a narrowly defined energy system, a turnaround is needed. For example, the current staggeringly low energy efficiency of just a few percent life cycle is certainly not acceptable, but the challenge of the weather dependence of solar and wind energy must also be tackled. At the same time, research and international practice prove that there are no technical barriers to this new direction of development. The problem is much more that we have very little time left for the transformation, because in the last 250 years - mainly through faulty energy management practices - we have put the ultimate burden on the ecosystem, thus bringing it to the brink of collapse. We must therefore devote material and human resources to strengthening the sustainable energy system as soon as possible. Every forint, euro and yuan spent on nuclear energy is holding back and hindering this transformation.

"With low-cost renewable energy based electricity in place in 2030 a parallel rapid transition and re-design of the national energy systems will be feasible, using a smart energy system approach combining electricity with energy efficient buildings, district heating, electrified transport and industry, as well as energy storage. We provide a deep understanding of the technical solution; decision makers now need to re-design the energy markets for the re-designed energy systems."

Brian Vad Mathiesen

Brian Vad Mathiesen, one of the world's most influential engineers[82] specializes in rapid energy transition and its feasibility. In his work he proves - with a multidisciplinary approach, but still with a strong technical foundation - that a 100% renewable energy system is not simply one of the many possible directions, but obviously the best solution from the economic, social and environmental points of view.

[82] According to "ISI Highly Cited (http://isihighlycited.com) he was ranked as one of the world's leading engineers in 2015 and 2016.

BIBLIOGRAPHY

Adapt Consulting AS. 2013. "Conversion Factors for Electricity in Energy Policy." 2013. február 15. https://www.energinorge.no/contentassets/e86a4dc8771845dfb03fee35c1d0f45d/2013-02-15--conversion-factors-for-electricity.pdf

Antal Attila. 2016. Környezeti demokrácia Magyarországon. Doktori értekezés. https://edit.elte.hu/xmlui/bitstream/handle/10831/33755/Disszertacio_Antal%20Attila.pdf?sequence=1

Aszódi Attila. 2015. "A paksi beruházás aktuális helyzete." Előadás. Fenntartható Fejlődés Bizottság, 2015. május 13., Budapest. https://www.parlament.hu/documents/129646/229814/Asz%C3%B3di+el%C5%91ad%C3%A1s/d7f414be-df0a-46d0-b4fa-6a259529fd24

Atombusiness. 2017. "A paksi bővítés kérdéseiről vitáztak a beruházás ellenzői és támogatói."2017. november 16. http://atombusiness.hu/hirek/a-paksi-bovites-kerdeseirol-vitaztak-a-beruhazas-ellenzoi-es-tamogatoi

Atomerőmű. n.d. Ideiglenes tárolás. http://www.atomeromu.hu/hu/Documents/Ideiglenes_tarolastol_a_vegleges_elhelyezesig.pdf

https://mavir.hu/web/mavir/eromuvi-termeles-forrasok-megoszlasa-szerint-netto-uzemiranyitasi-meresek-alapjan

Barkatullah, Nadira and Ali Ahmad. 2017. "Current status and emerging trends in financing nuclear power projects." *Energy Strategy Reviews* 18: 127-40. https://doi.org/10.1016/j.esr.2017.09.015

Beck, Ulrich. 2011. "Germany Is Right To Opt out of Nuclear Power." *Dissent Magazine*. 2011. július 30. https://www.dissentmagazine.org/online_articles/germany-is-right-to-opt-out-of-nuclear-power

Bunn, Matthew. 2010. „Securing the Bomb 2010." https://media.nti.org/pdfs/Securing_The_Bomb_2010.pdf

Cardwell, Diane and Jonathan Soble. 2017. "Westinghouse Files for Bankruptcy, in Blow to Nuclear Power." *The New York Times*. 2017. március 29. https://www.nytimes.com/2017/03/29/business/westinghouse-toshiba-nuclear-bankruptcy.html

Centers for Disease Control and Prevention. 2000. “Worker Health Summaries.” https://www.cdc.gov/niosh/pgms/worknotify/uranium.html

Cleveland, Cutler J., and Peter O’Connor. 2011. “Energy Return on Investment (EROI) of Oil Shale.” *Sustainability* 3, no. 11: 2307–22. https://doi.org/10.3390/su3112307

Coelho, Carlos, and Kristina Foltynova. 2020. “Everything You Need To Know About Novichok.” 2020. november 23. https://www.rferl.org/a/everything-you-need-to-know-about-novichok/30964840.html

Colthorpe, Andy. 2020. “Germany: Growth in home and industrial sectors but large-scale battery storage slowed down in 2019.” *Energy Storage News*. 2020. december 7. https://www.energy-storage.news/news/germany-growth-in-home-and-industrial-sectors-but-large-scale-battery-stora

Council on Foreign Relations. d.n. “Conflict in Ukraine.” https://www.cfr.org/global-conflict-tracker/conflict/conflict-ukraine

EIA. 2019. “Germany announces proposal to phase out coal by 2038, further changing its generation mix.” 2019. május 29. https://www.eia.gov/todayinenergy/detail.php?id=39652

electricity info. environmental news & information about the UK electricity supply industry. 2017. EDF. 2017. feburár 20. https://electricityinfo.org/news/edf-20-2-17-2/

Eriksson, Ola. 2017. “Nuclear Power and Resource Efficiency—A Proposal for a Revised Primary Energy Factor.” *Sustainability* 9, no. 6: 1063. https://doi.org/10.3390/su9061063

Fazekas Mihály, Főző Zsolt, Tóth István János. 2014. „Az atomerőmű-beruházások korrupciós kockázatai: Mire számíthatunk Paks II esetében?” https://energiaklub.hu/files/study/korrupcios_kockazatok_paksii.pdf

Flaute, Markus, Anett Großmann, Christian Lutz, and Anne Nieters. 2017. “Macroeconomic Effects of Prosumer Households in Germany.” *International Journal of Energy Economics and Policy* 7, no. 1: 146-55.

Fukushima-is-still-news.com. 2018. „Straight from the horse’s mouth.” 2018. augusztus 1. https://www.fukushima-is-still-news.com/2018/08/straight-from-the-horse-s-mouth/

Gray, Richard. 2019. “The true toll of the Chernobyl disaster.” *BBC*. 2019. július 26. https://www.bbc.com/future/article/20190725-will-we-ever-know-chernobyls-true-death-toll

Hall, Charles A. S., Stephen Balogh, and David J.R. Murphy. 2009. "What is the Minimum EROI that a Sustainable Society Must Have?" *Energies* 2, no. 1: 25–47. https://doi.org/10.3390/en20100025

Hambling, David. 2020. „'Drone Swarm' Invaded Palo Verde Nuclear Power Plant Last September — Twice." *forbes.com*. 2020. július 30. https://www.forbes.com/sites/davidhambling/2020/07/30/drone-swarm-invaded-palo-verde-nuclear-power-plant/?sh=6b071f8b43de

hirado.hu. 2019. „A legkorszerűbb eszközök alkotják az új légvédelmi rendszert." 2019. május 6. https://hirado.hu/belfold/belpolitika/cikk/2019/05/06/a-legkorszerubb-eszkozok-alkotjak-az-uj-legvedelmi-rendszert

Horváth Csaba László. 2018. „A paksi atomerőműhöz riasztották a honvédség vadászgépeit." 24.hu. 2018. július 20. https://24.hu/belfold/2018/07/20/a-paksi-atomeromuhoz-riasztottak-a-honvedseg-vadaszgepeit/

Human Rights Watch. 2020. "Russia. Events of 2019." https://www.hrw.org/world-report/2020/country-chapters/russia#

hvg.hu. 2014. „Sólyom keményen kikelt a kormány ellen." 2014. február 18. https://hvg.hu/gazdasag/20140218_Solyom_kemenyen_kikelt_a_hatalom_ellen

IDA. 2006. "The Danish Society of Engineers' Energy Plan 2030." http://www.fritnorden.dk/NF2007/Energyplan2030.pdf

IDA. 2015. "IDA's energy vision 2050. A Smart Energy System strategy for 100% renewable Denmark." https://vbn.aau.dk/ws/portalfiles/portal/222230514/Main_Report_IDAs_Energy_Vision_2050.pdf

IEA. 2016. "Re-powering Markets." https://www.iea.org/reports/re-powering-markets

index.hu. 2001. „Megerősítették Paks védelmét." 2001. október 10. https://index.hu/kulfold/pakseros/

Innovációs és Technológiai Minisztérium. 2020. "Nemzeti Energia- és Klímaterv 2020." https://ec.europa.eu/energy/sites/ener/files/documents/hu_final_necp_main_hu.pdf

Iurshina, Daria, Nikita Karpov, Marie Kirkegaard, and Evgeny Semenov. "Why nuclear power plants cost so much—and what can be done about it." *Bulletin of Atomic Scientists*. 2019. június 20. https://thebulletin.org/2019/06/why-nuclear-power-plants-cost-so-much-and-what-can-be-done-about-it/

Jacobson, Mark Z. 2010. “Nuclear power is too risky.” *CNN*. 2010. február 22. https://edition.cnn.com/2010/OPINION/02/22/jacobson.nuclear.power.con/index.html

Jandó Zoltán. 2018. “Túl drága, ezért nem épül több atomerőmű a világ legnagyobb atomhatalmában.” *G7*. 2018. április 19. https://g7.hu/vallalat/20180419/tul-draga-ezert-nem-epul-tobb-atomeromu-a-vilag-legnagyobb-atomhatalmaban/

Beckman, Karel. 2015. “Steve Holliday, CEO National Grid: “The idea of large power stations for baseload is outdated.” *Energypost.eu*, 2015. szeptember 11. https://energypost.eu/interview-steve-holliday-ceo-national-grid-idea-large-power-stations-baseload-power-outdated/

Kautsky, Ulrik, Peter Saetre, Sten Berglund, Ben Jaeschke, Sara Nordén, Jenny Brandefelt, Sven Keesmann, Jens-Ove Näslund, and Eva Andersson. 2016. “The impact of low and intermediate-level radioactive waste on humans and the environment over the next one hundred thousand years.” *Journal of Environmental Radioactivity* 151, no. 2: 395–403. https://doi.org/10.1016/j.jenvrad.2015.06.025

kernd.de. n.d. “Nuclear Power Plants in Germany.” https://www.kernd.de/kernd-en/nuclear-power/npps-germany/

Lardieri, Alexa. 2018. “Exelon Official: No New Nuclear Plants To Be Built in the U.S.” *U.S. News*. 2018. április 16. https://www.usnews.com/news/national-news/articles/2018-04-16/exelon-official-no-new-nuclear-plants-to-be-built-in-the-us

Lenzen, Manfred. 2008. “Life cycle energy and greenhouse gas emissions of nuclear energy: A review.” *Energy Conversion and Management* 49, no. 8: 2178–99. https://doi.org/10.1016/j.enconman.2008.01.033

Lewis, Robert. d.n. “Kyshtym disaster.” *Britannica.com*. https://www.britannica.com/event/Kyshtym-disaster

liteye.com. 2020. „Dozens More Mystery Drone Incursions Over U.S. Nuclear Power Plants Revealed.” 2020. szeptember 8. https://liteye.com/dozens-more-mystery-drone-incursions-over-u-s-nuclear-power-plants-revealed/

MAVIR. 2017. A magyar villamosenergia-rendszer (VER) 2017. évi adatai. https://erranet.org/wp-content/uploads/2016/11/Hungarian_Electricity_System_2017.pdf

Mudd, Gavin M. 2014. “The future of Yellowcake: A global assessment of uranium resources and mining.” *Science of The Total Environment* 472: 590–607. https://doi:10.1016/j.scitotenv.2013.11.070

Munkácsy Béla (szerk.) 2011. “Erre van előre - Egy fenntartható energiarendszer keretei Magyarországon.” https://edit.elte.hu/xmlui/handle/10831/51512

MVM gter. n.d. “Gázturbinás erőművek.” http://www.gter.hu/bemutatkozas/tevekenyseg/gazturbinas-eromuvek/

Országos Atomenergia Hivatal. n.d. “Közérthető összefoglaló a Kiégett Kazetták Átmeneti Tárolója üzemeltetési engedélyének módosításáról.” http://www.haea.gov.hu/web/v3/oahportal.nsf/B6A5660AF889CD35C1257CBE002A41ED/$FILE/KK%C3%81T%20RHK%20%C3%B6sszefoglal%C3%B3.pdf

Ökopolisz Alapítvány. 2017. „Paks II. - az évszázad üzlete, de kinek? - Ökopódium, Budapest, 2017. november 16. https://www.youtube.com/watch?v=6zOX40eTs4U&ab_channel=%C3%96kopoliszAlap%C3%ADtv%C3%A1ny

Parliamentary Office of Science and Technology. 2004. „Assessing the risk of terrorist attacks on nuclear facilities.” https://www.parliament.uk/globalassets/documents/post/postpr222.pdf

Pór Gábor. 2012. *Atomenergetikai alapismeretek*. Edutus Főiskola. https://regi.tankonyvtar.hu/hu/tartalom/tamop412A/2010-0017_61_atomenergetikai_alapismeretek/ch04.html

portfolio.hu. 2021. “Nincs elég ember Paks II engedélyezéséhez, nem versenyképes a bérezés.” 2021. január 21. https://www.portfolio.hu/gazdasag/20210121/nincs-eleg-ember-paks-ii-engedelyezesehez-nem-versenykepes-a-berezes-466256

Raineau, Laurence. 2011. “Vers une transition énergétique?” *Natures Sciences Sociétés* 19: 133-43. https://www.cairn.info/revue-natures-sciences-societes-2011-2-page-133.htm

Regionális Energiagazdasági Kutatóközpont. 2013. “Atomerőművi beruházások üzleti modelljei és várható megtérülésük.” Műhelytanulmány. https://rekk.hu/downloads/projects/rekk_atom_megterules.pdf

REN21.2020. “Renewables 2020 Global Status Report.” https://www.ren21.net/wp-content/uploads/2019/05/gsr_2020_full_report_en.pdf

Reuters. 2019. “Spain plans to close all nuclear plants by 2035.” 2019. február 13. https://www.reuters.com/article/us-spain-energy-idUSKCN1Q212W

Rifkin, Jeremy. 2011. *The Third Industrial Revolution: How lateral power is transforming energy, the economy, and the world*. New York, NY: Palgrave Macmillan.

Romhányi Balázs. 2014. “A Paks II beruházás költségvetés-politikai következményei.” https://energiaklub.hu/sites/default/files/a_paks_ii_beruhazas_koltsegvetes-politikai_kovetkezmenyei.pdf

Roser, Max. 2020. “Why did renewables become so cheap so fast? And what can we do to use this global opportunity for green growth?” *Our World in Data*. 2020. december 1. https://ourworldindata.org/cheap-renewables-growth

Sarlós Gábor. 2014, „Miért kell, ha lehet nem is?” *Magyar Narancs*. 2014. október 11. https://magyarnarancs.hu/publicisztika/miert-kell-ha-nem-lehet-is-91666

Schneider, Mycle et al. 2020. “World Nuclear Industry Status Report.” https://www.worldnuclearreport.org/

Sovacool, Benjamin K. 2011. *Contesting the Future of Nuclear Power: A Critical Global Assessment of Atomic Energy*. World Scientific Publishing Company. https://doi.org/10.1142/7895

Strom van Leeuwen, Jan Willem. 2006. “Secure energy: options for a safer world - Energy security and uranium reserves.” https://www.files.ethz.ch/isn/91713/06-07%20Factsheet%204.pdf

Strom van Leeuwen, Jan Willem. 2006. “Secure energy: options for a safer world - Energy security and uranium reserves.” https://www.files.ethz.ch/isn/91713/06-07%20Factsheet%204.pdf

Strom van Leeuwen, Jan Willem. 2016. “Nuclear power in its Global Context.” *Geographical Locality Studies* 4, no. 1: 726-87. https://www.stormsmith.nl/Resources/TYPESET_GLS4_Paper-1.pdf

Tanter, Richard. 2013. **„After Fukushima: A Survey of Corruption in the Global Nuclear Power Industry.”** *Asian Perspective* 37, no. 4: 475-500. http://www.jstor.org/stable/42704842

Tertrais, Bruno. 2017. “On The Brink”—Really? Revisiting Nuclear Close Calls Since 1945.” *The Washington Quarterly* 40, no. 2: 51–66. https://doi.org/10.1080/0163660x.2017.1328922

The Brussels Times. 2019. “Belgium closes down its nuclear plants by 2025.” 2019. október 29. https://www.brusselstimes.com/belgium/76210/no-clarity-on-alternatives-for-belgian-nuclear-plants/

The Guardian. 2011. “Nuclear power plant accidents: listed and ranked since 1952.” 2011. március 14. https://www.theguardian.com/news/datablog/2011/mar/14/nuclear-power-plant-accidents-list-rank

Thomson, Jonathan. 2020. „Nuclear power is clean – if you ignore all the waste. Compare the annual waste produced by a coal-burning power plant and a nuclear generating station.” *High Country News*. 2020. január 1.https://www.hcn.org/issues/52.1/nuclear-energy-nuclear-power-is-emissions-free-but-at-what-cost-waste

Tyner, Gene, Robert Costanza, and Richard G. Fowler. 1988. “The net-energy yield of nuclear power.” *Energy* 13, no. 1: 73–81. https://doi.org/10.1016/0360-5442(88)90080-1

Tyner, Gene, Robert Costanza, and Richard G. Fowler. 1988. “The net-energy yield of nuclear power.” *Energy* 13, no. 1: 73–81. https://doi.org/10.1016/0360-5442(88)90080-1

Weißbach, D., Ruprecht, G., Huke, A., Czerski, K., Gottlieb, S., & Hussein, A. 2013. “Energy intensities, EROIs (energy returned on invested), and energy payback times of electricity generating power plants.” *Energy* 52: 210–221. https://doi.org/10.1016/j.energy.2013.01.029

World Nuclear News. 2011. Siemens quits the nuclear game. 2011. szeptember 19. https://world-nuclear-news.org/Articles/Siemens-quits-the-nuclear-game

Yannick, Rumpala. 2018. “Alternative Forms of Energy Production and Political Reconfigurations: Exploring Alternative Energies as Potentialities of Collective Reorganization.” *Bulletin of Science, Technology & Society* 37, no 2. https://doi.org/10.1177/0270467618766995