Nuclear Fission as a Sustainable Energy Source for the Future

How does the development of the Kudankulam Nuclear Power Plant impact the energy generation within the surrounding regions of India, a developing country?

World Studies

Theme: Environmental and/or economic sustainability

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1.0 Introduction

We are currently living in an era where global warming is one of the most prominent issues in the world. Although this issue is multifactorial it can be largely accredited to humanity's energy production methods [Causes and Effects]. Since the industrial revolution, we have fallen into a cycle of consumption and production of energy which unfortunately comes from the burning of fossil fuels. As a civilization, we require this energy, yet we must also consider the needs of our planet as well. It is a well-known fact that the use of fossil fuels over the next century will become unsustainable, both in resource abundance and its negative impact on the environment [Fossil Fuels]. With this in mind, we must turn to clean energy sources.

Clean energy sources are methods of obtaining energy that are greenhouse gas emission-free. Throughout the world, a plethora of different energy sources are utilized and are displayed in Figure 1. Looking at the energy distribution graph for the world, it is

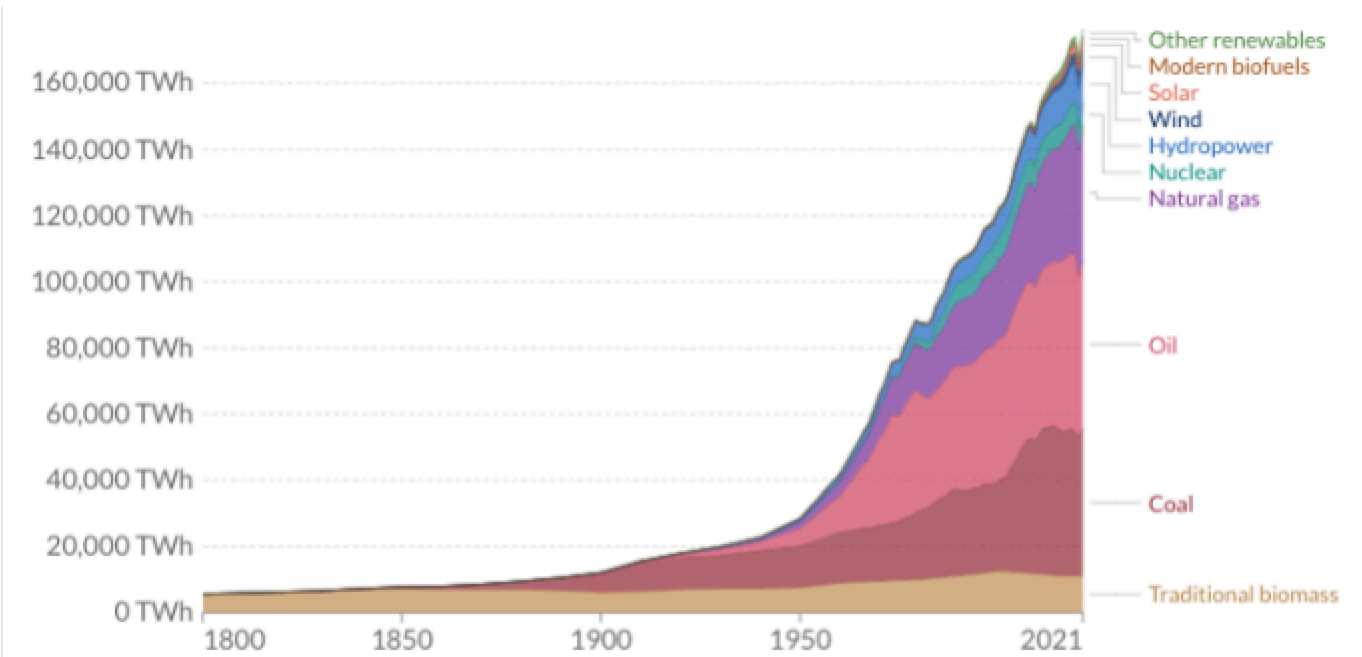


Figure 1: World Energy Distribution 1800-2021 [Energy Production]

clear that the majority of the world's energy is produced from fossil fuels such as oil, coal and natural gas.

Although the share of clean and renewable energy has been increasing in the last 50 years, there is still a long way before an equal share of clean energy is produced. However to fully achieve this goal, not only must clean energy be implemented in developed countries but it must also be accomplished in developing countries. Figure 2 displays a projection from the International Energy Agency that suggests that non-developed countries already consume as much energy as developed countries, and are set to contribute even more to energy consumption in the future. With this in mind, developing countries are extremely important in the process of mitigating carbon emissions from energy production. Thus, a developing country will be the focus of this investigation.

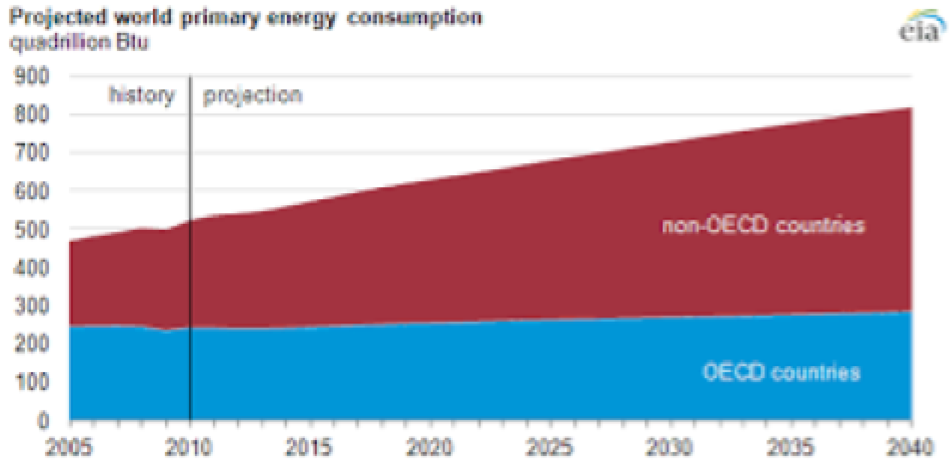


Figure 2: Projected World Energy Consumption 2005-2040 for OECD countries vs non-OECD countries [International Energy]

In the past century, there have been a great number of advances regarding clean energy [Types of]. Most of these types of energy sources are renewable energy, energy sources that can be replenished in short periods of time or can be continuously generated. However, nuclear fission is a clean, non-renewable energy source that is often overlooked. Nuclear fission occurs when a neutron collides with a larger atom and splits it up into two nuclei. These are known as fission products, and lots of energy is released with this which can then be harnessed, but only in the right conditions [Fission and Fusion].

At first glance, nuclear fission appears to have the potential to produce sufficient energy for the world but comes with great risks and consequences that could be detrimental to the environment. On a smaller scale, this essay will investigate a specific nuclear power plant and evaluate its positive and negative effects on its surrounding region. To do so, the fields of physics and geography will be utilized. The physics aspect of this investigation will discuss and evaluate the scientific methods by which nuclear fission and nuclear waste occur, the technical requirements for functionality, as well as energy output and efficiency across different circumstances in comparison to other forms of energy. The geography perspective will supplement this examination through an analysis of the resources required, the energy needs of the region, along with any effect stemming from the power plant on the environment or population.

The power plant being investigated in this essay is the Kudankulam Nuclear Power Plant (KNPP) in India, located on the south coast of India within the Tamil Naidu region as seen in Figure 3. India's significance emerges in its involvement in a group of countries titled BRICS. BRICS is an acronym conceived in 2001 by the bank Goldman Sachs for the countries Brazil, Russia, India, China, and

Figure 3: Map of India's Regions (India)

South Africa. The bank had identified these countries' explosive economic growth potential and marked their importance on the world's economy in the coming years. This is due to multiple factors, including almost half the world's population belonging to these countries, a quarter of the land mass, along a rapid expansion of the middle class and workers. This is more than enough to characterize India as a prominent developing country, and at the forefront of its energy development plans lies the Kudanulam Nuclear Power Plant.

This will help explore the research question: **How does the development of the Kudankulam Nuclear Power Plant impact the energy generation within the surrounding regions of India, a developing country?**

To answer the research question, two factors will be considered. Firstly, the power plant's influence and importance in the energy production of the region, and secondly the power plant's environmental and social impact on the overall country. The energy distribution of the Tamil Nadu region will be investigated to determine the influence of nuclear energy, and will then be compared to other leading regional energy sources. Following this, the impact of the power plant on its surroundings will be examined primarily through the lenses of resources, safety, and waste along with its greenhouse gas emissions. They will then be cross-examined to see whether the plant has a greater negative impact than its importance in the energy sector, or whether it is outperforming its energy importance with a very minimal impact. Both sections will contain elements of Physics and Geography for an integrated analysis.

2.0 Kudankulam Nuclear Power Plant

The Kudankulam Nuclear Power Plant is located just off Kudankulam, a small town along the southern coast of India. The power plant currently consists of two nuclear reactors, with plans for up to six in the future. Although the reactor was initially planned in 1988, the first reactor was only established in 2013 and the second in 2016 with a construction cost of $2.29 billion [Nuclear Power]. This was due to construction setbacks, political dissonance and local protests.Both Kudankulam reactors utilize the Russian model VVER-1000 pressurized water reactors as pictured in Figure 4 [Kudankulam Nuclear].

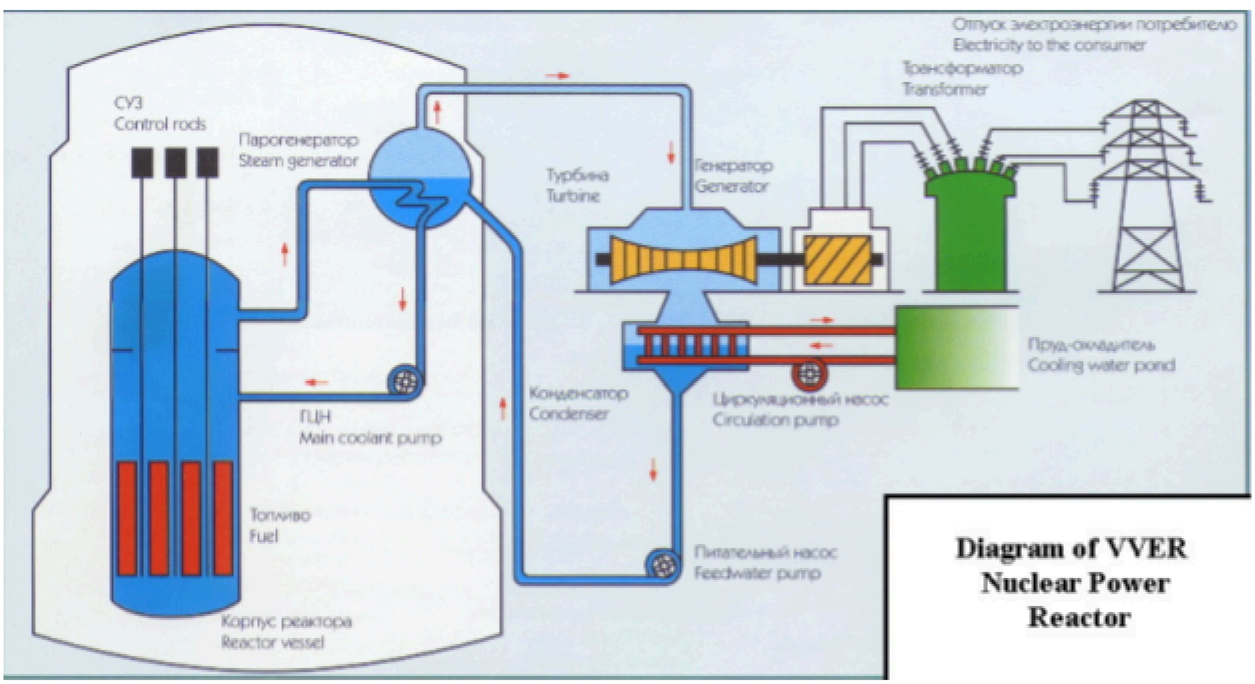


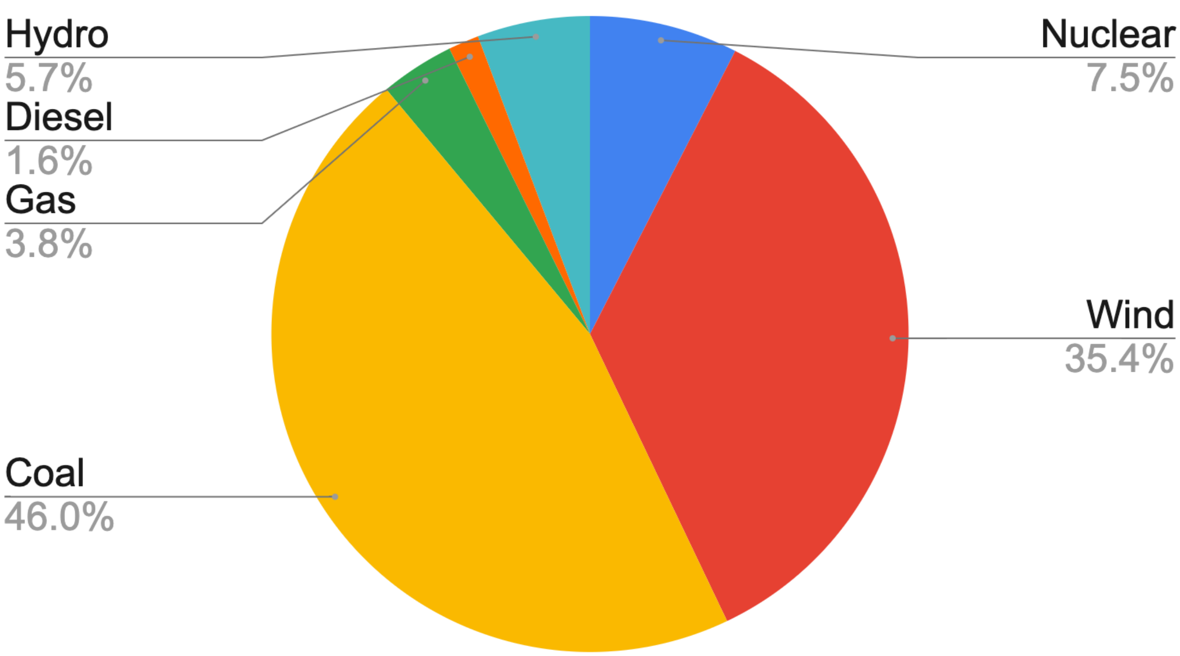
Figure 4: Diagram of VVER-1000 reactor [VVER]

It is important to note that this project is in collaboration with Russia, which provided the reactors to India as experimental technology.

3.0 Energy of the Region

The region in question is the Tamil Nadu region. With a population of 76.8 million people as of 2023, the region currently produces 26,550 MW of electricity [Pathways for]. The region's 2020 energy distribution as reported by the National Renewable Energy Laboratory is visualized in Figure 5, displaying a close to 50/50 split on clean vs non clean energy. Roughly 2000 MW of electricity comes from the KNPP power plants, amounting to 7.5% of the region's energy production. This shows the significance of the Kudankulam Nuclear Power Plant as for a single power plant, this is a large portion of the energy production with only one individual powerplant having a larger production value - the Neyveli Thermal (coal-based) Power Station has a capacity of 3390 MW, however, this takes 15 reactors to do so whereas KNPP only has 2 reactors [Neyveli New].

Figure 5: Energy distribution of the Tamil Nadu Region [Authors own]



4.0 Power plant

As in the name, nuclear fission has a large emphasis on the nucleus of an atom. One neutron collides with a Uranium-235 nucleus, which forms Uranium-236. Uranium-236 is very unstable, which will then split into two smaller nuclei along with two or more neutrons and energy. The energy produced is the difference in mass, referred to as the binding energy. It is the amount of work (energy) that is needed to be put into an atom (nucleus) to split it up into its individual nucleons (protons and neutrons) [Nuclear Binding]. In Figure 6, a few possible fission product equations are displayed.

$$n + {}^{235}\mathrm{U}_{92} \rightarrow {}^{236}\mathrm{U}_{92} \rightarrow \begin{cases} {}^{127}\mathrm{Sn}_{50} + {}^{105}\mathrm{Mo}_{42} + 4n + \sim 178\,\mathrm{MeV}. \\ {}^{136}\mathrm{Te}_{52} + {}^{97}\mathrm{Zr}_{40} + 3n + \sim 182\,\mathrm{MeV}, \\ {}^{137}\mathrm{I}_{53} + {}^{96}\mathrm{Y}_{39} + 3n + \sim 179\,\mathrm{MeV}, \\ {}^{139}\mathrm{Ba}_{56} + {}^{95}\mathrm{Kr}_{36} + 2n + \sim 174\,\mathrm{MeV}, \\ {}^{141}\mathrm{Ba}_{56} + {}^{92}\mathrm{Kr}_{36} + 3n + \sim 173\,\mathrm{MeV} \\ {}^{144}\mathrm{Ba}_{56} + {}^{90}\mathrm{Kr}_{36} + 2n + \sim 180\,\mathrm{MeV} \\ {}^{141}\mathrm{Cs}_{55} + {}^{93}\mathrm{Rb}_{37} + 2n + \sim 180\,\mathrm{MeV}, \\ {}^{139}\mathrm{Xe}_{54} + {}^{95}\mathrm{Sr}_{38} + 2n + \sim 184\,\mathrm{MeV}, \\ {}^{144}\mathrm{Xe}_{54} + {}^{90}\mathrm{Sr}_{38} + 2n + \sim 176\,\mathrm{MeV}, \\ {}^{144}\mathrm{La}_{57} + {}^{89}\mathrm{Br}_{35} + 3n + \sim 168\,\mathrm{MeV}. \end{cases}$$

Figure 5: Possible Fission Products [De Sanctis, 112]

5.0 Energy yields

Power plants are given two values regarding their energy production, megawatts electric (MWe) and megawatts thermal (MWt). Since it is impossible to retain all energy thermal energy from this system and transform it into electricity, these two values can help determine the efficiency of a reactor. MWt is the theoretical power output of the station calculated based on the amount of steam a reactor produces, whereas MWe is the actual output of the power plant in the form of electricity [Megawatts electric]. The efficiency of a reactor can be calculated by dividing the latter by the former. The Kudankulam reactors are 1000 MWe and 3000 MWt each [Kundakulam Nuclear]. It can then be calculated that the efficiency of the plant is $\frac{1000}{3000} * 100 = 33\%$. Although this may be concerning as the majority of the energy is lost, a comparison with other power plants as displayed in Figure 7 conveys this efficiency is common for power plants, coal or nuclear.

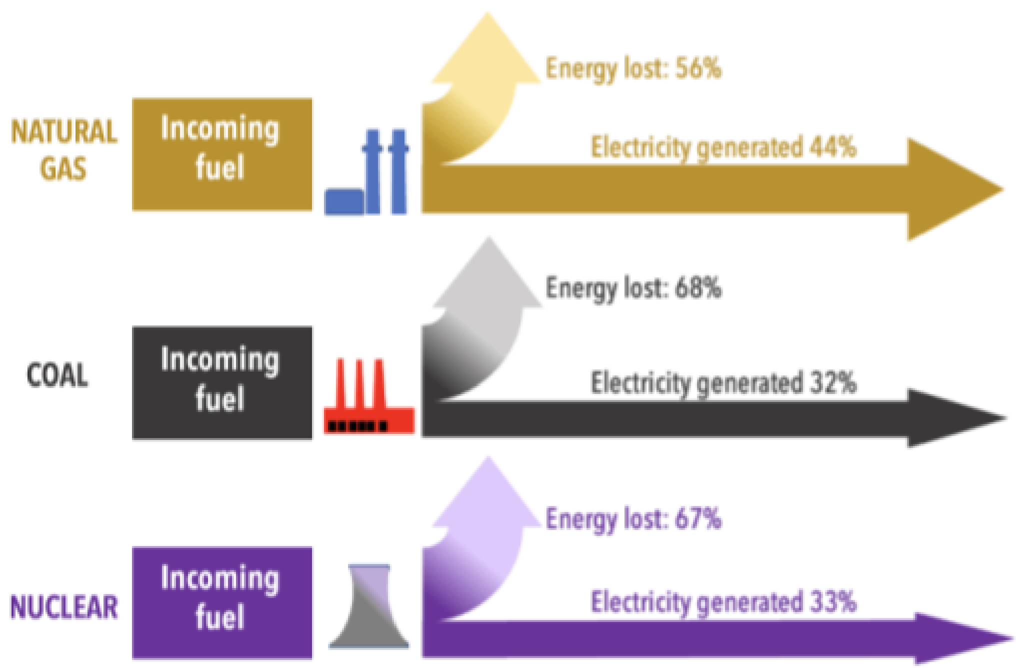


Figure 7: Efficiencies of different power plants [Energy loss]

Another method of comparison is through energy density. Energy density is the energy per unit mass, essentially how much energy is produced per kilogram of the substance [Bowen-Jones and Homer, 311]. To calculate this for Uranium, it is the measurement of energy released by the fission of 1 kg uranium-235. To do this, it must be determined the amount of nuclei in 1kg by dividing Avogadro's number by the molar mass of Uranium.

$$N = \frac{6.02x10^{23}}{0.235} = 2.56\,x\,10^{24}\,nuclei$$

From this point, an assumption of the energy released by 1 nucleus can be placed at 200 MeV [Physics of]. When multiplied by the amount of nuclei, this gives the total energy released in 1kg.

$$Energy = 2.56\,x\,10^{24} * 200\,MeV = 5.12\,x\,10^{26}\,MeV$$

To convert this into Joules, MeVs must be converted into eV and then through a conversion factor of 1.6 x 10^19 J / eV.

$$5.12\,x\,10^{26} * 10^{6} * 1.6\,x\,10^{19} = 8.19\,x\,10^{13}\,J$$

In section 3, coal was identified as the prominent source of energy in the region. The energy density of uranium can then be compared with that of coal. The accepted value for the energy density of coal is 2.4 x 10^7 J / Kg [Energy density]. It can then be seen the amount of coal needed to produce the same energy released by 1kg of U-235.

$$\frac{8.9x10^{13}}{2.4\,x\,10^{7}} = 3.4\,x\,10^{6}\,kg$$

Although this speaks to the power of nuclear fission, this might be slightly misleading due to the fact that the fuel used for nuclear fission is not pure Uranium-235 but rather only around 3.5% U-235 with the rest being U-238. This is due to the low natural abundance of Uranium, and this fuel is called enriched uranium. With this in mind, the calculation can be redone to determine a more accurate comparison of fuel sources.

$$8.9x10^{13} * 0.035 = 2.87\,x\,10^{12}\,J$$

$$\frac{2.87\,x\,10^{12}}{2.4\,x\,10^{7}} = 1.19\,x\,10^{5}\,Kg$$

The nuclear energy stored in 1kg of enriched uranium is equivalent to the chemical energy within 119000 Kg of coal. Although these power plants may have the same efficiency, the difference in scale shows how more fuel is being “wasted”; 67% of 1kg is substantially less than 67% of 119000kg. This shows how as a fuel source alone, the Kudankulam power plant is much more efficient in its resources used.

6.0 Russia-India Collaboration

An important factor in the evaluation of the research question is Kudankulam's partnership between Russia and India on this power plant. The Kudankulam power plant was/is the first large plant in India, provided by the Russian government and built by the Russian company Atomstroyexport [Kudankulam Nuclear]. Although this is India’s main source of nuclear energy right now, it is separate from their nuclear energy program and rather a way to develop quick energy production and necessary skill sets. India's civil nuclear energy development was impeded until 2009 as a consequence of its weapons program and its status outside the Nuclear Non-Proliferation Treaty, which led to a 34-year exclusion from nuclear trade [Ghosh, 2]. As a result of this India currently lacks the technical knowledge and experience to run their own power plant and therefore made a partnership with the Russian government and Atomstroyexport to develop the two reactors, as well as supply the necessary resources to sustain these reactors throughout their life [Russia offers]. When considering the impact of this on the region, this power plant is more than just an energy source, but rather a pathway for the future development of nuclear reactors around the country. The technology and experience provided by the Kudankulam power plant will allow for greater replication and success of nuclear development, further empowering India to begin the development of their program with an existing basis of nuclear fission. It should be emphasized that the positive aspects of this relationship do not specifically result in the participation of Russia, but rather from a country with considerable knowledge and experience regarding the topic. Any political issues regarding this relationship are likely beyond the scope of this investigation.

7.0 Water usage

The VVER-1000 model reactor employed at Kudankulam is a type of pressurized water reactor, a type of reactor that has high water requirements. VVER is an acronym for “Voda Voda Energo Reactor” meaning water-cooled, water-moderated energy reactor. In the context of nuclear physics, moderation is the process of slowing down emitted neutrons. After collisions, emitted neutrons travel at extremely high speeds, however, neutrons must be much slower to most effectively collide and react. Water is used to slow these neutrons down as their kinetic energy is absorbed as neutrons collide with water particles. The water used here is not immediately re-usable and must be treated which will be discussed in section 9.2.

The other water requirement for the Kudankulam nuclear power plant is cooling. Temperatures in a reactor are constantly high as a result of emitted kinetic energy, and water is required to cool it down. In general, for every MWh of energy produced, around 1,500 L of water is required; while this may appear to be a large value, this is very similar to the water usage of coal power plants [Green, 5]. For this reason, the

Kudankulam power plant reactors are built on a coastline. These reactors have developed a cycle of obtaining water from the ocean to use in the secondary circuit, steam generation, and cooling the steam back down before releasing this uncontaminated water back into the ocean. This allows for an unlimited supply of water in the process. However, the water released back into the ocean is often still very hot and can be around 30-40 degrees Celsius [Verbruggen, 12]. This has a direct negative impact on the ecosystems surrounding the power plant, and a study through thermal imaging concluded a 5-7 °C increase in water temperature ranging within 3-5 square kilometres of the power plant [Alagan, 6]. Thermal imaging used to determine this is

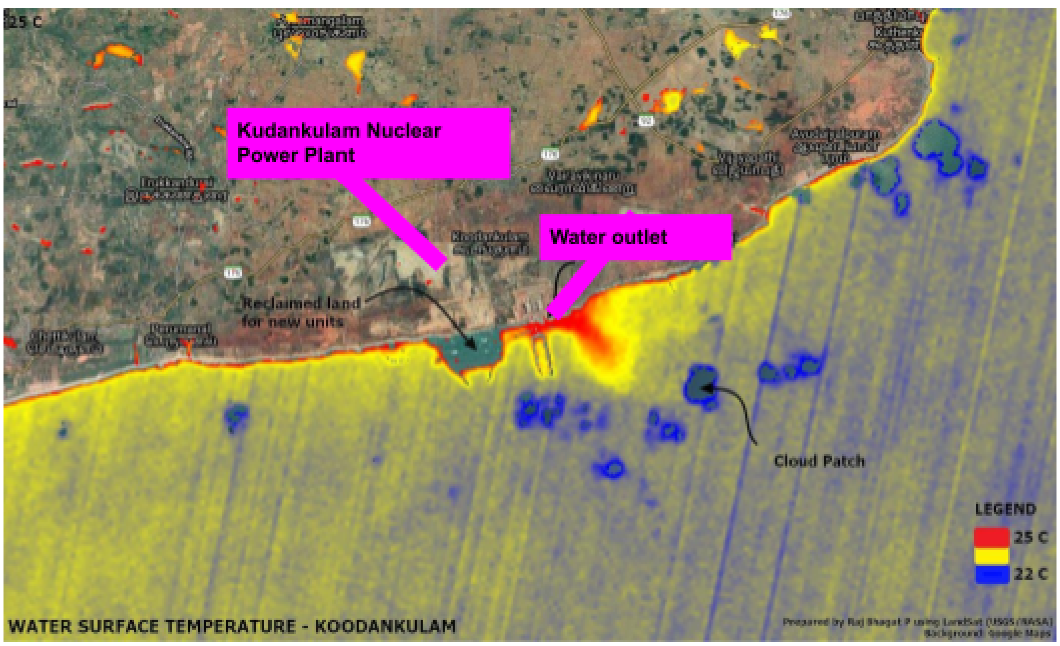


Figure 8: Thermal imaging of water temperature surrounding KNPP [Agrawal, 11]

pictured below in Figure 8. The thermal impact is not only isolated to the water outlet, but the entire coastline has an inflated temperature compared to the rest of the ocean.

8.0 Safety Concerns

The two mainstream nuclear disasters of Fukushima and Chernobyl showcased the dangerous potential of nuclear fission but also propelled a new generation of safety measures [Mohan, 2]. The International Atomic Energy Agency (IAEA) has since published multiple standardized regulations and guidelines to limit the occurrence of accidents. Among these safety standards include the creation of a regulatory body for every country. This body oversees the safety of the reactors within a country performing inspection checks annually, externally from individual reactors safety protocols, manifested in India’s Atomic Energy Regulatory Board.

The Kudankulam reactors align with International regulations and have fail-safe mechanisms implemented in their reactors. The VVER reactors have a mechanism to completely shut down a reactor and stop all collisions in a worst-case scenario [Agrawal, 4]. The nuclear reactor is built with control rods made of an element that can absorb neutrons and effectively slow down the reactions [Horder, 4]. Control rods can be mechanically controlled to change how much of the rod is immersed, allowing for complete control over the absorption of neutrons. In this model, the control rods are electromagnetically controlled from above the reactor core. Thus, in a complete reactor failure where power in the station is lost, the rods will fully drop down into the water and quickly absorb all the neutrons, effectively stopping the nuclear fission process.

During its commissioning, the Kudankulam power plants received large protests against it, specifically after the Fukushima disaster in Japan where an extremely large earthquake and a subsequent tsunami caused a nuclear disaster. To the public eye, the largest source of concern is that another disaster like this may happen to the Kudankulam Nuclear Power Plant. However, there are fundamental differences in the settings. Despite the overall improvement in safety to the point where the plant is earthquake and tsunami-resistant, the plant also resides on a non-seismically active area of land. Thus, there is a low chance of disaster at this power plant from natural disasters. This is visualized in Figure 9, where the gray colour of the Kudankulam plant indicates a low hazard, whereas the conditions around Japan are red indicating a high hazard.

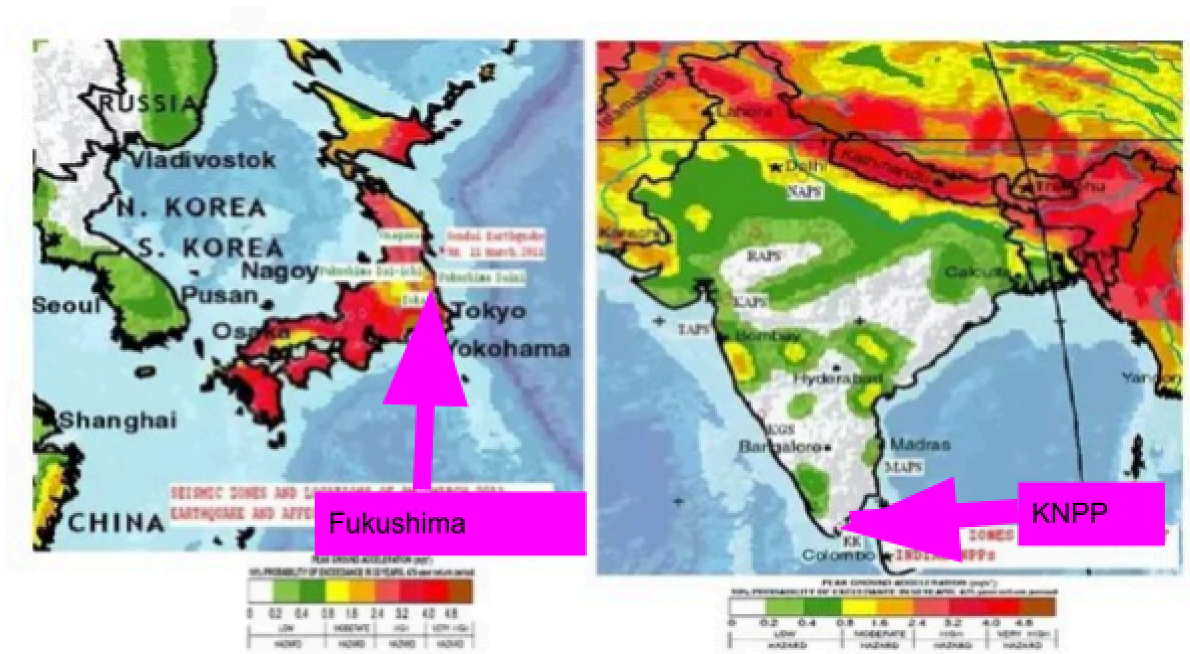


Figure 9: Seismic activity of Japan vs India [India energy]

9.0 Waste

When considering the waste of nuclear reactors, it is important to remember that due to the large energy density of nuclear fission, the amount of waste per energy produced is extremely minimal. In the Kudankulam power plant, around 30 tons of nuclear waste is produced every year; whereas a coal power plant of the same size produces roughly 6 million tonnes of CO_2 and 300,000 tons of ash per year. [Mohan, 8]. Instead, concerns regarding the waste stem from its radioactive capabilities which can be potentially harmful if not properly managed. There are generally two different levels of waste that will be discussed.

9.1 High-Level Waste

As indicated in the name, High-Level Waste (HLW) is nuclear waste that exerts high levels of radioactivity and therefore long-lasting activity and heat production.The majority of nuclear waste is HLW and is primarily composed of the used fuel rods from the core reactor [De Sanctis, 231]. After the content of U-235 in the fuel rods has reacted, it is turned into radioactive products, as depicted in Figure 10. However, this radioactivity has prolonged effects as fission products themselves are also often unstable having too many neutrons. As a result of this, these nuclei will go through β^- and γ decays until a stable nucleus is formed with the same mass number [Guo, 5]. A possible example of this is depicted below. The initial fission reaction occurs when U-236 undergoes fission to produce I-137 and Y-96.

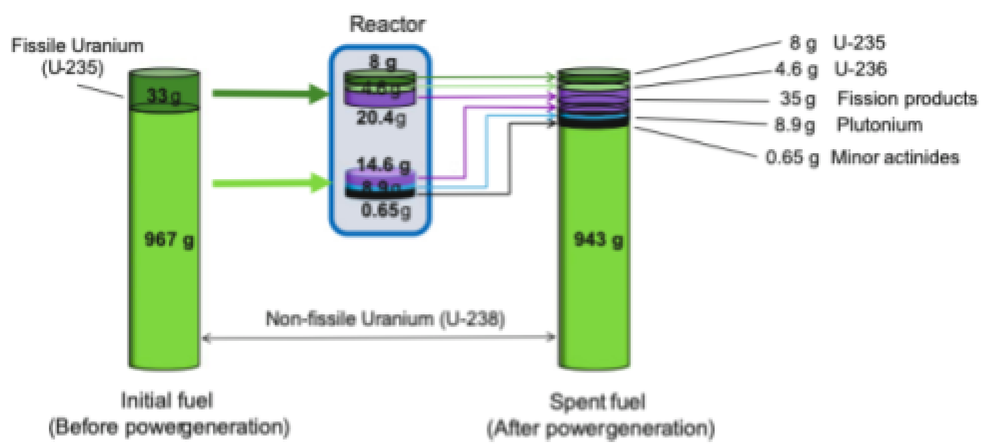


Figure 10: Fuel rod composition before and after [De Sanctis, 231]

$$^{236}U_{92} \rightarrow \; ^{137}I_{53} + \; ^{96}Y_{39} \; + 3n$$

However, both I-137 and Y-96 are unstable with extremely short half-lives, therefore decaying.

$$^{137}I_{53} \rightarrow \; ^{137}Xe_{54} + e + \tilde{v} \quad \textit{(Beta decay, half-life = 24.5s)}$$

$$^{137}Xe_{54} \rightarrow \; ^{137}Cs_{55} + e + \tilde{v} \quad \textit{(Beta decay, half-life = 3.82 min)}$$

$$^{137}Cs_{55} \rightarrow \; ^{137}Ba_{56} + e + \tilde{v} \quad \textit{(Beta decay, half-life = 30 years)}$$

$$^{96}Y_{39} \rightarrow \; ^{96}Zr_{40} + e + \tilde{v} \quad \textit{(Beta decay, half-life = 5.23 seconds)}$$

Thus, Ba-137 is formed, a stable nuclei, along with Zr-96 which although is not stable like Ba-137, has an exceptionally long half-life of 2.0 x 10^{19} years. Apart from the fission products which were outlined earlier, the following decay equations show the formation of radioactive waste.

$$^{235}U_{92} + \; ^{1}n_{0} \rightarrow \; ^{236}U_{92} + \gamma$$

$$^{238}U_{92} + \; ^{1}n_{0} \rightarrow \; ^{236}U_{92} + \gamma$$

$$^{239}U_{92} \rightarrow \; ^{239}Np_{93} + \; ^{0}\beta_{-1}$$

$$^{239}Np_{93} \rightarrow \; ^{239}Pu_{94} + \; ^{0}\beta_{-1}$$

$$^{239}Pu_{94} \rightarrow \; ^{239}Am_{95} + \; ^{0}\beta_{-1}$$

$$^{239}Am_{95} \rightarrow \; ^{239}Cm_{96} + \; ^{0}\beta_{-}$$

Due to the constant decays and radioactivity of these products, treatment of HLW is long-term and requires both cooling down as well as shielding from surroundings [Blowers, 4]. In processing the waste from fuel rods there are two different approaches to treatment, “once-through cycle” or “closed cycle”. Referring back to Figure 10, only a minimal amount of spent fuel is radioactive and needs to be treated, with the rest remaining as U-238. Approximately 3.3% (1 ton) of a nuclear reactors anual waste is HLW, yet it accounts for over 95% of the radioactivity. In a once-through cycle, the entire portion of fuel rods is considered waste, whereas, in a closed cycle, the fuel rods undergo special extraction to separate the radioactive waste from the reusable U-238. The Kudankulam board has adopted this closed cycle and sends its waste to the Bhabha Atomic Research Centre (BARC), which processes nuclear waste for all of India. At this site, U-238 and Plutonium can be recycled, while the radioactive sections of the spent fuel are appropriately cooled and provided long term storage.

9.2 Low-Level Waste

The other main classification of nuclear waste from a power plant is low-level waste (LLW). Low-level waste is much greater in volume, but much less radioactive than HLW. The first main LLW is the water used to moderate/cool the reactor. Although the water is not very radioactive, it still must be properly treated before being released back into the ecosystem. Similar to the HLW from Kudankulam, this treatment is done at Bhabha Atomic Research Centre [Radioactive waste]. The minimal amounts of radioactivity in this waste allow for a fairly simple treatment process and a sustainable continuation of this process. Another type of low-level waste produced is the power plant itself. Although the plant has a lifetime of around 100 years, once decommissioned, most of the power plant will be considered low-level waste. When the Kudankulam nuclear power plant decommissions, there will be a few courses of action.

The first option is to dismantle the power plant instantly. In this scenario, the entire power plant would be dismantled a few months after shutting down, and the site would be re-opened for other uses within a decade [Nuclear Decomissioning]. The second

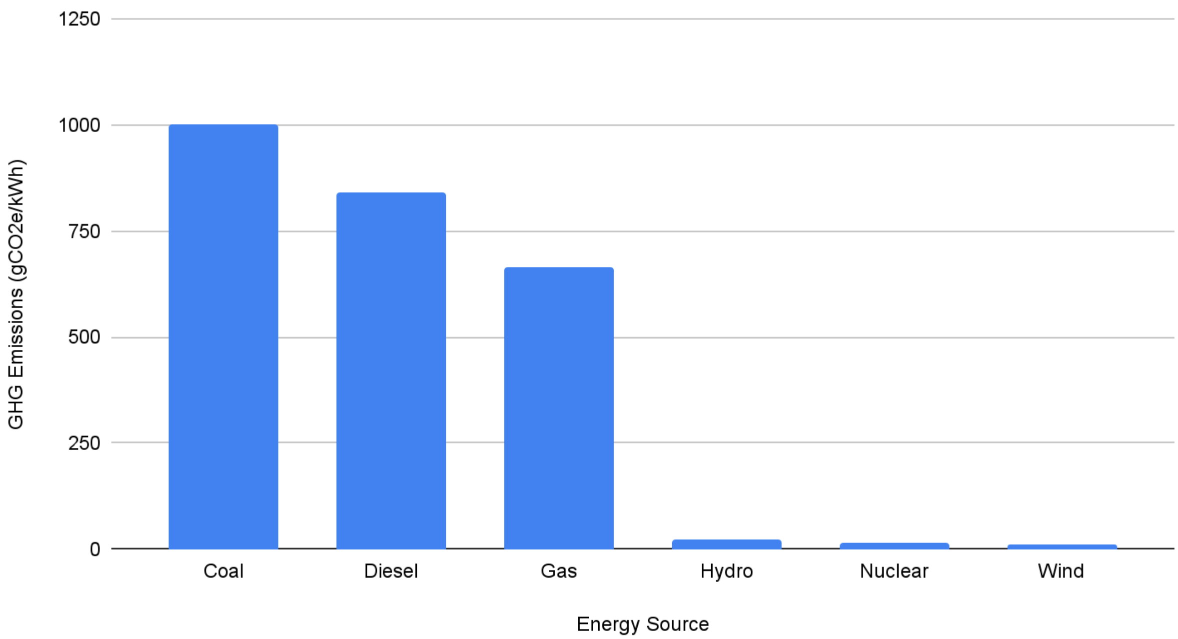
Figure 11: Satellite image above Kudankulam [Google maps]

option involves leaving the power plant for around 40-60 years before beginning the dismantling process, and the third option is “entombment”; the power plant would be enclosed in a structure such as concrete to contain the radioactivity. With the area of the village of Kudankulam being 26.96 sq Km, all of these options are not a major concern as there is a minimal population surrounding the plant to be affected by it [Kudankulam, Radhapuram].

10.0 Comparison of greenhouse gas emissions with other energy sources

Although many specific geographical, environmental and socio-economic impacts of nuclear power plants are unique, greenhouse gas emissions are a factor that can be directly compared with other energy sources. To justify nuclear fission as a clean energy source, it is helpful to look at CO_2 emissions coming from varying energy sources. Although nuclear fission does not produce greenhouse gasses in its energy production as fossil fuels do, there are still some CO_2 emissions that primarily come from the building and decommissioning of the site; therefore the comparison will be made using "life-cycle emissions" which includes the emissions during the construction, installation, and decommissioning of a power plant [Electricity From]. Data from the International Energy Association is displayed in Figure 12 which is measured in the equivalent amount of grams of CO_2 emitted per kilowatt hour of energy produced.

Figure 12: Life-cycle Greenhouse Gas Emissions from Varying Energy Sources



This graph shows the disparity between nuclear energy and fossil fuels while displaying how nuclear energy is similar in CO_2 emissions to other pronounced forms of clean energy production, having minimal contribution to global warming.

11.0 Conclusion

The purpose of this essay was to evaluate whether the Kudankulam Nuclear Power Plant’s implications align with its contribution to the energy of the region Tamil Nadu in India. It was discovered that the power plant alone produces 7.5% the region's energy, but more than any other individual power plant. Along with this substantial amount of energy production, nuclear energy is significantly denser than the primary sources of energy in the region such as coal while still rivaling the efficiency of such power plants.

Safety concerns were established as a large factor of concern due to the high risk if an accident does occur as it has in the past. However, the non-seismically active location of the power plant along an increase in the safety of nuclear reactors with new fail safe mechanisms greatly reduces that risk.

Another part of safety concerns is the waste management of the power plant. While the power plant produces a minor amount of waste, the content of this waste is highly radioactive and poses a threat for a long period. An effect ocean temperatures was also documented, potentially harming marine life ecosystems. This is unlike its impact on land, as the area surrounding the power plant is mostly uninhabited and with little safety concern. Although the power plant has its strengths and weaknesses, perhaps the two most significant factors that play in favour of the power plant are the low carbon emissions and the Russian partnership. The premise of this investigation is the need for a clean energy source, and the low carbon emissions of nuclear fission at this power plant provide that. Additionally, the experience gained from the partnership is extremely beneficial to the region and country as it can kickstart their nuclear program. This power plant serves as a working symbol of development and possibilities, one that could potentially influence a fleet of nuclear reactors and clean energy in the region, country, and developing nations across the world.

For this reason, the Kudankulam Nuclear Power Plant can be concluded to have a greater positive impact than negative. However, this is not without uncertainty. While the power plant plays a notable role in the energy's production and shines in comparison to fossil fuels, the underlying waste and safety concerns may pose a threat for the future.

Works Cited

Alagan, Muthamilselvan. “(PDF) Sea Surface Temperature Mapping near Kudankulam Nuclear Power Plant, Tamil Nadu, India; A Thermal Remote Sensing Approach.” *ResearchGate*, 13 May 2022, https://www.researchgate.net/publication/326177048_Sea_Surface_Temperature_Mapping_near_Kudankulam_Nuclear_Power_Plant_Tamil_Nadu_India_A_Thermal_Remote_Sensing_Approach. Accessed 26 August 2023.

Blowers, Andrew. "Nuclear waste and landscapes of risk." Landscape research 24.3 (1999): 241-264.

Bowen-Jones, Michael, and David Homer. IB Physics Course Book: For the IB Diploma. Oxford University Press, 2014.

“Causes and Effects of Climate Change | United Nations.” *the United Nations*, https://www.un.org/en/climatechange/science/causes-effects-climate-change. Accessed 25 August 2023.

De Sanctis, Enzo, et al. *Energy from Nuclear Fission: An Introduction*. Springer International Publishing, 2016. Accessed 14 May 2023.

“Electricity From Nuclear Power: Is It A Solution To Greenhouse Gas Emissions In India.” *International Journal of Scientific & Technology Research*, http://www.ijstr.org/final-print/dec2013/Electricity-From-Nuclear-Power-Is-It-A-Solution-To-Greenhouse-Gas-Emissions-In-India.pdf. Accessed 1 September 2023.

“Energy density.” *Energy Education*, https://energyeducation.ca/encyclopedia/Energy_density. Accessed 1 September 2023.

“ENVIS Centre: Tamil Nadu Status of Environment & Related Issues.” *ENVIS Centre: Tamil Nadu Status of Environment & Related Issues*, 28 May 2021, https://tnenvis.nic.in/Database/Energy_1170.aspx. Accessed 30 August 2023.

“Fission and Fusion: What is the Difference?” *Department of Energy*, 1 April 2021, https://www.energy.gov/ne/articles/fission-and-fusion-what-difference. Accessed 25 August 2023.

Ghosh, Arundhati. “India and the Non-Proliferation Regime: Consistency or Change?” Indian Foreign Affairs Journal, vol. 1, no. 1, 2006, pp. 32–44. JSTOR, http://www.jstor.org/stable/45340543. Accessed 6 Sept. 2023.

Green, Kate. “Nuclear power and its water consumption secrets.” *Monarch Partnership*, 30 January 2019, https://monarchpartnership.co.uk/nuclear-power-water-consumption/. Accessed 26 August 2023.

Guo H, Tian C, Wang X, Lv N, Ma M, Wei Y. Decay Chain Deduction of Uranium Fission Products. Health Phys. 2016 Jul;111(1):17-21. doi: 10.1097/HP.0000000000000521. PMID: 27218290.

Horder, Chris. *Safety Features at KKNPP*. Insight of. Location: The Kudankulam is located on the coast of the Gulf of Mannar, at 25 kM to the north- east from Kanyakumari,in. India. Accessed 27 August 2023.

"India – Travel guide at Wikivoyage." *Wikivoyage*, https://en.wikivoyage.org/wiki/India. Accessed 25 August 2023.

"International Energy Outlook Consumption - By 2050, global energy use in the Reference case increases nearly 50% compared with 2020—mostly a result of non-OECD economic growth and population, particularly in Asia - U.S. Energy Information ..." *EIA*, https://www.eia.gov/outlooks/ieo/consumption/sub-topic-03.php. Accessed 14 May 2023.

Kirk, Karin. "Energy loss is single-biggest component of today's electricity system » Yale Climate Connections." Yale Climate Connections, 24 October 2022, https://yaleclimateconnections.org/2022/10/energy-loss-is-single-biggest-component-of-todays-electricity-system/. Accessed 5 September 2023.

"Kudankulam Nuclear Power Plant, Tamil Nadu." *NS Energy*, https://www.nsenergybusiness.com/projects/kudankulam-nuclear-power-plant-tamil-nadu/. Accessed 14 May 2023.

"Kudankulam, Radhapuram, Tirunelveli, Tamil Nadu, India." *Geolysis*, http://geolysis.com/p/in/tn/tirunelveli/radhapuram/kudankulam. Accessed 27 August 2023.

"Megawatts electric." *Energy Education*, https://energyeducation.ca/encyclopedia/Megawatts_electric. Accessed 3 September 2023.

“Neyveli New Thermal Power Project, Tamil Nadu, India.” NS Energy, https://www.nsenergybusiness.com/projects/neyveli-new-thermal-power-project/. Accessed 5 September 2023.

“Nuclear Binding Energy.” *HyperPhysics Concepts*, http://hyperphysics.phy-astr.gsu.edu/hbase/NucEne/nucbin.html. Accessed 26 August 2023.

“Nuclear Decommissioning: Decommission nuclear facilities.” *World Nuclear Association*, https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/decommissioning-nuclear-facilities.aspx. Accessed 27 August 2023.

“Nuclear Power in India | Indian Nuclear Energy.” *World Nuclear Association*, https://world-nuclear.org/information-library/country-profiles/countries-g-n/india.aspx. Accessed 14 May 2023.

“Pathways for Tamil Nadu's Electric Power Sector 2020-2030.” *NREL*, 15 January 2021, https://www.nrel.gov/docs/fy21osti/78266.pdf. Accessed 26 August 2023.

“Physics of Uranium and Nuclear Energy.” *World Nuclear Association*, https://world-nuclear.org/information-library/nuclear-fuel-cycle/introduction/physics-of-nuclear-energy.aspx. Accessed 27 August 2023.

“Radioactive Waste Management.” AERB, https://www.aerb.gov.in/english/regulatory-facilities/radioactive-waste-management. Accessed 5 September 2023.

Ram Mohan, M. P., and Akshay Shandilya. "Nuclear energy and risk assessment by Indian courts: analysis of judicial intervention in the Kudankulam Nuclear Power Project." Journal of Risk Research 18.8 (2015): 1051-1069.

Ritchie, Hannah, et al. “Fossil Fuels.” *Our World in Data*, https://ourworldindata.org/fossil-fuels. Accessed 14 May 2023.

Ritchie, Hannah, and Max Roser. “Energy Production and Consumption.” *Our World in Data*, https://ourworldindata.org/energy-production-consumption. Accessed 14 May 2023.

“Russia offers advanced nuclear fuel for Kudankulam Reactor - Civilsdaily.” *CivilsDaily*, 26 November 2022, https://www.civilsdaily.com/news/nuclear-fuel-russia-kudankulam/. Accessed 26 August 2023.

“Types of Renewable Energy.” *Department of Energy*, https://www.energy.gov/eere/renewable-energy. Accessed 14 May 2023.

Verbruggen, Aviel, Erik Laes, and Sanne Lemmens. "Assessment of the actual sustainability of nuclear fission power." Renewable and Sustainable Energy Reviews 32 (2014): 16-28.

“VVER Reactor.” *Nuclear Tourist*, 5 January 2006, http://www.nucleartourist.com/type/vver.htm. Accessed 26 August 2023.

.K. Agrawal, Ashok Chauhan, Alok Mishra, The VVERs at KudanKulam,Nuclear Engineering and Design,Volume 236, Issues 7–8,2006,Pages 812-835,ISSN 0029-5493, https://doi.org/10.1016/j.nucengdes.2005.09.030.

“.” . - YouTube, 2 October 2022, http://india-energy-scenario.blogspot.com/2014/03/aftermaths-of-fukushima-reaction-in_15.html?showComment=1394962838573#c1520638083278026602. Accessed 5 September 2023.