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Comparison of Nuclear Power & Coal Energy in Europe Narrative Literature Review

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ABSTRACT

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Most energy systems are dependent on weather, whereas coal and nuclear power are not. This leaves the general public confused which one to choose to provide a stable energy source growing populations needs. The purpose of the study was to analyze via narrative literature review eight chosen literatures/articles/sources on coal and nuclear power that were released between 2010-2021 by using only Andor search tool. English language literature was only accepted, and case studies were excluded. The aims were to determine whether nuclear power is superior to coal power in terms of energy production, environmental impacts, and whether Europe should choose coal or nuclear power taking future technology and politics into consideration.

According to research, nuclear power is superior in every aspect of energy production and environmental impacts, expect nuclear waste. Even though there are not as many nuclear fuel reserves in Europe, nuclear fuel would be still economical to import from outside of Europe. Both nuclear power and coal power have similar environmental impacts in mining, but in emissions nuclear power is superior due to low emissions compared to coal power. Coal power wastewater showed negative environmental impacts, while nuclear power cooling water provided wetlands to support wildlife. Coal is superior in terms of waste due to low hazard and recyclability, while nuclear waste must be stored in a safe place for hundreds of years until it does not emit dangerous radioactivity. Politically, coal has a higher approval rate than nuclear does despite coal having a higher death rate. New technology looks promising for nuclear power possibly solving the nuclear waste issue.

More recent studies on coal environmental impacts with new technology is suggested in Europe to assess appropriately coal utilization in Europe. Nuclear power mining was also lacking in literature significantly, where more research of the environmental impacts should be available.

Key words: coal, nuclear, energy production, environmental impacts

CONTENTS

ABBREVIATIONS AND TERMS

EPA	Environmental Protection Agency
European Union countries	Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden.
GW	Gigawatt
GWe	Gigawatt of electric energy
Kg	Kilogram
kJ/kg	Kilojoule per kilogram
l/MWh	Liter per megawatt hour
Mt	Million tonnes
Mtce	Million tonnes of coal equivalent
MW	Megawatt
OECD	Organisation for Economic Co-operation and Development
OECD countries	Australia, Austria, Belgium, Canada, Chile, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, the Slovac Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom, the United States.
OECD Europe countries	Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, The Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom.
TWh	Terawatt-hour
μSv	Microsievert

1 INTRODUCTION

Increasing worry of environmental effects of fossil fuel usage worldwide has made many countries to investigate other alternatives, for instance nuclear power. However, nuclear power has received much criticism from many countries causing the decline in nuclear power usage and increase of fossil fuel usage. Many people would like to choose other renewable energy sources, for example wind power, solar power, and hydropower. However, wind power is dependent on the weather as well as solar energy, which means they do not produce energy all the time. Hydropower is one alternative as well, but not all rivers are suitable for dams, not to mention of the environmental impacts of one. Hydropower is dependent on weather as well; draughts would cause problems in electricity production. Nuclear power and fossil fuels would be essentially the only type of energy sources to provide a baseload, which is the minimum level of electricity required to satisfy the demand for electricity for a 24-hour period or more (EIA N.d.). Essentially, nuclear power and fossil fuels would not be weather dependant and could produce energy consistently. Thus, nuclear power would be the best alternative to fossil fuels, because of its equal baseload capabilities. This has left many people confused whether fossil fuels or nuclear power would be the best energy source for electricity production.

This study is concentrated on analysing nuclear power and coal power for electricity production as the only viable baseload energy sources as well as their environmental impacts. Coal was chosen out of the other types of fossil fuels because it produces 37% of world’s electricity according to World Coal Association (2020) and is projected to continue being used significantly in the future as well. Coal is also highly scrutinized as an energy source, thus making comparison with nuclear power more interesting. Future technology and politics involved in both energy sources are briefly analysed as well to accomplish a comprehensive review of both energy sources.

The aims of this study are to identify environmental impacts of coal and nuclear power as well as identify their energy production capacities today and in the future and lastly, determine which one would be the better energy source in the future for Europe. Purpose of the study was to analyze coal and nuclear power through scientific books/articles/studies and perform a literature review on the current information as well as compare them to each other.

2 METHODS

2.1. Research questions

First, research questions needed to be determined, that were specific and not too broad. Hence, the first research question of fossil fuels were narrowed down to coal energy, instead of all fossil fuels consisting of coal, natural gas, and petroleum. The second research question was about the environmental impacts comparison between nuclear power and coal. It provides the positives and negatives of both and link with the first research question, which will show whether the energy produced is worth the risk and determines, which would be the least risky energy production method. Third research question was to assess the hypothetical future of nuclear power compared to coal power usage in Europe.

This report's aim is to answer the following three (3) research questions:

1. Is nuclear power superior in terms of electricity production compared to coal energy?
2. What are the differences in environmental impacts between nuclear power and coal energy?
3. Would it be more beneficial for European countries to increase or diminish nuclear power usage in the future in terms of energy production, environmental impacts, and clean technology?

2.2. Literature review

Narrative literature review is defined according to Charles Sturt University (2021) as “a comprehensive, critical and objective analysis of the current knowledge on a topic.” The topic in this case is coal and nuclear power. In this case chosen literature is summarized to the most important points in this report and compared to each other in order to answer the research questions, leading up to the last question on future. Narrative literature review was chosen due to its flexible structure because there is no consensus on how narrative literature structure should be. In fact, Ferrari (2015) points out that methods are not even necessarily required as well as research questions. In this aspect, this report will have some characteristics of systematic literature review, due to having methods and research questions. (Ferrari 2015.)

2.3. Research & literature evaluation

Andor was used as the sole search engine tool to find relevant literature. Relevant literature in this case was determined as 2010 studies up to 2021. All literature was accepted if the search engine would allow access to the literature online, since due to corona restrictions, library book rental was not possible. The literature search words generally had to have the following: coal/nuclear energy, coal/nuclear environmental impacts, alternative energy, coal utilization, nuclear utilization. The literature also needed to be in English. The information in the literature would need to have worldwide and/or include information on Europe or OECD countries. Case studies were not included in this study.

2.4. Chosen literature

In total of eight books and articles were chosen for the literature review as shown in the table (Table 1). Some of the literature would include both nuclear and coal and some would only have one or the other.

Statistics mentioning IEA Europe energy production and consumption for coal were excluded from International Energy Agency (2019) in this report, due to never defining what countries were part of IEA Europe, thus excluding IEA Europe results from this report. The lack of definition was crucial as different entities sometimes add Turkey as part of Europe, while other times do not. If definitions are not clear, then the comparison of literature would be impossible and present misleading results. Due to this, OECD-member countries and non-OECD-member countries definition was used instead as many European countries are OECD-member countries to obtain as accurate representation on Europe as possible.

TABLE 1. Literature chosen for literature review

Literature	Year	Author
Alternative Energy	2012	Lerner, K. L., Lerner, B. W., et al.
Clean coal engineering	2016	Miller, B. G.
Coal information	2019	International Energy Agency
Energy resources	2014	Skipka, K. J., Theodore, L.
Environmental impact and cost analysis of coal versus nuclear power: The U.S. Case	2012	Vujic, J. et al.
Human health and environmental impacts of coal combustion and post-combustion wastes	2017	Munawer, M. E.
Nuclear power	2017	Breeze, P.
Renewable & nuclear energy: Comparison of environmental impacts	2016	McCombie, C., Jefferson, M.

Themes of the literature are exhibited on Appendix 1, where the literature is divided to sections of coal and nuclear power as well as the subjects, where the literature is compared. The themes are divided into sections of energy production, environmental impacts and future. These sections are then divided into more specific subsections. Energy production of coal and nuclear are divided into their fuel characteristics, production and consumption and fuel reserves. Environmental impacts of coal and nuclear are the most extensive, where mining, transportation, emissions, radioactivity, water and waste are assessed. Lastly, future section is brief, where politics and future technology are evaluated. The themes do not include the introductions of coal and nuclear energy production, which are considered as base knowledge for the reader.

3 COAL ENERGY PRODUCTION

Fossil fuels are defined by Lerner et al. (2012, 1) as “substances that formed underground millions of years ago from prehistoric plants and other living things that were buried under layers of sediment.” There are three types of fossil fuels generally, which are coal, petroleum, and natural gas. Coal is solid, petroleum is liquid and natural gas is gas. This study will be concentrating on coal as the fossil fuel energy source. Miller (2016, 3) defines coal as “chemically and physically heterogenous, “combustible,” sedimentary rock consisting of both organic and inorganic material.” IEA (2019, 1.3) in turn defines coal as “a variety of solid organic fuels and refers to a whole range of combustible sedimentary rock materials spanning continuously quality scale.”

Miller (2016, 3) states that coal is a biological fossil, that consists of organic and inorganic compounds. Organically coal is made carbon (C), hydrogen (H) and oxygen (O) with small amounts of sulphur (S) and nitrogen (N). Inorganically coal consists of a multitude of trace elements and minerals, sometimes including thorium (Th) and uranium (U). (Miller 2016, 3.) Skipka and Theodore (2014,112) refers to the sulphur and ash in coal as impurities that are not desired.

When coal is mined, it is generally sent to a preparation plant that removes the dirt, rock, ash, free sulphur, and other unwanted impurities through different processes. This increases the heating value of the coal, which is essentially how much heat is produced when material is burned (Lerner et al. 2014, 43). The coal is then transported to a coal power plant. Then the energy is generated by burning coal, which releases energy in a form of heat in a boiler. Sometimes this is sufficient if the wanted result is heat, however, to produce electricity, this heat is used to turn water into a high-pressure steam. This high-pressure steam passes through a turbine, where at the end of the turbine is a generator consisting of wire coils that are rotated rapidly in a strong magnetic field. Once the steam passes through a turbine, the steam is condensed once again and returned into to the boiler to be heated again. In order to keep the burners running, constant supply of coal is required. (Lerner et al. 2012, 8, Skipka & Theodore 2014, 124). This happens generally in electricity plants, combined heat and power plants (CHP) and heat plants. The coal used to produce electricity and heat is generally called steam coal, while other coals can be used to for various purposes, for instance steelmaking. (IEA 2019, 1.9.)

3.1. Coal as a fuel

Most Earth’s coal was formed during Carboniferous and Tertiary period, at the earliest 350 million years ago. Coal is found in coal seams, which are essentially coal deposits. Coal is essentially dead plant material, that has absorbed the energy from the sun via photosynthesis. However, generally the energy is released when plants decompose, but when coalification happens, the energy stays trapped in the dead plant material. Generally, for this to happen, swampy environment was required in the beginning. (Lerner et al. 2012, 41-42, Miller 2016, 4, Skipka & Theodore 2014, 105).

There are generally four different ranks of coal that are classified as anthracite, bituminous, subbituminous and lignite. Skipka and Theodore (2014, 107) defines coalification “as the chemical and physical process in where plant matter is transformed into coal”. Essentially peat transforms into soft coal called lignite, which is the lowest rank of coal over millions of years by the earth’s temperature and pressure. When the pressure and temperature are increased further the lignite transforms into subbituminous coal, which then transforms into bituminous coal, which is harder than the previous coal rank. Earth’s crusts movement accompanied with high temperatures and pressure transforms bituminous coal into anthracite, which is the hardest and the highest rank of coal (Kopp 2018, Miller 2016, 6-18.) In addition to temperature and pressure, Miller (2016, 6) adds acidity and natural movement of water influence the coalification as well. The higher the coal rank is, the higher the carbon content, but lower the oxygen content. High-quality bituminous coal is often wanted due to its low sulphur content. (Miller 2016, 7-21.) Essentially, coal differs around the world by plant material deposited, which is called type of coal. Coal rank created by coalification, is called the rank of coal. Lastly, the impurities in the coal are called the grade of coal (Miller 2016, 3.)

Coal has a decent energy density, meaning the amount of energy stored in a mass or volume (Afework et al. 2019). The average energy density for 1 kg of coal is 8 kWh of electricity, which makes coal a rather convenient energy source. (McCombie & Jefferson 2016, 759). This is because coal burns better than wood (Lerner et al. 2012, 45). Moisture content of peat is often as high as 70%, while for lignite 30%. Sub-bituminous moisture content is between 15-30%, while bituminous is below 15-30%. Anthracite has the lowest moisture content at about 3%. (Skipka & Theodore 2014, 105-107.)

Heating value is an important indicator for coal. Essentially the more carbon the coal has the higher the heating value. (Lerner et al. 2012, 43.) The table (Table 2) below depicts the two literature sources that provide coal's heating values, while numbers are slightly different, they are mostly in line with each other. Biggest difference among the two would be lignite heating value, where Lerner et al. (2012, 43-44) provides a starting point, whereas Skipka and Theodore (2014, 105-107) does not. Essentially, higher the coal rank, the lower the moisture content unlike the heating value, which increases with the coal rank as shown in the table (Table 2). Even though lignite and sub-bituminous coal have a quite high moisture content, they are still quite flammable and when exposed to air, have a risk of spontaneous combustion. Bituminous coal is most used in electric utility boilers and coking coal. (Skipka & Theodore 2014, 105-107). But it is clear that there is a massive difference on heating values between coal ranks, where anthracite possesses the highest heating value.

TABLE 2. Coal heating value

Coal rank	Heating value (kJ/kg) (Lerner et al. 2012, 43-44)	Heating value (kJ/kg) (Skipka &Theodore 2014. 105-107)
Lignite	9304-19306	<19,000
Sub-bituminous	19306-30238	19,000-27,000
Bituminous	24423-36053	24,500-32,500
Anthracite	31401-36286	35,000

Lerner et al. (2012, 43-44) has quite drastically different definitions on carbon content. Lerner et al. (2012, 43-44) goes by pure carbon content, which presumably includes the volatile matter, while fixed carbon does not. Pure coal and fixed carbon do not include mineral matter (Bowen & Irwin 2008, 7, Miller 2016, 7-9). Miller (2016, 7-8) has drastically different numbers even though classifies as pure carbon content in lignite and sub-bituminous coal as shown in the table (Table 3) below. Lerner et al. (2012, 43-44) never defined the pure carbon content as Miller (2016, 7-9) did. However, there are two types of chemical coal analyses comprised of proximate and ultimate analysis, where techniques differ. Miller (2016, 8-9) seems to have used the proximate analysis, while Lerner et al. (2012, 43-44) might have used the ultimate analysis. This can ultimately explain the drastic difference in the carbon contents in the table (Table 3). It is clear that carbon content correlates highly with coal heating values as both of them increase with the coal rank. This would make higher coal ranks a better choice from energy production standpoint.

TABLE 3. Carbon content of coal ranks

Coal rank	Carbon content (%) (Lerner et al. 2012, 43-44)	Carbon content (%) (Miller 2016, 7-8)
Lignite	25-35	70
Sub-bituminous	35-45	75
Bituminous	60-86	80-90
Anthracite	86-98	>90

3.2. Electricity production

In 2010 coal supplied 30% of world's energy (Lerner et al. 2012, 41). In 2012 coal was ranked as second primary energy source in the world, where coal was responsible for 31,7% of the world's primary energy production (Miller 2016, 88.) So there has been an initial increase in coal energy production globally. However, this number would include other uses for coal instead of just electricity, for example anthracite coal is best for space heating and chemical production. Bituminous coal is for electricity and steel making while the other coal types can be used as steam coal for electricity production or converted to other petroleum substitutes as shown in the table (Table 4) below. (Miller 2016, 15.) It is rather interesting that anthracite is not used in electricity production, even though it has the highest carbon content and heating value.

TABLE 4. Coal ranks used for electricity production (Miller 2016, 15)

Coal rank	Uses
Lignite	• Electricity production • Char production • Space heating
Sub-bituminous	• Electricity production • Conversion to other petroleum substitutes
Bituminous	• Coking coal • Cement production • Electricity production
Anthracite	• Space heating • Chemical production

Vujic et al. (2012, 35) states that in 2007 coal generated 41,6 % world's electricity, while Skipka and Theodore (2014, 110) mentioned much the same, since coal fired plants fuelled 41% of world's electricity in 2014. This would mean between 2007 and 2014 a 0,6 % change has happened using coal as an electricity supply, even though many efforts have been made by many countries to lower coal usage. Essentially, the world has been highly dependent on coal energy. Vujic et al. (2012, 35) also mentions that in 2007 coal supplied 37,2 % of OECD member countries electricity. IEA (2019, xvi) in turn reports that in 2017, 66,5% of coal in the world was primarily used for generation of electricity and heat worldwide, while in contrast OECD countries used 82,3% of coal to generate electricity and heat. This means most of the coal is used to generate electricity and heat. Minority would be for other uses as shown in the table (Table 4) above. But comparison is rather difficult due to the fact that IEA (2019, xvi) has included heating as well, versus Vujic et al. (2012, 35) has just included electricity production. Vujic et al. (2012, 31) expects world energy generation needs to increase to 35200 TWh in 2035. This is mostly because energy needs are expected to rise in non-OECD countries. In fact, coal fired electricity generation is expected to increase 2,3% per year. (Vujic et al. 2012, 31.) According to IEA (2019, VI.43-VI.45) the world produced 6860,97 TWh of heat and electricity via coal and for OECD Europe it was 253,60 TWh in 2017.

Miller (2016, 88) and IEA (2019, xvi) both state that in Europe coal consumption has been declining, however, many countries in Europe conducting nuclear phase out does not leave other options for reliable energy besides fossil fuels to meet the energy needs. Nuclear phase out means the discontinuation of nuclear power for energy purposes, which was mostly sparked by the Fukushima Daiichi power plant accident in Japan in 2011. Since fossil fuels are the only energy source able to provide a baseload besides nuclear power, it leaves many countries with only fossil fuels after nuclear phase out, even though renewable energies are increasing.

Steam coal imports in Europe/Eurasia decreased to 191,3 Mt in 2018 and in general is expected to decrease as Europe is thriving into completely carbon neutral Europe in the future. Asia-Oceania represented 77,9 % of worlds steam coal trade in 2018 and is expected to continue same in the future as coal consumption is increasing in Asian countries. (IEA 2019, ix). IEA (2019, xiv) reported that global steam coal consumption increased to 95,9 Mt, which is 1.6% more in 2018. Global total coal consumption increased to 66 Mtce, which is 1.2% more, while for OECD member countries consumption decreased to 39.6

Mtce, which is 3.2% less and non-OECD member countries increased to 105, 5 Mtce, which is 2.5% more.

Older power plants have considerably lower efficiency, while new supercritical and ultrasupercritical plants have considerably higher efficiency and are planned to replace older coal power plants in the next 10-20 years. Integrated gasification combined cycle (IGCC), where coal is gasified to produce electricity, similar to natural gas and is expected to become more popular as well. (Climate Technology Center & Network N.d., Skipka & Theodore 2014, 124.) Vujic et al. (2012, 32-33) states that the average capacity factor in the United States for coal fired power plant is 65,4 %. Essentially capacity factor means the operating efficiency of the plant. In this case coal has much higher operating efficiency compared to renewable energies like hydro, wind or solar. (Vujic et al. 2012, 32-33.)

Vujic et al. (2012, 33) provides coal energy production cost, which is on average 6,2 cents/kWh (US dollars), but depending on a country if they have carbon tax, these costs would go up depending on the country's policies. For example, the United States had a 25-dollar carbon tax to every ton of coal, which would increase the cost of coal energy production to 8,3 cents/kWh (US dollars). (Vujic et al. 2012, 33.) Coal power plants do not require many highly trained workers, which saves money in labour costs as well. Additional costs to coal power plant are usually pollution control devices such a scrubbers. (Lerner et al. 2012, 236-237.)

The average coal power density is 135,1 $\frac{\mathrm{W}}{\mathrm{m}^2}$, where power density is the amount of power in a mass or volume (Afework et al. 2019). However, depending on the coal rank the power density changes drastically as shown in the table (Table 4) below. Essentially, higher the coal rank, the higher the power density. Especially anthracite and bituminous coal, which have a higher power density than the average coal density. These would be in line with the heating value and carbon content discussed previously. This is important to understand as the power density can be 45,8 $\frac{\mathrm{W}}{\mathrm{m}^2}$ more than the average coal density and thus providing more power. (Zalk & Behrens 2018, 87.) When the average coal power density is compared with renewables for example wind, which has power density of 0,5-1,5 $\frac{W}{m^2}$ and solar photovoltaic has power density of 4-10 $\frac{W}{m^2}$. It shows that even the lowest ranking coal has a higher power density than many other renewables. (McCombie & Jefferson 2016, 759).

TABLE 5. Coal rank power densities (Zalk & Behrens 2018, 87)

Coal rank	**Power density ($\frac{W}{m^2}$)**
Lignite	96,1
Sub-bituminous	126,7
Bituminous	147,0
Anthracite	180,9

3.3. Coal reserves

Coal resources generally refer to the quantity of coal estimated to be present in a deposit but does not mean it is feasible to recover with today's technology nor economical. Coal reserves refer to the proven quantity to be present and recoverable with current mining technology, however, the definitions might differ to some degree in different countries and literature, thus making comparisons difficult (Miller 2016, 37, Skipka & Theodore, 2014, 109). Skipka & Theodore (2014,109) interestingly adds that proven coal reserves are subject to change according to the current coal prices, effectively decreasing proven reserves when price of coal is low and vice versa.

According to Miller (2016, 38-39) coal is the most abundant fossil fuel in the world and estimates to have sufficient amounts for 115-150 years of global production at the current consumption. Essentially, there are higher coal resources than oil or natural gas (Miller 2016, 38). This makes coal available with proven reserves in around 70 countries according to Miller (2016, 39), while Skipka and Theodore (2014, 112) mentions over 100 countries and all continents except Antarctica. Miller (2016, 39) estimated global coal reserves to be over 891 billion tonnes. Skipka and Theodore (2014, 109) in turn stated one trillion tonnes of proven coal reserves worldwide and similarly claims to last 150 years with current global production levels. In contrast, IEA (2019, xviii) reports 1054,8 billion tonnes of global coal reserves in 2018, estimating coal amount to last 139,3 years at current global production levels. The difference in estimates is shown in the table (Table 6) below, which shows that the literatures are mostly in consensus with each other. It is interesting to note as well that between 2006-2018 there has been very little change in the world coal reserves, which could be explained by either declining consumption of coal or countries discovering new deposits. Considering that coal consumption is increasing worldwide, it suggests that the countries are discovering new coal deposits. However, as earlier was mentioned, coal prices will affect the reserves as well, which might have in this case increased the reserves.

TABLE 6. World Coal reserves (Skipka & Theodore 2014, 109, Miller 2016, 38-39, IEA 2019, xviii)

Author	Year	Coal Reserves (tonnes)	Years of reserves with current usage
Skipka & Theodore	2006	1 trillion	150
Miller	2016	>891 billion	115-150
IEA	2018	1,054 trillion	139,3

While coal is found practically in every country around the globe, 77% of the proven coal reserves are located in the United States with 238 billion tonnes, Russia with 157 billion tonnes, China with 114 billion tonnes, Australia with 76 billion tonnes, India with 61 billion tonnes and lastly, Germany with 41 billion tonnes (Miller 2016, 38). Skipka & Theodore (2014, 112) mentions the United States, Russia, China, India, and Australia as well as the countries with the largest coal reserves in the world, but not providing statistics as Miller (2016) did. Additionally, Miller (2016, 39) admits, reserves could increase in the future as technology advances in mining techniques as well as finding new deposits around the world. However, IEA (2019, xix) mentions that most proven coal reserves are found in countries that are significantly dependent on coal, thus making it worth for them to spend their time to find new coal reserves. Lastly, Skipka & Theodore (2014, 125) & Lerner et al. (2012, 236) mention that transporting can easily cost more than the coal itself, because of the high quality needed, thus making lower quality coals uneconomical to transport globally, making efficiency of the transporting vessel crucial in transporting coal.

However, there are many countries that do not naturally have great coal resources, Western European countries are a good example, so these European countries need to import coal such as low-sulphur bituminous coal from other countries (Miller 2016, 21). Europe has some anthracite coal, but mostly lignite and sub-bituminous coal, which would be fine as these coal ranks can be used for electricity generation. Germany, Russia and Ukraine have the highest estimated recoverable coal reserves in Europe as shown in the table below (Table 7). European Union estimated recoverable coal reserves constitute mostly of Germany's coal reserves. Germany carries the most lignite and sub-bituminous coal, which is used predominantly for electricity generation. However, Ukraine has both anthracite and bituminous as well as sub-bituminous and lignite coal. European Union has reserves-to-production ratio of about 103 years, whereas countries like Germany has 213 years, Russia 452 years and Ukraine 384 years. Europe should keep in mind especially Germany and Ukraine because of their coal exportation, which could be of great benefit for European countries in electricity generation when looking for lower rank coal. In higher rank coal European countries would have to import either from Ukraine, Russia or outside of Europe. In fact, most of the steam coal exportation for Europe comes from the United States, making Europe more energy dependent on countries outside of Europe due to declining coal production in Europe. (Miller 2016, 40-80.) Considering coal's power density, lower ranking coal is simply not as economical to transport from long distances and thus would be considered as a disadvantage for coal.

TABLE 7. Estimated recoverable coal reserves (Miller 2016, 40-51)

Country	Anthracite /Bituminous (million metric tonnes)	Sub-bituminous /Lignite (million metric tonnes)	Total (million metric tonnes)
Bulgaria	1.814882	2364.791	2366.606
Czech republic	181.4882	871.1434	1052.632
Germany	48.09437	40510.89	40558.98
Greece	0	3020.871	3020.871
Hungary	12.70417	1647.005	1659.71
Poland	4178.766	1287.659	5466.425
Romania	9.981851	281.3067	291.2886
Russian federation	49100.73	107951	157051.7
Spain	199.637	330.3085	529.9456
Ukraine	15354.81	18527.22	33882.03
United Kingdom	227.7677	0	227.7677
OECD country	155536.3	229383.8	384920.1
Non-OECD country	247772.2	259081.7	506853.9
European Union	4883.848	51213.25	56097.1

4 NUCLEAR POWER ENERGY PRODUCTION

Nuclear energy can be defined as “an energy that is released from the nucleus of an atom.” (Lerner et al. 2012, 191). Essentially, atoms are made of subatomic particles, which are protons, neutrons, and electrons. Protons and neutrons are in the nucleus of the atom, while electrons are outside of the nucleus. Protons are positively charged particles, while electrons are negatively charged particles and lastly, neutrons are neutrally charged particles. To produce nuclear energy, fission or fusion would need to take place. Fission occurs when atom’s nucleus is split apart and fusion when two or more light nuclei are combined and transform into a heavier nucleus. This study will be concentrating only on fission nuclear energy because it is what is currently used in nuclear power plants. Fusion is currently only feasible in theory. (Lerner et al. 2012, 191-213, Skipka & Theodore 2014, 197.)

Breeze (2017, 5-27), Lerner et al. (2012, 191-213), Skipka and Theodore (2014, 205-206) state that there are two ways for fission to take place, one is using a heavy element where the element breaks down into smaller pieces. Second is for lighter elements, where a free neutron hits the nucleus, which in turn breaks apart the nucleus. Then this nucleus releases some neutrons as well, which will travel towards a next nucleus, becoming a chain reaction. Slower neutron increases the chance of nuclear reaction, especially when large amounts of uranium (U) is present. This energy is released slowly, the opposite of an atomic bomb that releases the energy at once. Fission happens in the reactor core of the nuclear power plant. The reactor core consists of fuel rods and control rods, which are surrounded by water, which is often called a moderator, that slows down neutrons. Graphite can be used as a moderator as well. When fission takes place, a significant amount of energy is released by emitting gamma rays and heat. This is when radioactivity is produced as well. Heat makes up 85% of the energy released. Heat warms up the water in the nuclear reactor to create high pressure steam. In fact, the steam generated has even higher temperature and pressure than coal powered plants, thus causing the turbines to be larger as well. This in turn drives the turbines, which converts mechanical energy into electricity. Once the steam passes the turbine, much like in coal plants, it is condensed once again either by cooling tower or using local water supply and then returned to the nuclear reactor to be heated again. The water that essentially slows down the neutrons, is used as a steam to make electricity as well as prevent the reactors from overheating. (Breeze 2017, 5-27, Lerner et al. 2012, 191-213, Skipka &Theodore 2014, 205-206.)

Lerner et al. (2012, 218) mentions only two types of nuclear reactors, which are pressurized water systems and boiling water systems. Essentially, pressurized water reactor system is based on keeping water under pressure when heated, so that it will not boil. The water acts as a coolant in the reactor since it can also absorb some neutrons. Control rods show up in the lid of the pressure tank. The water is heated to 270 Celsius and is channeled to a heat exchanger where the water in the heat exchanger is converted to steam. This steam is what turns the generator in the turbine and produces electricity to be condensed again by a cool water source or returned to the heat exchanger.

The second system Lerner et al. (2012, 218) mentions is the boiling water reactor system, which is more efficient than the pressurized water system. The control rods show up in the bottom of the containment chamber, instead of in the top. This is because water inside the chamber is boiled into steam, that rises top of the chamber, where pipelines carry the steam to turbines. Once again generator in the turbine produces electricity. The steam is then condensed and returned to the containment chamber. Also, as a safety measure underneath the reactor is a tunnel, where water is kept. The purpose in the event of water or steam were to leak from the containment chamber, it would fall into the tunnel, where it would pose no threat. (Lerner et al. 2012, 218.)

However, Breeze (2017, 6-7) admits that most nuclear power plants do consist of pressurized water reactors (PWRs) and boiling water reactors (BWRs), but there are other types as well, but in considerably lesser quantity. Light water graphite reactors only exist in previous Soviet Union countries, while advanced gas-cooled reactors only in the United Kingdom (Breeze 2017, 7).

Radioactivity is caused by a radioactive material overtime breaking down called as radioactive decay, where the material releases neutrons and energy spontaneously. Control rods are used in the reactor core to control the nuclear chain reaction, which are made of graphite and boron, which in turn absorb neutrons. (Lerner et al. 2012, 191-215, Skipka & Theodore 2014, 205.) Vujic et al. (2012, 39) mentions fuel rods remain 3-4 years in the reactor until removed. However, Skipka and Theodore (2014, 203-204) mentions that fuel rods are generally 6 years inside the reactor, until they are moved to a spent fuel pool for about 5 years, where the fuel rods can decay and thermally cooldown. However, this cooling time differs among literature as Breeze (2017, 15) mentions that it can be 2-4 years as well. This difference is probably due to different standards in different reactor types. Also, Vujic et al. (2012, 39) was released two years earlier then Skipka and Theodore (2014, 203-204), thus Skipka and Theodore (2014, 203-204) is probably more accurate than the earlier one, as standards could have changed during that time in different countries.

4.1. Nuclear fuel

Uranium (U) is used as a fuel in nuclear reactions because it is the heaviest element to naturally occur, which makes the element highly unstable, perfect for nuclear fission. Scientists believe uranium (U) was formed by supernovas 6,6 billion years ago and is the Earth's main source of heat. Uranium (U) is present in soils, rocks, seawater, even in groundwater in small concentrations. Plutonium (Pu) is heavier than uranium (U), but it is not nearly as abundant as uranium (U) in nature, which is generally mined and found in rocks, though can be found in the seawater as well. These rocks containing high amounts of uranium (U) are referred as uranium ores. Generally, 0,9 tonne of rock usually contain 1,3-4,5 kg of uranium (U). (Breeze 2017, 11-16, Lerner et al. 2012, 193-215, Skipka & Theodore 2014, 197-204.)

Breeze (2017, 12-15), Lerner et al. (2012, 193-215), Skipka and Theodore (2014, 204-205), Vujic et al. (2012, 39) state uranium (U) atoms contain 92 protons and 92 electrons but differ from each other in neutrons. This would make them isotopes, which are essentially the same element, but they can have 143 or 146 neutrons and they would differ in atomic weight. Atomic weight of 238 of uranium (U) is most abundant on Earth. In fact, there are 16 isotopes of uranium (U), but the one with atomic weight of 235 is the most important, because of its odd 143 neutrons, making it the easiest one to split via nuclear fission. 238-Uranium (U) is not fissile by itself, so it is first milled into yellowcake. Yellowcake is essentially powder called uranium oxide (U_3O_8), which is just oxidized uranium dioxide (UO_2). The yellowcake is then transported to an enrichment plant, where yellowcake is converted to uranium dioxide (UO_2), which in turn is then converted to hexafluoride (UF_6) gas. The 235-Uranium (U) concentration is increased from 0,7% to 3,5-5% in the hexafluoride (UF_6) gas, which is then converted back to uranium dioxide (UO_2) and added in the form of pellets into fuel rods made of zirconium (Zr) or zirconium alloy, that are essentially metal tubes. These fuel rods are then placed underwater at the core of the nuclear reactor. Nuclear reactor is the place where the nuclear reaction takes place. (Breeze 2017, 12-15, Lerner et al. 2012, 193-215, Skipka & Theodore 2014, 204-205, Vujic et al. 2012, 39.)

Uranium (U) has immensely high energy density, in fact, 1kg of 235-uranium (U) generates on average 24, 000, 000 kWh of electricity (McCombie & Jefferson 2016, 759). When compared to coal, one kilogram of uranium (U) would generate 10^{17} Joules, which in turn would power a 1-GW turbine generator for a year at 35% efficiency corresponding to 2,5 million tons of coal (Skipka & Theodore 2014, 198). Another example would be one tonne of uranium (U) powering a 1000 MW nuclear power plant for two weeks, whereas 160,000 tonnes of coal would be required to produce the same amount of energy (Lerner et al. 2012, 235).

Breeze (2017, 28), Lerner et al. (2012, 214- 215), Skipka & Theodore (2014, 206) add plutonium (Pu) can be found in nature, but only in small amounts. It is extremely toxic, more than uranium (U). Generally, it is formed in the reactor core as the atomic weight of 239-Plutonium (Pu) by 238-uranium (U) absorbing a neutron. By now having an odd number for plutonium (Pu) makes it fissile. However, 239-Plutonium (Pu) can sometimes absorb neutrons as well, making the atomic weight of the plutonium (Pu) into 240. 240-Plutonium (Pu) is now even number, thus making it non fissile. Overtime 239-Plutonium (Pu) and 240-Plutonium (Pu) build up in the reactor core’s fuel rods, thus making it incapable to have a fissile reaction. After that, they can be used in breeder reactors also called nuclear fast reactor or reprocessing plant, depending on the nuclear reactor type, to produce once again usable nuclear fuel by taking advantage of fast neutrons. However, this is considered to be economically a very expensive option, compared to standard fuel cycle, considering new uranium (U) is cheaper than recycling it. By using reprocessing plants or breeder reactors the radioactive decay time required for the nuclear waste to turn to safe levels is considerably shorter. (Breeze 2017, 28, Lerner et al. 2012, 214- 215, Skipka & Theodore 2014, 206.)

4.2. Electricity production

Vujic et al. (2012, 35) states that in 2007 nuclear power produced 13,8 % of worlds electricity and 21,4 % of OECD member countries electricity. Skipka and Theodore (2014, 202) mentioned nuclear power provided during 2014 provided 6% of worlds energy and 15% of world's electricity. Whereas Breeze (2017, 9) mentions nuclear power to provide 10,6% of worlds electricity in 2013 as shown in the table (Table 8) below. Breeze (2017, 7) uses World Nuclear association as a source that claims nuclear power production was about 10% in 2015. Essentially, electricity produced by nuclear power saw decrease, increase, and decrease again as shown in the table (Table 8), when compared between literature. This is most likely due to the Fukushima Daiichi power plant accident in Japan in 2011. It is important to note as well that the Fukushima Daiichi power plant was closed for many years, thus not providing power, thus it cannot be included in the electricity production statistics. Due to this accident many countries planned a nuclear phase out programs, where nuclear power plants were decommissioned. Decommissioned nuclear power plants would naturally lower the electricity produced. Renewable energies have also become more popular and economical, which could have influenced nuclear power decline as well. However, Skipka and Theodore (2014,202) proportion of nuclear generating electricity in the world being 15 %, is not in line with the other literature and cannot be explained.

TABLE 8. Proportion of electricity generated in the world via nuclear power by literature (Breeze 2017, 9, Skipka & Theodore 2014, 202, Vujic et al. 2012, 35)

Year	**Proportion of nuclear generating electricity (%)**
2007	13,8
2013	10,6
2014	15
2015	10

Nuclear power makes 30% of the electricity produced in the European Union, in fact France produced 80% of its own electricity via nuclear power in 2006 but lowered it to 75% in 2013 as shown in table (Table 9). After France (74,7%), Ukraine (43%) and Sweden (43,3%) used the most nuclear power proportionally when compared to other countries, even though the electricity generated is less than Germany and Russia as shown in the table (Table 9) below. Germany and Russia produce less electricity via nuclear power proportionally to other energy sources in those countries. (Breeze 2017, 8-9, Skipka & Theodore 2014, 202-203). Nuclear power generation increases worldwide by 2,5% per year and in Europe 0,7% per year according to Miller (2016, 100). Vujic et al. (2012, 31) predicted in 2012 that nuclear power will increase 2,0% per year in the world. This is a slight difference of 0,5 % in Vujic et al. (2012, 31) and Miller (2016, 100) in their worldwide predictions, but Miller (2016, 100) is more up to date, thus proving to be a more reliable source than Vujic et al. (2012, 31). Unfortunately Miller (2016, 100) is the only one to provide a statistic for Europe, but does not generally state what countries are considered as Europe. Vujic et al. (2012, 31) predicts that nuclear power electricity production in the world will increase to 45 000 TWh in 2035. However, countries discontinuing their nuclear power programs in the future could impact these estimations negatively. Table (Table 9) below clearly demonstrates that these countries in Europe have a higher nuclear power production than the world average.

TABLE 9. Nuclear electricity production in Europe in 2013 (Breeze 2017, 8-9)

Country	Nuclear power generated (TWh)	Nuclear production as a percentage of national total (%)
France	424	74,7
Russian Federation	173	16,3
Germany	97	15,5
Ukraine	83	43,0
United Kingdom	71	19,8
Sweden	66	43,4
World	2478	10,6

Skipka and Theodore (2014, 202) stated, that in 2007 there were 438 nuclear power reactors operating. Vujic et al. (2012, 38) mentioned that in 2011, there were 439 operating nuclear power plants. While according to Breeze (2017, 6-7) in 2015, there were 442 nuclear reactors operating globally as shown in then table (Table 10) below, however, three were fast breeder reactors and 439 left were commercial reactors. As previously mentioned, most of the reactor types are pressurized and boiling water reactors. There is very little of breeder reactors available, which shows that majority of nuclear power plants do not recycle their nuclear fuel. This means the number of nuclear power plants globally have stayed virtually the same in eight years. However, construction and planning of a nuclear power plant can even take decades, good example would be Olkiluoto nuclear power plant in Finland, which has been under construction for over decade. Nuclear power plant accidents, like Fukushima Daiichi power plant accident in Japan in 2011, have had most likely the biggest impact on the lack of constructing nuclear power plants in the past years. Some countries have embraced nuclear power in Europe, while others have not. (Lerner et al. 2012, 205-209.) The highest number of reactors being built are in China and Russia as their energy needs are expected to increase in the future (Vujic et al. 2012, 38).

TABLE 10. Nuclear reactors in the world in operation in 2015 (Breeze 2017, 6)

Nuclear reactor type	Number	Proportion of total number (%)
Pressurized water reactor	283	64,0
Boiling water reactor	78	17,6
Pressurized heavy water reactor	49	11,1
Light water graphite reactor	15	3,4
Advanced gas-cooled reactor	14	3,2
Nuclear breeder reactor	3	0,7
Total	442	100

Total global nuclear power generation in 2013 was 2478 TWh as shown in the table (Table 11) below, while in 2015 it went down to 2441 TWh, which are both about 10 % of annual global energy production (Breeze 2017, 7). The table (Table 11) shows that while total power production has increased over the years steadily, nuclear power generation has had the opposite effect. The annual power generation by nuclear power has been decreasing due to nuclear phase outs as well as decommissioning old nuclear power plants. OECD countries are more dependent on nuclear power where the percentage of annual production is about 19 %, which is considerably higher than the global average. Global annual nuclear generating capacity has increased steadily over the years, meaning nuclear power plant can produce more power, this could be achieved by increasing efficiency (Breeze 2017, 7-8). It is clear since the total power generation has been increasing over the years, the demand for power has been increasing in the world.

TABLE 11. Nuclear power generation by year (Breeze 2017, 7-8)

Year	Global nuclear power generation (TWh)	Total global power generation (TWh)	Nuclear production as a a percentage of annual production (%)	Global nuclear generating capacity (GW)
2004	2738	17,450	15,7	357
2005	2768	18,239	15,2	368
2006	2793	18,930	14,8	369
2007	2719	19,771	13,7	372
2008	2731	20,181	13,5	373
2009	2697	20,055	13,4	371
2010	2756	21,431	12,9	375
2011	2584	22,126	11,7	369
2012	2461	22,668	10,9	373
2013	2478	23,322	10,6	372

Breeze (2017, 18-19) states that uranium (U) production is generally conducted by countries with the highest reserves. In fact, three countries made up 63% of global uranium (U) production in 2012, which were Kazakhstan 36%, Canada 15% and Australia 12%. Russia produced 5% and Ukraine 2%. Essentially a total of 58,816 tonnes uranium (U) was produced in 2012 by different countries in the world. Uranium (U) consumption, however, is a bit different story. While North America consumes uranium (U) the most, European Union came in second at 17,235 tonnes and Non-European Union countries 6635 tonnes in 2012. It is clear that European Union consumes more uranium (U) than Non-European Union countries do. World uranium (U) consumption was 61,600 tonnes in 2012. (Breeze 2017, 18-19.) Breeze (2017, 20) states that it is clear that uranium (U) consumption exceeded the uranium (U) production, but says it is because of the use of weapons-grade uranium (U) as nuclear fuel.

Nuclear power provides an immense amount of energy and according to Lerner et al. (2012, 223) a typical nuclear power plant produces 1000 megawatts of electricity, while requiring very little land area compared to the power it provides. McCombie and Jefferson (2016, 759) agree as well that nuclear power plants require much less space compared to the power it provides, having a

power density up to 4000 $\frac{\mathrm{W}}{\mathrm{m}^2}$. Other renewables have considerably lower power densities, even when compared to fossil fuels, however, McCombie and Jefferson (2016, 759) do not provide a specific power density for coal, besides claiming that fossil fuels have higher power density than other renewable sources to compare. Wind and solar farms would require huge areas to produce anywhere near the similar amount of energy nuclear power plants do. In comparison, nuclear plant that requires 200 hectares of space is equal in terms power production to 14,000 hectares of space in solar farm and 55,000 hectares of space in a wind farm. (Lerner et al. 2012, 235.) In fact, generally the land required corresponds to 0,6 $\frac{\mathrm{m}^2}{\mathrm{GWh}}$, whereas wind farms can require 500 times the land area of a nuclear plant requires. In order for wind farms to provide the same energy as nuclear power plant, 300 times the area of a nuclear power plant is needed. However, in the case of a nuclear accident the nuclear power plant land area could render useless for several hundred years. (McCombie & Jefferson 2016, 760.)
Vujic et al. (2012, 32-33) states that the average capacity factor of nuclear power plant in the United States is 91,2 %. Nuclear power plants are considered to have among the highest operating efficiency, which would explain nuclear powers popularity in many countries like France. (Vujic et al. 2012, 32-33.)

Costs of nuclear fuel are relatively cheap as well. The nuclear electricity production cost is at 6,6 cents/kWh (US dollars). Carbon taxes would affect other energy sources thus increasing the costs, but nuclear power cost stays the same as carbon tax does not apply to it, thus keeping the costs at 6,6 cents/kWh. (Vujic et al. 2012, 33.)

There are many costs associated in building and maintaining a nuclear power plant, besides the initial expensive cost of constructing one. Costs of maintaining one is also a bit more expensive than coal power plants due to the extensive safety requirements. For example, Lerner et al. (2012, 236) mentions that corrosion and cracking of water pipes in boiling water reactors is common. Replacing these components is rather expensive and while maintenance is ongoing the nuclear power plant cannot produce electricity. Labour costs are generally higher, because highly trained staff is required to operate the nuclear power plant. (Lerner et al. 2012, 236-237.) Vujic et al. (2012, 33-34) states that even though the costs of building and maintaining a nuclear power plant are large, the total project cost isn’t what is most important, but the energy output cost that should then be compared to other energy forms. Also, Vujic et al. (2012, 34) found that deregulation increased nuclear plant capacity factor up to 90,1 %, where these consolidated companies would reduce reactor outages time and frequency. This increased electricity production by 40 billion kWh annually. It is important to mention that when efficiency is increased for the existing nuclear power plants, no new nuclear power plants need to be constructed. In fact, even small increases in efficiency can bring extensive profits to the company. (Vujic et al. 2012, 34.)

4.3. Nuclear fuel reserves

Lerner et al. (2012, 223-224) states uranium (U) to be abundant on Earth and estimates it to last at least 50 years. On the contrary, McCombie & Jefferson (2016, 760) estimates that there is enough uranium (U) to last about 90 years but can be extended additional 50 years if breeder reactors in a closed fuel cycle would be used. This would require an increase in construction of nuclear breeder reactors as there are very few existing currently as mentioned before. Breeze (2017, 11) claims that there are enough uranium (U) reserves for at least a century. However, Vujic et al. (2012, 39-40) estimates that large-scale breeder reactors could extend the uranium (U) resources for thousands of years. The difference between the literature’s claims are significant and if Vujic et al. (2012, 39-40) has any merit, breeder reactors would be revolutionary in the nuclear energy field.

Uranium (U) is mined globally at least in 20 countries. This has kept the price of uranium (U) at reasonably low. (Lerner et al. 2012, 223-224). Also, this leaves the high possibility that new uranium (U) reserves will be found in the future. The fact that during nuclear reaction, plutonium (Pu) is produced as well and can be reused as fuel, should be considered as a fuel reserve as well. It is important to note, that countries like Sweden, embrace nuclear energy more due to lack of fossil fuel reserves or otherwise they would have to depend on importing coal (Breeze 2017). The transportation of uranium (U) would also be rather economical for long distances as uranium (U) has a high energy density (Lerner et al. 2012, 236).

The highest-grade uranium (U) can be found in Canada, while low grade uranium (U) can be found in Namibia. However, the largest recoverable deposits are found in Australia as shown in table (Table 12) below. Uranium (U) deposits can be found around the world, but in case of Europe besides Russia, the only other country with significant deposits is Ukraine. (Breeze 2017, 17-18). If thorium (Th) would be used as nuclear fuel as well, this could increase nuclear fuel resources significantly further according to Vujic et al. (2012,40).

TABLE 12. Global uranium (U) resources in 2013 (Breeze 2017, 17-18)

Country	Proven recoverable resource (Tonnes)	Percentage of world total (%)
Australia	1,706,100	29
Kazakhstan	679,300	12
Russian Federation	505,900	9
Canada	493,900	8
Niger	404,900	7
Namibia	382,800	6
South Africa	338,100	6
Brazil	276,100	5
The United States	207,400	4
China	199,100	4
Mongolia	141,500	2
Ukraine	117,700	2
Uzbekistan	91,300	2
Botswana	68,800	1
Tanzania	58,100	1
Jordan	40,000	1
Other	191,900	3
Total	5,902,900	100

5 COAL ENVIRONMENTAL IMPACTS

5.1. Mining

Coal has multitude of environmental impacts. The environmental impacts start from mining. There are two types of coal mining, which are underground mining and surface mining mentioned by Miller (2016, 105-118). Skipka and Theodore (2014, 123) and Lerner et al. (2012, 45-46) mention environmental impacts of mining briefly. Lerner et al. (2012, 45) describes coal as not very environmentally friendly. Coal dust coats everything in black for example buildings and trees, making it quite dirty. Sometimes coal can even catch on fire inside a mine, which often called eternal fire. Distinguishing eternal fires can be nearly impossible, as drilling more will just provide more oxygen to the fire. Tajikistan mine has been burning since 330 BCE and Pennsylvania mine since 1962. Many countries have this problem, but China and India have possibly the largest number of mines on fire, because of the rapid mining development to provide energy to the growing population’s needs. (Lerner et al. 2012, 46.)

5.1.1 Underground mining

Underground mining also called subsurface mining is used on coal seams that are deep underground of varying depths but is accessible with current technology. Generally, the deeper the coal is, the more valuable it is (Skipka & Theodore 2014, 123). While both mining methods change the landscape of the mining area, subsidence can change the surface structure and the hydrological movement of the land permanently. Also, the usage of water from the groundwater for mining operations can cause local water level declines or even change the groundwater flow direction entirely if not properly considered in planning phase. (Miller 2016, 105-118.)

Another environmental impact is methane (CH_4). Methane (CH_4) is highly explosive in air in concentrations of 5-15 %. Methane (CH_4) is also considered as a greenhouse gas and is in fact twenty-eight times more potent than carbon dioxide (CO_2). When coalification happened, methane (CH_4) was trapped in the coal seams many years ago, called CBM or coalbed methane. When the coal seams are fractured, the trapped methane (CH_4) is released. The amount of methane (CH_4) depends on multitude of things, but generally, higher the coal rank, the higher the amount of methane (CH_4) trapped in the coal seam. This is because coal's absorption capacity increases, when the pressure increases, which happens in higher depths. This methane is called CMM or coal mine methane. CMM can be released into the atmosphere by any holes or cracks in the ground from the underground mines, in fact, underground mines account 80% of the total CMM emissions. These cracks can then reach surface mines, from where methane can reach the atmosphere. Two human made methane (CH_4) sources are degasification and ventilation air. Both were developed to remove methane (CH_4) from underground mines. Degasification's purpose is to extract the methane (CH_4) in the coal mines and depending on the gas quality, it could be used for electricity generation, district heating, boiler fuel, town gas or sold to natural gas pipeline systems. Ventilation air does not unfortunately have much of an end use, it is simply emitted into the atmosphere. Its sole purpose is to lower the methane (CH_4) concentration in the coal mines for the safety of the workers. Underground mining releases an estimate of 10-25 m^3 of methane (CH_4) per a ton coal that is mined. Global estimation for CMM emissions in 2010 was 584 million metric tons of CO_2 (MmtCO_2eq). Globally the highest CMM emitter country was China. However, coal mines account only about 8 % of all methane (CH_4) emissions. (Miller 2016, 105-115.)

Additionally, wastewater, which is often called tailings, can disturb groundwater systems, thus making the water highly saline or acidic (AMD). AMD is highly acidic water, which is produced by sulphide minerals, air and water coming into contact, thus oxidizing sulphur (S) and elevating acidity and metal concentrations in the water. The sulphide minerals are released from coal. These changes can have adverse effects on fish and wildlife. Fish are especially vulnerable to chemical water changes. The metals will stay dissolved in the water until basic conditions are met and then the metals will precipitate. There are two different methods to counteract this, by using chemical or passive method. Chemical treatment requires the use of alkaline chemicals to counteract the acidity such as calcium carbonate ($CaCO_3$), sodium hydroxide ($NaOH$), sodium bicarbonate ($NaHCO_3$) or anhydrous ammonia (NH_3). While the chemical treatment option is expensive, it effectively diminishes the dissolved metals in the water. Passive treatment in turn uses naturally occurring chemical and biological reactions to treat the contaminated water in a controlled environment before releasing the water back into the nature. Passive treatment uses methods such as aerobic wetland, compost or anaerobic wetland, open limestone channels, diversion wells, anoxic limestone drains, vertical flow reactors and lastly, the pyrolusite process. Passive treatment method is considerably cheaper than chemical treatment because it does not require expensive chemicals. (Miller 2016, 105-115.)

5.1.2 Surface mining

Surface mining also called strip mining means as the name suggests that a coal seam is near the surface. Besides the unaesthetically pleasing land, there are varying environmental impacts. Holes can be left in the land as well as tops of mountains destroyed (Lerner et al. 2012, 13-46). Due to the land disturbance, mining and transportation dust levels can be rather high as well as noise and ground vibrations. These can cause sedimentation as well and affect the surface and groundwater negatively. Erosion is a big problem as well, generally caused by the surface mining, because the aftermath of the land often does not look anything like the land nature had created. Unless the land is reclaimed to be constructed to look like the original landscape as much as possible, erosion will most likely take place. This means multiple factors must be considered when reclaiming the land and pictures of the land before mining. Globally, today Canada, Germany, United Kingdom, The United States, Australia, and South Africa exercise mine reclamation, where the land is returned as close to the original form as possible. (Miller 2016, 116-118.) Topsoil is often saved, and local plants are stored in greenhouses until reclaiming can begin. This requires hiring biologists, botanists, and fish experts to make this happen before mining can even begin. (Lerner et al. 2012, 46.) In contrast, in developing countries land reclamation is less popular. However, old mines from the days when environmental laws requiring mine reclamation were not yet applicable, left the abandoned mines as they are even in developed countries. Though today some programs exist in some countries reclaiming old mining sites. (Miller 2016, 116-118.)

Methane (CH_4) is released as well, but not as much as in underground mining does. Surface mining releases an estimate 0,3-2,0 $m^3$of methane (CH_4) per a ton of coal mined, which is considerably less compared to underground mining. Surface mining releases about 25-33 times less methane (CH_4) than underground mining. (Miller 2016, 116-118.)

Soluble salts and sulphides released due to mining activity can change the topsoil chemistry into saline and acidic (AMD). Topsoil chemistry changes can upset the ecological balance of the area, as many living things as well as plants are highly sensitive to these changes, as well as the surface waters and streams (Lerner et al. 2012, 41-46, Miller 2016, 116-118). There is also a possibility to hinder or increase surface flow by changing the soil infiltration rates. (Miller 2016, 116-118.) This can be done by leaving the land previously under water exposed or the mining activity having destroyed the vegetative cover over the land, thus making the land bare, which enables the soil particles to be dislodged easier (USDA & NRCS N.d.). These soil particles are then moved by wind or water to somewhere else. Lastly, compaction of soil can also change the soil infiltration rate, thus not allowing the water to penetrate the soil as it used to. This can lead to lower groundwater levels or reduce water availability in the nearby area.

Surface mining also creates more waste rock than underground mining. Depending on mining technique an estimated 3-10 tonnes of solid waste is produced per 900 tonnes of coal removed. Dust is also produced in the surface mining, which is greater in surface mining than underground mining. (Miller 2016, 116-118.)

5.2. Transportation

Coal is commonly transported via conveyers or trucks when the distance is short. Trucks and cars obviously contribute to air pollution due to burning fossil fuels. Trains and barges are often used in case of longer distances, that are still domestic generally. Obviously, these transport methods have various different ways of releasing emissions depending on the type of transport, even many electric vehicles contribute to emissions, because the electricity is provided via coal plants or natural gas plants. Since fossil fuels are burned in the transportation process, particulate matter often called black carbon pollution, that is generally visible to the eye, is released in the air. However, smaller particulate matter is harder to see and when inhaled in larger quantities can cause health problems to living beings. (Lerner et al. 2012, 13-14.) Miller (2016, 124) estimates that 0,2-1,0% of coal is lost during loading and transportation. This, however, depends on the size of the load and length of the transportation, meaning it can be even more in long distances. Coal fly ash particles (PM) can enter the atmosphere during transportation to the dumping site (Munawer 2017, 90).

Additionally, another method of transporting coal can be as a slurry in a pipeline, most commonly used in arid regions. However, large amounts of water are required during transportation, which is then removed and recovered before the coal can be fed directly into the system. However, generally coal power plants are located near the coal mines, to save on time and transportation costs. Longer international transportation tends to require an efficient ship, which is used when coal is transported to Europe for example, from the United States. (Skipka & Theodore 2014, 125.)

5.3. Coal power plant

Most of the coal power plants globally are older, which are not as environmentally friendly as the newer ones. Coal power plants with old technology not being updated to more current technology release great amount of pollution. Therefore, the amount of pollution a coal plant produces is linked to the power plant's age and if improvements have been made during the power plant's lifespan. Developing countries often still use power plants that are very old and often the technology used is outdated thus often releasing more pollution than developed countries. (Lerner et al. 2012, 45-46, Vujic et al. 2012, 35.) Munawer (2017, 93) essentially states, that the farther away from the coal power plant, the higher the life expectancy and vice versa, which is interestingly not mentioned by other literature.

5.3.1 Coal emissions

People tend to worry the most about emissions during the coal burning phase. When people worry about the emissions, they often forget the largest emissions is water vapor, which is harmless, and carbon dioxide (CO_2) and nitrogen (N) (Miller 2016, 126-127). However, coal will not burn completely unless sufficient oxygen and temperature levels are met. This would then increase the amount of air pollution. This pollution would cause acid rain and global warming among other issues (Lerner et al. 2012, 45). In the next subchapters carbon oxides, sulphur oxides as well as nitric oxides environmental effects will be assessed. Oxides are essentially chemical compounds where oxygen is combined with another element (Zumdahl 2018). Lastly, trace elements & heavy metals, radionuclides and organic compounds environmental effects that are related to the emissions of a coal power plant.

5.3.2 Carbon oxide (CO_x)

Carbon dioxide (CO_2) emissions are probably the most cared about in our society these days, mostly due to governments and companies constantly speaking about carbon neutral future. Many people fear the climate change and believe it is caused by carbon dioxide (CO_2). For every 1,8 million tonnes of coal consumed in a 1 GWe coal fired plant, 5,5 million tonnes of carbon dioxide (CO_2) is emitted on average or 920 grams of carbon dioxide (CO_2) for every kWh electricity generated (McCombie & Jefferson 2016, 761, Vujic et al. 2012, 36). Munawer (2018, 88) states coal based chemical processing releases carbon dioxide (CO_2) 2-4 times more than oil-based chemical processing, which is one of the disadvantages in coal utilization. Skipka and Theodore (2014, 127) state the carbon dioxide (CO_2) emissions per unit of energy generated for coal were 50% higher when compared to oil and doubled when compared to natural gas. Essentially making coal the highest carbon dioxide emitter out of all the fossil fuels. However, carbon dioxide (CO_2) is rather difficult to control, when compared to other emissions. (Vujic et al. 2012. 35-36.) Depending on the coal rank, the amount of carbon content varies. Lignite has more than 60% carbon content versus anthracite 80%. These gases are considered by many to be the cause of global warming and greenhouse gases. In fact, carbon dioxide (CO_2) emissions are considered to cause about three-quarters ($3/4$) of greenhouse gases. Out of the global carbon dioxide (CO_2) emissions in 2011, about 90% was coming from fossil fuels. (Munawer 2018, 88.) In fact, Vujic et al. (2012, 31-35) admits that unless non-OECD member countries like China accept policies that limit greenhouse emissions, coal consumption will continue to increase worldwide. As carbon dioxide (CO_2) reacts with other gases, it forms a shield in the atmosphere, where sun light is allowed in, but heat is not allowed out. However, this effect is needed on Earth, as otherwise Earth would be too cold hold life, so debate whether it is good or bad is ongoing since it is naturally occurring as well. (Lerner et al. 2012, 14.)

Carbon monoxide (CO) itself is far more harmful to living beings than carbon dioxide (CO_2) because it reduces the oxygen in the blood stream. Carbon monoxide can be emitted naturally or via human activities, essentially when fuel has not burned completely or in the case of wildfires. Miller (2016, 133) states carbon monoxide (CO) emissions on coal-fired power plants are low, however, are most likely formed during system start-ups or another unusual situation. Generally, as long as the power plants have a good combustion control, the carbon monoxide (CO) emissions remain low. Carbon monoxide (CO) has been linked with ozone formation via photochemical reaction but has not been linked to cause harm to any vegetation nor general material. (Miller 2016, 133.) Ozone is generally good when its high in the atmosphere, protecting the planet from ultraviolet rays. Ground level ozone has the ability to travel long distances. Generally, ozone presents itself as smog at ground level which is unhealthy to breath in. While Miller (2016, 133) claims there is no harm with ozone, but the United States Environmental Protection Agency (EPA) says the opposite, claiming ground level ozone being unhealthy to breath and damaging to sensitive vegetation thus causing havoc to the sensitive ecosystem. (EPA 2021.)

5.3.3 Sulphur oxides (SO_x)

Skipka and Theodore (2014, 126) emphasizes, coal industry's biggest environmental challenge is to remove sulphur. Many forms of sulphur oxides (SO_x) like sulphur dioxide (SO_2), sulphur trioxide (SO_3), sulfite (SO_3^{2-}) and sulfuric acid (H_2SO_4) are released from coal power plants, which form acid rain (H_2SO_4) when they come into contact with water, which in turn is harmful to the environment (Munawer 2018, 88-90). Though, most of the emissions of sulphur oxides (SO_x) is sulfur dioxide (SO_2) (Miller 2016, 127). For every 1,8 million tonnes of coal consumed in a 1 GWe plant 109 thousand of sulphur dioxide (SO_2) is emitted in the atmosphere on average (Vujic et al. 2012, 36). These pollutants can travel hundreds of kilometres from the original spot via air and water ways, thus becoming a problem in nearby countries as well.

Acid rain (H_2SO_4) can be in a form of fog, hail, or snow, it is not inclusive to only rain, even though its name suggests so (Miller 2016, 128, Munawer 2018, 88-90). Acid rain (H_2SO_4) destroys building material and textiles due to its high corrosivity, affects harmfully to vegetation and fish by contaminating flora and fauna (Miller 2016, 127, Munawer 2018, 88-90). Contamination happens via leaching heavy metals into the soil due to the acidity dissolving the heavy metals in the soil, such as zinc (Zn), aluminium (Al), cadmium (Cd), lead (Pb), manganese (Mn), mercury (Hg) and iron (Fe). (Munawer 2018, 88-90). Because of its ability, sulphur oxides (SO_x) accelerate metal corrosion, where temperature and relative humidity affect the rate of corrosion (Miller 2016, 127). Munawer (2018, 88-90) and Miller (2016, 127-128) also mention that the increased acidity in the water due to acid rain has been observed to lower reproduction rates of fish as well as plankton and bottom fauna. This occurs usually in pH below 5,5. However, nutrients can also leach into the water from the soil, which can lower the productivity of the crops and vegetation in the area, thus having too many nutrients in the water, thus resulting in eutrophication (Miller 2016, 127-128).

Sulphur dioxide (SO_2) gas damages flora and crops via phytotoxicity by damaging the leaves as well as plant growth, which in turn will affect the plant species in that area. (Munawer 2018, 88-90.) It can also destroy chlorophyll, which is the green pigment that give plants their green colour that is used in photosynthesis, which in turn hinders the plants' ability to photosynthesize (Merriam-Webster 2021, Munawer 2018, 88-90). This is because normally plant cells would convert sulphur dioxide (SO_2) into sulphite (SO_3^{2-}) and then sulphate (SO_4^{2-}). However, when sulphur dioxide (SO_2) is in excess, the plant cells are unable to oxidize it fast enough, thus disrupting the cell structure. Leafy greens are most susceptible to this. (Miller 2016, 127). However, Muhammad Munawer (2018, 88-90) notes, that more studies are needed as the damages have not been clearly yet studied.

Due to the negative environmental impacts of sulphur oxides (SO_x), coal that is low in sulphur content is generally more desired, which exist especially in western parts of the United States. It is important to note that huge coal deposits with high sulphur content exist as well in the United States and the rest of the world. (Munawer 2018, 88-90, Skipka & Theodore 2014, 125.) However, coal industry has made important changes in lowering sulphur emissions via wet scrubbers, thus enabling the use of high sulphur coal. Essentially, the job of scrubbers often called flue gas desulfurization unit (FGD), which removes gases containing sulphur via chemical reaction of water and limestone mixture, which reacts with sulphur dioxide (SO_2) and forms sludge, which is then removed. These scrubbers can be up to 98 % effective and thus are widely used these days. However, modern scrubbers can be rather expensive, which is why undeveloped countries are not as updated in their technology like developed countries are. (Miller 2016, 125-126, Skipka & Theodore 2014, 126-127.)

5.3.4 Nitric oxides (NO_x)

Nitric dioxide (NO_2) is highly corrosive as well as oxidizing, which is also released in coal combustion. Nitrogen oxides (NO_x) also play a role in producing ground level ozone gas and photochemical smog by reacting to volatile organic compounds in the air when sunlight is present. This hinders visibility by absorbing light. When Nitrogen dioxide (NO_2) reacts with water, it forms nitrous acid (HNO_2) and nitric acid (HNO_3), which in turn creates acid rain much like sulphur oxides (SO_x) do. It also has much of the same environmental impacts of destroying buildings and harming vegetation and textiles as well as the gases reducing the plants' ability to photosynthesize. (Miller 2016, 129, Munawer 2018, 90, Vujic et al. 2012, 36.) Nitrogen oxides (NO_x) in the form of acid rain that can corrode metal as much as sulfur oxides (SO_x) and change the soil pH, thus affecting the plants, because some plants are very sensitive to pH changes, and thus plants that can withstand lower pH levels, will outcompete the plants that cannot. Acidification of lakes and ponds will also cause eutrophication, which is harmful to aquatic animals for example, nitrogen dioxide (NO_2) can affect beans, tomatoes and oranges growths and yields. (Miller 2016, 128-129.) For every 1,8 million tonnes of coal consumed in a 1 GWe plant, 23 million tonnes of nitric oxides (NO_x) are emitted in the atmosphere (Vujic et al. 2012, 36).

5.3.5 Trace elements & heavy metals

Miller (2016, 134) points out that trace elements end up in the atmosphere through natural processes as well such as soil, seawater and volcanic eruptions. Coals might contain many elements in trace amounts, in fact, up to 76 elements (Miller 2016, 18). Trace elements are not usually toxic in low concentrations whereas heavy metals are. Heavy metals are indestructible chemical elements. Lead (Pb), mercury (Hg), arsenic (As), cadmium (Cd), chromium (Cr), and antimony (Sb) are usually found in trace amounts in coal, which Munawer (2017, 90-93) concentrates only. Whereas Miller (2016, 134) mentions different classifications depending on the United States Clean Act (CAAA) or the US National Research Council (NRC) and Lerner et al. (2012, 45) does not mention anything else besides lead (Pb), arsenic (Ar) and barium (Ba) by name and does not go into further detail. Volatilization, melting, decomposition and oxidation are the main forms of how metals get released into the soil and water, which in turn contaminates the soil and water. Aquatic creatures then intake these pollutants via food, skin, or gills, which are then bioaccumulated in liver, gills, or kidney of fish. If eaten by humans, they will bioaccumulate in humans as well. (Munawer 2017, 90-93.)

Lead (Pb) is considered extremely poisonous for humans and animals. Lead (Pb) can be deposited in the leaves, which then can be eaten by animals and thus accumulate in their bodies. It can accumulate in the soil and sediments as well, which in turn can affect the ecosystems by contaminating the land and water. Humans can end up accumulating it as well if they are eating a contaminated animal or plant material, thus causing various neural and organ issues (Miller 2016, 136, Munawer 2017, 90-93). In fact, according to Munawer (2017, 90-93) lead (Pb) has been found to be extremely mobilized, thus contaminating the nearby area of power plants easily. Miller (2016, 136) states that due to the usage of lead (Pb) in human history for various reasons, lead (Pb) can be found practically everywhere, even in Antarctica. Operating vehicles, mining and coal combustion are considered to be the main sources of lead (Pb) according to Munawer (2017, 91). Lead (Pb) can also corrode the pipelines as well. (Miller 2016, 136, Munawer 2017, 91-99, Vujic et al. 2012, 36-37.)

Mercury (Hg) is extremely toxic in methylmercury (CH_3Hg) form, which can be emitted from power plants either in gaseous form or inside fine particles (Miller 2016, 135). Mercury (Hg) in turn can accumulate in fish and wildlife and when eaten, accumulate in mammals or humans that consumed the mercury affected animal. Essentially becoming more concentrated in the body the further the food chain goes. Due to the mercury's (Hg) toxicity, it can cause various neural and organ issues. It can destroy crops as well due to soil contamination and can be absorbed by plants in small amounts (Miller 2016, 135). (Munawer 2017, 91-93, Vujic et al. 2012, 36-37.) According to Munawer (2017, 91) out of the coal power generation lifecycle, coal combustion is the main source of mercury (Hg) emissions and estimates that a quarter (1/4) of mercury (Hg) emissions are caused by coal utilization between years 1850 and 2008.

Arsenic (As) is extremely poisonous, where coal combustion is one of the major sources of arsenic (As), but however, differ according to coal rank and grade. Essentially, the arsenic (As) content on bituminous and lignite coal are 7,4-9,0 mg/kg, while for higher coal grades 49-50 mg/kg, concentration being highest in the volatile and particle form. (Munawer 2017, 92.) Essentially, arsenic (As) can accumulate on food chain as well, thus effecting marine life, mammals, and humans. Munawer (2017, 93) even states that once it has contaminated the environment it cannot be destroyed. However, Miller (2016, 136) claims coal combustion does not contribute much to the arsenic emissions, but in turn fly ash disposal and coal cleaning wastes do. Arsenic poisoning can do damage to nerves, skin and body and even damage fetuses (Miller 2016, 136).

Other elements of concern are cadmium (Cd), chromium (Cr), antimony (Sb), barium (Ba), molybdenum (Mo), selenium (Se), boron (B), beryllium (Be), fluorine (F), manganese (Mn), nickel (Ni), vanadium (V). Many are considered essential nutrients like in trace amounts, but once higher concentrations are present, damage to environment and living beings is possible. (Miller 2016, 139.)

5.3.6 Particulate matter (PM)

Particulate matter is defined as "a collective name for fine solid or liquid particles added to the atmosphere by processes at the earth's surface. Particulate matter includes dust, smoke, soot, pollen and soil particles." (European Environment Agency 2021). Particle sizes are generally between 0,001-500 μm (Miller 2016, 130).

Essentially, previously mentioned compounds in this chapter can be particulate matter if they are suspended in the atmosphere for some time, for example, sulphur (S) compounds and nitrogen (N) compounds can persist in the atmosphere as particulate matter, which can impair visibility in the area. (Miller 2016, 132, Vujic et al. 2012, 36). According to Miller (2016, 132), additional negative environmental impacts of particulate matter is that it may fall on vegetation thus affecting the plants' ability to photosynthesize, ability to gas exchange and increase its temperature. However, Miller (2016, 132) admits that there is not much known about the particulate matter effects on vegetation. Particulate matter can also absorb other pollutants from the air, thus causing further havoc. (Munawer 2017, 90). A very small particulate matter can concentrate in the lungs of living beings and thus cause cancer and emphysema or even result in DNA mutation (Munawer 2017, 90, Vujic et al. 2012, 36).

Fly ash particles can travel large distances from the coal plant and thus affect animals and humans from a larger distance. Fly ash can also decrease the soil pH to below 5, thus affecting agriculture negatively, as many crops do not thrive in such low pH conditions.

However, dry scrubbers a.k.a. electrostatic precipitators (ESPs) were invented to capture particulate matter. Essentially ESPs use static electricity to remove particles from the exhaust fumes before they exit into the atmosphere, thus letting only clean hot air to enter the atmosphere. It is essentially, air pollution control. However, for ESPs are usually designed for a particulate plant as coal types and other components combusted differ greatly from each other. Also, 2-4% of power plants electricity output goes to operating ESPs, which is considered a high cost. (Hanania, Stenhouse & Donev 2018.) However, Skipka and

Theodore (2014, 127) points out that ESPs are not capable to capture particulate matter in high collection efficiencies, especially since some low-sulfur coals have a high electric resistivity, making capturing particulate matter more difficult.

5.3.7 Organic compounds

Organic compounds are the gaseous matter that remain uncombusted when coal is not burned properly. Organic compounds are generally emitted in small amounts but can be emitted in increased concentrations during system start-ups or disruptions. Organic compounds are also called polycyclic organic matter (POM) or polycyclic aromatic compounds (PACs). However, the most common organic compound found in coal power plant are polycyclic aromatic hydrocarbons (PAHs), while they do not do corrosive damage to materials, ethylene can diminish plant growth and cause injury to some plants. Some PAHs can be carcinogenic as well. (Miller 2016, 133).

5.3.8 Radioactivity

While many people have the perception of coal burning being radioactive free, in reality it is not the case. This is because coal often contains trace elements of uranium (U), thorium (Th), radioactive potassium ($^{40}\mathrm{K}$), radium (Ra), 210-polonium ($^{210}\mathrm{Po}$) and radon (Rn). (Lerner et al. 2012, 13, Munawer 2017, 92, Vujic et al. 2012, 36-37.) Coal power plants are not generally built to obstruct radioactivity like nuclear power plants are (Munawer 2017, 92). Uranium (U) can also be released in fine particles to the atmosphere and even dissolve into water, thus polluting water sources and when coal is combusted 100 % of the radon (Rn) gas is released into the atmosphere and it can dissolve into the water as well, thus polluting water sources. Exposure to these radionuclides can cause bone and kidney damage as well as cancers (Miller 2016, 139, Munawer 2017, 92). However, Miller (2016, 139) states that radioactivity emitted from coal power plants is low, thus not really a concern.

5.4. Water

Coal preparation plants use a lot of water, besides mining process or transportation of slurry. The wastewater effluent often contains fine coal particles as well as coal refuse, which are essentially colloidal particles in the water. Treating this water efficiently proves to be particularly difficult for older coal power plants, but newer coal power plants generally have proper water clarification systems in place and even closed-circuit systems to lessen the pollution. This wastewater effluent is often contained; thus the environmental impacts would consist of the land being unsuitable for other uses, water pollution, possible landslides and dam failure, thus destroying and contaminating surrounding environment. Coal refuse wastewater would be especially detrimental to the aquatic species that are extremely sensitive to chemical and physical water conditions. (Miller 2016, 121-122.) Skipka and Theodore (2014, 319) also interestingly mentions that coal utilization also increases water temperatures of the local water source that the plant uses but does not disclose to what extent and the environmental impacts of it.

5.5. Coal waste

For every 1,8 million tonnes of coal consumed in a 1 GWe plant, 272 thousand tonnes of dust and ash particles are generated as waste according to Vujic et al. (2012, 36). McCombie and Jefferson (2016, 763) in turn provides an annual estimate of 400, 000 tonnes of ash in a 1 GW coal plant. Lerner et al. (2012, 237) mentions fly ash as the only waste to be disposed, while Miller (2016, 125) mentions others such as bottom ash, boiler slag, fluidized-bed combustion ash and flue gas desulfurization (FGD) material. Essentially, fly ash is captured by the control devices, while bottom ash is the large particles in the bottom of the boiler. Boiler slag in turn is molten inorganic material in the bottom of the boiler and finally, flue gas desulfurization (FGD) material is synthetic gypsum left after sulphur dioxide (SO_2) is removed via calcium-based reagents. (Miller 2016, 125). Coal combustion products (CCPs) such as fly ash is accumulated in the process, it is often recycled to create by-products such as road-building materials, cement additives or even pellets used to rebuild oyster beds (Skipka &

Theodore 2014, 127). Vujic et al. (2012, 36) includes other uses for coal ash like blasting grit, mine backfill, wallboards and can be even used in agriculture. While Miller (2016, 125) includes roofing applications, waste stabilization, AMD control and anti-skid materials, even fillers and extenders. So, there are clearly many uses for coal waste. Europe in fact utilizes 92% of the coal combustion products (CCPs), which is the second most after Japan of 96%. This is mostly due to raw material shortages as well as regulations encouraging the use of coal waste due to high disposal expenses. (Miller 2016, 125-126.)

There are some worries about the health effects of using fly ash as construction material as it would increase the average radiation dose on the people residing in the house by 135 μSv, even increasing emissions of radon (Rn) or decay product of thorium (Th). However, Miller (2016, 139) states that radioactivity emitted from these sources are not much different compared to other concrete additives and building material in the market. The coal combustion products (CCPs) do also carry iron (Fe), aluminium (Al), magnesium (Mg), manganese (Mn), calcium (Ca), potassium (K), sodium (Na) and silica (Si), which are not harmful. However, coal combustion products (CCPs) contain trace amounts of arsenic (As), barium (Ba), beryllium (Be), cadmium (Cd), cobalt (Co), chromium (Cr), Copper (Cu), nickel (Ni), lead (Pb), selenium (Se), zinc (Zn) and mercury (Hg). They are not inherently bad depending on the concentrations as small amounts can be considered as nutrients. Munawer (2017, 90) claims that CCRs in the soil and nearby pond can lower the pH to below 5, which would be too acidic to most vegetation. There is a risk of groundwater contamination and inhalation via wind or water into living beings as well, although EPA has concluded that coal combustion products (CCPs) do not pose much of a risk to the environment. (Miller 2016,125-126.)

6 NUCLEAR POWER ENVIRONMENTAL IMPACTS

6.1. Mining

Much like coal, the environmental impacts for nuclear power start from mining. Similar to coal mining, underground and surface mining methods are used depending on the uranium ore location. These in turn have similar environmental impacts. In some cases, in situ leach mining can be used as well, where the uranium ore is left underground, and the uranium (U) is dissolved via an acid or alkaline chemical and then the dissolved uranium (U) solution is pumped to the surface to be recovered. (Skipka & Theodore 2014, 203-204). Mining uranium often results in tailings. Tailings contain trace amounts of uranium (U), radium (Ra) and thorium (Th) and need to be disposed appropriately as some are radioactive (Lerner et al. 2012, 229). Lerner et al. (2012, 235) admits that fossil fuels need to be burned in the process of making fuel out of uranium (U), however, the amount of fossil fuels required to be burned would only make 2% of the energy uranium (U) produces.

6.2. Transportation

Much like coal transportation, uranium (U) needs to be transported to the nuclear plant from the mines and the nuclear waste from nuclear plant to a storage site. Generally, transportation costs for long distances would uneconomical, however, the high energy density of uranium (U) makes nuclear fuel economical. Also, due to the high energy and power density of uranium (U), less uranium (U) is required than many other energy sources to accomplish the same energy output. (Lerner et al. 2012, 229-236.)

6.3. Nuclear power plant

Nuclear power plant will have many effects on the nature, though many would argue, mostly positive. However, constructing a nuclear power plant would require large amounts of steel and concrete. The required amounts differ depending on the nuclear power plant's design. However, McCombie and Jefferson (2016, 760) states that concrete needed would be much less when compared to wind power farms. Additionally, traffic in and out of nuclear power plants will cause some change to the environment in the construction phase, considering that constructing a nuclear power plant takes a long time. These changes can affect negatively nearby wildlife by having some of their habitat destroyed combined with air pollution and noise pollution. (Breeze 2017, 92.)

6.3.1 Emissions

Nuclear power is considered to be renewable energy source, because of its low emission rate. According to Lerner et al. (2012, 232-235) nuclear power plants do not emit carbon dioxide (CO_2) nor sulphur dioxide (SO_2). Nuclear power prevents the release of 1451 million tonnes of carbon dioxide (CO_2) as well as 82,000 tonnes of metal each year in the world that coal releases. For example, France's air pollution has lowered 80-90% due to nuclear power. Therefore, nuclear power is considered to be cleaner than fossil fuels and does not contribute to air pollution, smog, nor the greenhouse gas effect. Since nuclear power does not release sulphur (S), it does not contribute to acid rain either, unlike coal does. (Lerner et al. 2012, 232-235.) Vujic et al. (2012, 32-35) states that nuclear power is the only technology currently to provide a safe baseload, while emitting zero greenhouse gas emissions, making it stand out positively from the other energy sources. In fact, Vujic et al. (2012, 34) estimated an annual decrease of 2,3 billion tonnes of carbon dioxide (CO_2) emissions by using nuclear power, which is a significant decrease in carbon dioxide (CO_2) compared to wind and solar energy together in the United States for the same period of time. Essentially, nuclear power is the only baseload that can replace fossil fuels and reduce global warming according to Vujic et al. (2012, 35).

When a nuclear power plant is built, that is when carbon dioxide (CO_2) is emitted the most, for example, building a 1 GW nuclear power plant releases about 300, 000 tonnes of carbon dioxide (CO_2). If we estimate a nuclear power plant age of 40 years, then 1 gram of carbon dioxide (CO_2) is released to every kWh of electricity generated. However, throughout the fuel life cycle emissions can be 40-288 grams of carbon dioxide to every kWh electricity generated. This depends on the fissile concentration of the nuclear ores. This means even though the nuclear power plant is not releasing directly carbon dioxide (CO_2), at some point of the nuclear energy life cycle some carbon dioxide will be released, though considerably less compared to other energy sources generally. Essentially, nuclear energy beats other renewable energy sources in lower emissions and certainly beats the highest emissions of coal power. (McCombie & Jefferson 2016, 761.)

6.3.2 Radioactivity

Radiation is the most feared aspect of nuclear power when it comes to the general population's worries. However, people often forget that they are exposed to different levels of radiation daily. Lerner et al. (2012, 224-225) mentions background radiation, which is for example radiation from the sun. Many variables affect the radiation levels, like altitude or geography. Countries considered to be in high altitudes, such as Finland receive more background radiation than countries in low altitudes, such as Australia. This is because Finland is closer to north pole and Australia is closer to the Equator. In fact, coal power plants emit more radiation than a nuclear power plants, according to Vujic et al. (2012, 37) population near coal power plants are exposed to radiation 100 times more than the population near nuclear power plants. However, some radioactive gases are released such as Krypton-85 (^{85}Kr), Xenon-133 (^{133}Xe) and Iodine-131 (^{131}I), which McCombie & Jefferson (2016, 761) states that they can result in small doses of radiation on humans.

It is important to note that besides uranium (U) and plutonium (Pu), cesium-137 ($^{137}\mathrm{Cs}$) and strontium-90 ($^{90}\mathrm{Sr}$) are produced as nuclear waste as well. These two are highly radioactive as well for a very long time. Half-life of plutonium (Pu) is 24, 000 years and others can be even more. (Lerner et al. 2012, 228.) It is crucial to store these radioactive materials properly as large doses of radioactivity are lethal, smaller doses can be lethal as well, but generally require a longer exposure time. High doses of radioactivity can cause multitude of cancers, which might not show up immediately. Genetic mutation is also possible, which would have consequences for generations. (Breeze 2017, 86.)

6.4. Water

Nuclear power plants require water to cool down steam turbine condenser, which will require large amounts of water (Breeze 2017, 92). Generally depending on the cooling system in the nuclear power plant water usage can vary from 1500-2700 l/MWh or 32 $\frac{\mathrm{m}^3}{\mathrm{s}}$. Evaporation has to be taken into account as well, which is usually about 1 $\frac{\mathrm{m}^3}{\mathrm{s}}$. (McCombie & Jefferson 2016, 760.) Massive amounts of water are used, which is then cooled by using cooling ponds or cooling towers. Skipka and Theodore (2014, 319) mentions that the water released increases the temperatures of water sources. Breeze (2017, 92-93) does claim that higher temperature water released in the nature can have some effects on the aquatic or marine environment and thus should be monitored. After water has been cooled, it can be released back into nature. Also, the released water does not come into contact with radiation, thus making the water safe for the environment. In fact, there has been some benefits in the cooled water released, which has increased wetlands. This in turn has attracted wildlife and even endangered species into these areas. Essentially, these animals such as bald eagles, wild turkeys, pheasants etc. are thriving. In fact, some nearby nuclear plant areas have been made into wildlife preserves and parks. (Lerner et al. 2012, 233-235.) McCombie and Jefferson (2016, 760) states that nuclear power uses less water than coal or biogas, but more than wind and solar. However, fails to provide numerical proof.

6.5. Nuclear waste

Nuclear waste is considered to be the biggest concern after the fear of nuclear plant accidents and is probably the most reasonable fear as well. For every 27 tonnes of nuclear fuel consumed, 26 tonnes of uranium (U), 0,27 tonnes of plutonium (Pu) and 0,8 tonnes of fission products are generated (Vujic et al. 2012, 36). However, Vujic et al. (2012, 36) and Breeze (2017, 90) describe in this case uranium (U) and plutonium (Pu) as not waste exactly, claiming only 3 % of the spent nuclear fuel is an actual nuclear waste as uranium (U) and plutonium (Pu) are often recycled in the case of closed fuel cycle. Skipka and Theodore (2014, 207) states that nuclear waste cannot be recycled, yet mentions about reprocessing nuclear fuel and breeders, which is essentially recycling parts of the nuclear waste, which is rather contradictory. Skipka and Theodore (2014, 207) states that nuclear waste is generally divided into categories of low-level waste, intermediate-level waste and high-level waste. However, Lerner et al. (2012, 227) mentions only two nuclear waste level types as low-level and high-level. The goal of nuclear waste management is to keep the nuclear fuel waste confined until it poses no threat to the environment or living beings. During containment it is imperative to avoid leakage of the radioactive material outside of its intended containment. If leakage were to happen, the radioactive material could leak into ground water and spread for long distances.

High-level waste is usually buried underground in steel and concrete tanks for centuries, which generally consist of spent fuel and reprocessing plant waste. Skipka and Theodore (2014, 208) adds that underground repositories are the cheapest and safest option. Lerner et al. (2012, 228) does not mention about the price nor the safety of underground repositories, just that they are more accepted, however, notes that it is important to place the underground repositories in a geological area that is not known to have earthquakes, tremors, or volcanic activity. The nuclear waste would be mixed with silica to create glass beads, which in turn stabilize the nuclear waste, reducing the rate of radiation seeping through into the air or water. Once these repositories would be full, they would be sealed. Another problem with underground repositories would be the general public, that do not want a repository near them. Generally, people would prefer the repositories in a more rural area far from general public, but this would increase other risks in the transportation phase. (Breeze 2017, 89-91, Lerner et al. 2012, 228-229.)

Intermediate-level waste is usually metal cases from fuel rods that are put in concrete cribs, where the bottom of the crib is open to the soil, where water passes through taking the radioactive isotopes with it. Luckily, intermediate-level waste does not have to be cooled down like high-level waste is. Low-level waste is usually just stored on site in the surface ponds or incinerated. Lerner et al. (2012, 228) mentions launching the nuclear waste into space, burying in a remote island or polar ice sheets or under seabed. However, these are considered rather expensive options and therefore, not as realistic. (Breeze 2017, 91.)

Another example of nuclear waste created would be a 1000 MW nuclear power plant generating around 200-300 m^3 of low and intermediate waste and 25 tonnes of fuel waste. In about nuclear plants 60-year lifetime 1500 tonnes of fuel waste is generated, where about 5 % of the waste is an actual high-level waste. Essentially, high-level waste would make 1,5 tonnes per GW electricity generated in a year. (McCombie & Jefferson 2016, 763-764.) This is a slight difference from Vujic et al. (2012, 36) and Breeze (2017, 90) claims of 3% being actual nuclear waste. However, Vujic et al. (2012, 36) and Breeze (2017, 90) did not exactly mention what amount was high-level waste as McCombie & Jefferson (2016, 763-764) did. Either way there is a small discrepancy in the nuclear waste percentages between the literature.

Also, when a nuclear power plant is decommissioned a large quantity of nuclear waste is created and according to Breeze (2017, 90-91) can in fact, generate the largest amount of waste. This is because over the nuclear power plant's lifespan most of the components in the plant are considered contaminated and treating large radioactive waste can be rather costly. Best would be to dismantle the plant and get rid of the radioactive waste in a safe fashion, but this is the most expensive option. Other option is to seal the plant indefinitely for hundreds of years, everything inside as is the case of Chernobyl plant in Ukraine or take most radioactive material out and seal the plant for less than a century. Decommissioning a nuclear power plant is an extremely costly process of 450-1,3 billion dollars, which is often required to be planned ahead of time by regulations in their prospective countries. (Breeze 2017, 91-92.) Decommissioning will once again just as in its construction phase cause a lot of traffic in and out of the nuclear power plant, which can once again disturb the wildlife (Breeze 2017, 93).

7 FUTURE OF COAL POWER

7.1. Politics

According to McCombie and Jefferson (2016, 764) in 2011 the public support of coal was at 48 %, which was the second lowest rating. In turn, solar-, wind-, hydro- and natural gas energy had a higher public support than coal energy. While public right now is more against coal power than in favor, especially in developed countries, some countries have decided to embrace coal power. Also, it is important to note that if these coal power plants often employ majority of the people from the community, thus in closing would affect many people's livelihood. Especially considering that coal power plants do not require as high education level as nuclear power plants. Demand for coal power is expected to rise in the future even more. (Lerner et al. 2012, 47, Vujic et al. 2012, 41.) Vujic et al. (2012, 31) stresses that unless non-OECD countries are going to adopt policies to limit greenhouse gases, then the world coal consumption will continue to increase in the future.

Interestingly, Vujic et al. (2012, 41) states that coal energy has been under-regulated, considering the early health implications on humans contributed to coal energy. Coal has also 25 deaths to every TWh electricity generated. This means coal is second to oil, which has 35 deaths to every TWh electricity generated. These high death rates can influence coal usage even more in the future negatively as safety is becoming more important. However, it is important to note that coal fatality rates are much higher in undeveloped countries such as China. (McCombie & Jefferson 2016, 761-762.)

7.2. New technology

Scientists have been creating new methods to use coal, that are more environmentally friendly. This is often called clean coal technology. This is where coal gasification comes into the picture. Lerner et al. (2012, 47-49) states coal gasification is where coal is turned into a gas, which can be used as fuel. Essentially, sub-bituminous coal is crushed and then heated in a boiler combined with air and steam, which releases gases that can be used as fuel to generate electricity much like natural gas. Carbon dioxide (CO_2) and sulphur dioxide (SO_2) are removed from the gas via scrubbers. Effectively, removing the pollutants before the gas is burned thus lowering emissions significantly, when compared to coal burning power plants. What is left is non-hazardous coal ash, which is to be disposed of, but is believed it could be used to build roads and buildings. Coal gasification also produces methane (CH_4) and other gases consisting of carbon monoxide (CO) and hydrogen (H), which can be used by chemical industries and plants. However, the reason why it is not as popular is because it is very expensive, in fact, costs three times as much as natural gas. Large quantities of water are also required, which might not be as feasible in some areas. The main benefit is the environmental advantage; however, efficiency of the coal energy goes down significantly, up to 30-40% of the coal energy is often lost in the gasification process. While coal gasification has existed for a long time already, many believe it will become more popular in the future if the technology will improve further via using catalysts or performing the gasification inside the mines. (Lerner et al. 2012, 47-49.)

Lerner et al. (2012, 43-48) also mentions coal liquefication, where coal is turned similar to petroleum, that powers motor vehicles. Coal pulverization in turn is where coal is broken into small particles and then burned and Hydrosizers use water to extract the coal left out from the mining waste. There are expected to be better coal scrubbers in the future than right now to reduce pollution in all stages of coal production as well as the use bacteria to separate pollutants from organic components thus allowing the removal of pollutants before burning. Lastly, fluidized bed technology is where elements are added in the furnaces to remove pollution or burning coal at lower temperatures. (Lerner et al. 2012, 43-48.)

8 FUTURE OF NUCLEAR POWER

8.1. Politics

According to McCombie and Jefferson (2016, 764) in 2011 public support for nuclear power was at 38 %, which was the lowest out of all the major energy sources, showing people prefer renewables the most. Even though nuclear power has many benefits, the public tends to still worry about the risks associated with nuclear power. These risks are nuclear accidents and the possibility to make nuclear weapons (Breeze 2017, 85). This is due to the fear of radiation that is an invisible enemy, making it hard to fight against it thus making it scarier for the general public. This has divided the public into nuclear power supporters and opposers. Opposers fear possible catastrophic accidents in the future, even though the chances are low, they are not zero. Vujic et al. (2012, 41) states the opposite of coal in case of regulations, claiming nuclear power tends to be over-regulated, considering the small number of deaths related to nuclear energy. Lowering regulations on nuclear power often had positive effect in efficiency and reducing the duration and frequency of reactor outages (Vujic et al. 2012, 34). However, there is a fine line deregulating to improve efficiency and safety, but if deregulated too far and it can make the nuclear plants more susceptible to accidents. Essentially, nuclear power is competing with hydro and wind in less than three deaths to every TWh electricity generated (McCombie & Jefferson 2016, 761-762). This will most likely affect positively in the future of nuclear power, though the fear of nuclear power accidents might be too extensive and leave these positive points in the darkness forever.

Some countries have a high opposition to nuclear power, namely Germany, Austria, Italy, and Australia. Germany and Switzerland had announced to discontinue the nuclear power programs completely after Fukushima Daiichi power plant accident in Japan in 2011, however, Germany had to reverse some of the nuclear plant shutdowns soon after. In fact, nuclear power has seen a decline of 55% in nuclear power production in Germany (Eurostat 2021). It is rather natural for the support of nuclear power to decrease after a nuclear accident. There have been many countries in high support for nuclear power as well, namely

China, India, South Korea, Finland, Switzerland, and Netherlands. Many of these are building or planning on building more nuclear power plants or extending the lifetimes of current nuclear power plants. (McCombie & Jefferson 2016, 765.) Many countries are becoming more concerned of climate change, but if they want to tackle climate change, the globe will have to double nuclear power generation to 930 GW of installed capacity. Reality is as well that nuclear power is most popular in developed considered rich countries that invested into nuclear power long time ago. Wind and solar however, are considered fairly low costing, which have started to undermine nuclear power. (Breeze 2017, 87-88.)

8.2. New technology

What used to make nuclear power plants so expensive, was their huge size used to produce greatest amount of power possible. However, now plans in the future are to make smaller and thus cheaper nuclear power plants, which lowers the expensive initial cost of nuclear power plant that larger nuclear power plants have. The benefit of smaller nuclear power plants would be that they could be used in more rural locations that have harder time having access to the power grid. (Lerner et al. 2012, 217, Vujic et al. 2012, 39.)

Nuclear power plants are essentially divided into generations, where Generation I was the first kind of nuclear reactors, which were built between the 1950’s and 1970’s. Generation II reactors were built in 1970’s to 1990’s, which are mostly still in use today. Generation III are considered as advanced reactors due to their safety systems compared to Generation II. However, new designs called Generation III+ have been underway, which are considered to have even better safety systems and simpler designs than its predecessors. Generation III+ would also require less concrete and steel, which in turn would drastically lower the footprint of the plant as well as require less maintenance. A few of these have been already built. Generation IV is considered to be the most advanced nuclear reactor system at the moment. Its purpose is to improve reactors and fuel cycles performance with even better safety than Generation III+ plants, while minimizing nuclear waste. This would be due to an effective closed fuel cycle and thus decaying the radioactive waste in just few hundred years. As an added bonus it lowers the chances for unwanted groups to make nuclear weapons out of the nuclear waste that comes out of Generation IV plants. (Vujic et al. 2012, 39-40.)

Nuclear fusion has been an extremely debated topic and lots of research has been done, with very little of success. According to Breeze (2017, 29-30) and Lerner et al. (2012, 218-222) states that nuclear fusion is actualized in the sun and stars at extremely high temperatures of 100 million degrees Celsius and at an extremely high pressure. Unfortunately, these temperatures do not occur naturally on Earth. However, Breeze (2017, 30) states that the fusion reaction would be controlled via magnetic field because nothing else could withstand such temperatures. There have been two magnetic fields under research; toroidal and inertial confinement. The benefits of nuclear fusion would provide large amounts of energy, with very little of nuclear waste, making it much safer option rather than nuclear fission. In fact, fusion reaction would never spin out of control. Nuclear fusion is based on fusing atoms together to form a heavier and larger atom. The fused atom’s mass is less than the mass of the two separate atoms combined. Only conclusion to be made is that the difference in mass is released in energy. For example, it is estimated that a small quantity of heavy hydrogen could provide the corresponding energy of 18 tonnes of coal. Since fusion reaction is not quite feasible, some believe cold fusion, which is fusion reaction at low temperatures, could be more practical. It has not quite been actualized yet, however, many believe in the future with technology advancement and further research, it could be possible. (Breeze 2017, 29-30, Lerner et al. 2012, 218-222.)

Thorium (Th) is another nuclear fuel that can be used but is not quite as popular yet, but it can be turned into a fissile isotope of uranium (U). Natural thorium (Th) is not fissile, which is why breeder reactor must be used. Essentially, thorium (Th) is bombarded with neutrons that create 233-protactinium (Pa) which becomes 233-uranium (U) once it decays. 233-Uranium (U) is fissile and can be used. Thorium (Th) breeder reactors have the advantage of being able to be used in conventional reactors, which 238-Uranium (U) does not have. It is even more abundant in nature than uranium (U) is. Thorium (Th) is found in high quantities in India. In fact, Norway, India and China are experimenting with thorium (Th) reactors. (Breeze 2017, 11.) There is estimated 6,2 million tonnes of thorium (Th) reserves in the world, mostly found in Monazite, which is a phosphate mineral containing 6-12% of thorium (Th). Essentially, Monazite can be found in India, Brazil, Australia, the United States, Egypt, Turkey and Venezuela. Thorium (Th) could increase nuclear fuel reserves significantly in the future if used. (Breeze 2017, 20-29.)

Skipka and Theodore (2014, 207) mention briefly Molten-salt reactor and Molten-salt breeder reactors, which could have a great deal of potential in the future. Molten-salt reactors use molten salt as a coolant rather than water. Also, there would be no need for fuel rods as the nuclear fuel would be dissolved in the molten salt directly. The benefit of molten salt reactors is that they can use different types of nuclear fuel such as thorium (Th). Molten salt reactors are also more efficient and safer than light water reactor. (Pacific Northwest National Laboratory 2018.)

9 COAL POWER & NUCLEAR POWER COMPARISON

9.1. Nuclear & coal energy generation comparison

Nuclear power and coal power utilize similar systems to generate electricity in terms of using high pressure steam according to the literature. McCombie and Jefferson (2016, 789) and Lerner et al. (2014, 45) provide the energy density of coal, while McCombie and Jefferson (2016, 789) is the only one to provide one for nuclear. Energy density of an average coal fuel generates 8 kWh of electricity for 1 kg of coal versus 1 kg of uranium (U) generates an average 24,000,000 kWh of electricity. This difference is absolutely massive and it is clear that nuclear fuel has an energy density of 23,999,992 kWh more than average coal fuel does. Due to the energy density of uranium (U), it would be more economical for Europe to import uranium (U) than coal.

Coal power density was not provided by any of the literature, thus outside source by Zalk and Behrens (2018, 87) was used, whereas power density of nuclear power was provided by McCombie and Jefferson (2016, 759). Average coal power density is 135,1 $\frac{\mathrm{W}}{\mathrm{m}^2}$, whereas nuclear power can be as large as 4000 $\frac{\mathrm{W}}{\mathrm{m}^2}$. Essentially, nuclear power density has 3864,9 $\frac{\mathrm{W}}{\mathrm{m}^2}$ higher power density than the average coal power density. However, this is just average coal power density, which depends on the rank of the coal. It is clear that nuclear power has a considerably higher power density than coal, which makes nuclear power superior in terms of size of the power plant compared to coal and renewables. Many renewables require large areas and while coal power plants do not require as large areas, but it still provides less power compared to nuclear power.

Vujic et al. (2012, 32-33) states that coal power plant average capacity factor in the United States is 65,4 %, while the average nuclear capacity factor in the United States is at 91,2 %. Essentially, nuclear power has 25,8 % higher efficiency than coal power. Nuclear power is clearly superior in terms of efficiency. This is however, for the United States and results can differ globally as some countries have older coal and nuclear power plants still in commission. Developed countries have generally newer nuclear and coal plants with newer technology, thus having a higher efficiency.

When comparing Vujic et al. (2012, 35) and Skipka and Theodore (2014, 110) statistics on coal fired electricity generation, it is clear that between 2007-2014 coal power in the world stayed close to the 41%. There have been some recent changes to coal power according to World Coal Association (2020), where in 2020 coal power generated 37% of world's electricity. Whereas nuclear power generated 13,8 % of world's electricity in 2007 according to Vujic et al. (2012, 35), but lowered to 10,6 % in 2013 according to Breeze (2017, 9). Essentially, both coal and nuclear power electricity generation have decreased worldwide over the years.

Coal supplied 37,2 % of OECD member countries produced electricity during 2007 according to Vujic et al. (2012, 35). Whereas Skipka and Theodore (2014, 202-203) stated nuclear power provided 30 % of the electricity generated in Europe. However, Skipka & Theodore (2014, 202-203) did not define Europe and even then, comparing coal and nuclear would prove to be difficult due to Vujic et al. (2012, 35) stating OECD member countries, which not all are part of Europe. Even though Miller (2016, 100) predicted nuclear power to increase 0,7 % a year in Europe and even more in the world, many countries in Europe have gone through a sharp drop in nuclear power, namely Germany by 55 % (Eurostat 2021). This proves Skipka and Theodore (2014, 202-203) to be quite dated information as it seems nuclear power grows generally slowly, but it can see a fast decline. Breeze (2017, 7-8) explained that total energy production is growing in the world, but nuclear is going through the opposite effect. However, global nuclear generating capacity has been increasing steadily and when generating capacity and efficiency are increasing, it enables higher power production by nuclear power plants, thus lowering the need for additional nuclear power plant construction.

According to IEA (2019, VI.43-VI.45) coal generated 6860,97 TWh of heat and electricity in the world and OECD member countries 253,60 TWh in 2017. It provides a good comparison of other uses for coal as according to IEA (2019, xvi) in 2017, 66,5 % of the coal in the world is used for electricity and heat, while

OECD member countries use 82,3 % of coal for electricity and heat. Nuclear in turn generated 2478 TWh in the world in 2013 and 2441 TWh in 2015 according to Breeze (2017, 7), but it used to be even more. This decrease in power generation in nuclear power is likely due to the Fukushima Daiichi nuclear power plant accident in Japan in 2011. It is clear that coal is still superior in the world in terms of demand in electricity production usage when compared to nuclear power.

Either way, coal fired electricity is expected to increase 2,3 % a year according to Vujic et al. (2012, 31), while Vujic et al. (2012, 31) and Miller (2016, 100) believe nuclear power will increase 2,0 % and 2,5 % per year. Coal and nuclear power are expected to increase in the world despite the renewables taking over more in the energy sector.

According to Vujic et al. (2012, 33) coal power costs an average 6,2 cents/kWh, without the carbon tax. However, some countries such as the United States have a 25-dollar carbon tax to every ton of coal. This adds up to 8,3 cents/kWh. Nuclear power cost is an average of 6,6 cents/kWh. Essentially, without the United States carbon tax, coal power cost would be 0,4 cents/kWh cheaper, but once carbon tax is added coal power cost is 1,7 cents/kWh more expensive. (Vujic et al. 2012.) In the case of Europe none of the literature provided costs. However, Europe has a carbon tax to every ton of carbon dioxide equivalent (CO_2e), which is different from the United States specific carbon tax per ton of coal. Essentially, for every ton of carbon dioxide equivalent (CO_2e), the average carbon tax in Europe would be 35,85 euros, which is 39,21 dollars (Asen 2020). Effectively, if 1,8 million tonnes of coal emit 5,5 million tonnes of carbon dioxide (CO_2), which would cost 197,175 euros. Nuclear power plant emits none, so none of the carbon taxes apply nuclear power in Europe. Essentially, making nuclear power a cheaper option once carbon taxes are added in. It is, however, important to note that different countries have different carbon taxes and above-mentioned carbon tax was only an average for Europe. Thus, in some countries carbon tax could be very low while others very high.

Miller (2016, 88) and IEA (2019, xvi) stated that coal consumption has been decreasing in Europe, which makes sense considering many European countries are trying to decrease fossil fuels dependency in the energy sector. However, coal consumption has been increasing in other parts of the world, especially Asia and if Europe is planning on tackling environmental issues, their chances of doing much will be diminished if undeveloped countries are not joining in. According to IEA (2019, ix) global and non-OECD -member countries total coal consumption has increased 1,2 % and 2,5 % respectively, while OECD member countries have decreased total coal consumption by 3,2 %. It is important to note that OECD member countries consist of European countries the most. Interestingly OECD member countries are more dependent on nuclear power than non-OECD member countries are according to Breeze (2017, 7-8).

Coal reserves are rather difficult to compare between countries according to Miller (2016, 37) and Skipka and Theodore (2014, 109), mostly because different countries have different definitions on reserves. Miller (2016, 38-39) and Skipka and Theodore (2014, 109) stated coal to be the most abundant fossil fuel, ready to last for roughly for 115-150 years in current production levels, while Lerner et al. (2012, 223-224) states uranium (U) to be abundant as well. However, McCombie and Jefferson (2016, 760) and Breeze (2017, 11) are more in consensus, while Vujic et al. (2012, 39-40) estimated if breeder reactor were to be used in the future more, uranium (U) reserves could be extended by thousands of years. Additionally, if thorium (Th) gains more popularity in nuclear power production, then the reserves would be even more. However, Vujic et al. (2012) is among the oldest literature sources, causing it to be the most unreliable among Lerner et al. (2012). Western Europe itself does not have many coal or uranium (U) resources available. Germany, Russia and Ukraine have the highest coal reserves in Europe; however, many other European countries have coal reserves, consisting mostly lower ranking coal. Russia and Ukraine also have uranium (U) deposits as well according to Miller (2016, 40-48) and Breeze (2017, 17-18). Coal reserves are more abundant in Europe than uranium (U) reserves, in which case only options would be either Russia or Ukraine. Politically, Russia might not be every European country’s first choice due to European Union having sanctions on Russia in various subjects due to the Ukraine dispute, which would essentially leave Ukraine as the only choice (European council 2021). Ukraine in turn would have only 2 % of the world’s uranium (U) as stated by Breeze (2017, 17-18), thus some European countries will be better off looking for elsewhere. However, as before discussed the energy density of uranium (U) is large, which would make transporting uranium (U) rather cheap and thus more reasonable for Europe's uranium (U) needs.

9.2. Coal and nuclear environmental impacts comparison

Coal and nuclear power's environmental impacts both start from mining. Perhaps the most extreme difference in literature is in mining. Literature on uranium (U) mining was almost glided through compared to coal environmental impacts. Miller (2016) provides a very detailed description of the environmental effects of coal, but Skipka and Theodore (2014) and Lerner et al. (2012) are very brief, lacking especially in any statistics. They would however, mention that uranium (U) ore mining is very similar to coal.

Both coal and nuclear use underground and surface mining methods to obtain coal and uranium (U) according to Skipka and Theodore (2014). Miller (2016) mentions that mining can cause subsidence thus changing the entire structure of the land down to the hydrological movement. Considerable amount of water is used as well, which creates large amounts of wastewater and if used in excess it could affect the groundwater flow or level. Methane (CH_4) is released a considerable amount in underground mining as it is estimated to account 80% of total coal methane emissions according to Miller (2016). In the case of uranium (U) mining, methane (CH_4) is not mentioned but can be presumed to be included in nuclear mining as well. There are methods to extract the methane (CH_4), but one is either releasing it to the atmosphere to reduce accidents or to be extracted to be used as an energy source.

Surface mining affects top of the land the most, which essentially often requires the land to be destroyed to gain access to the coal or uranium (U). The mining activity can cause dust levels and noise levels to raise as well affect negatively on the wildlife. Sedimentation can as well affect the groundwater negatively as well as the soil chemistry. Surface water streams can change as well. Additionally, erosion is considered to be a massive problem due to changing the topsoil infiltration rates or overly compacted topsoil can lower the soil infiltration rate thus lowering the groundwater levels, but these can be diminished with a proper land reclamation. This, however, does not always happen. Methane (CH_4) is released as well, but in lesser extent than underground mining.

Waste rock is accumulated in the mining process as well as wastewater in uranium (U) and coal mining. Wastewater can be acidic or alkaline and if it can reach the groundwater systems, it can change the pH of that water. These changes can kill aquatic creatures and thus affect negatively on the wildlife animals. There are methods to treat the wastewater as it can include even radioactive materials, which have to be handled appropriately. However, accidents are always a possibility. (Miller 2016.) However, uranium (U) can also be recovered via in situ leaching, which allows a chemical to recover the uranium (U) from the land with minimal land changes according to Skipka and Theodore (2014).

Transportation in the case of coal power is better detailed than nuclear, but both are still rather vague. Literature mentioned coal transportation four times, while uranium (U) transportation was only mentioned by Lerner et al. (2012) briefly. Essentially, proper information on uranium (U) transportation is severely lacking and more studies would be needed on this. The vagueness is partly due to different transportation methods, which use different fuel methods depending often on the location and distance to the destination. Of course, fossil fuels used on this period for both causes emissions, but the extent of it is not disclosed in the literatures. Coal is also lost during the transportation of an average of 0,2-1,0 % depending on the distance. Coal can as well be transported via slurry in a pipeline to arid regions, but large quantities of water are required. Nuclear waste transported will require extra security and is often not allowed to leave nation's borders for the fear of terrorist attacks. The tight security requirements could be why uranium (U) and nuclear waste transportation information is lacking.

While mining and transportation had many similarities among coal and nuclear power, in emissions differences are more profound. Emissions depend tremendously on the age and technology of the coal power plants. Coal emissions decrease with the newer and more advanced coal power plants, while nuclear power plants do not have emissions per se, but new technology will increase the efficiency and safety of the nuclear power plants. (McCombie & Jefferson 2016.) McCombie and Jefferson (2016, 761) stated that 920 grams of carbon dioxide (CO_2) is emitted to every kWh generated. Vujic et al. (2012, 36) provides another example as stated before for every 1,8 million tonnes of coal consumed 5,5 million tonnes of carbon dioxide (CO_2) is emitted. However, the coal rank makes a difference on how much carbon is released as they have different carbon contents. Nuclear power plant in turn emits none in direct emissions. In fact, according to Lerner et al. (2012, 232-235) nuclear power prevents the release of 1451 million tonnes of carbon dioxide (CO_2) and 82,000 tonnes of metal in the atmosphere every year compared to coal. However, nuclear power plants do emit an estimated 300,000 tonnes of carbon dioxide (CO_2) in the construction phase when building a 1 GW nuclear power plant for example. Also, indirectly, fuel lifecycle emissions are generally between 40-288 grams of carbon dioxide (CO_2) to every kWh electricity generated, this is depending on ore concentration. (McCombie & Jefferson 2016.) Essentially, even though nuclear power in the end does release some carbon dioxide (CO_2), the amount is considerably less compared to coal and once the amount of electricity generated is taken into consideration, it could be considered almost negligible. Carbon monoxide (CO) emissions are very small in case of coal power and non-existent in case of nuclear power.

Sulphur (S) is another element that is released in coal combustion, where sulphur (S) can increase water acidity, leach nutrients and metals into the water, thus affect aquatic animals negatively and lastly, hinder plants' ability to photosynthesize. (Munawer 2018, Miller 2016.) Coal industry has improved technologically to lower the sulphur (S) amount released in the atmosphere through wet scrubbers, which are essentially 98% effective. They can be rather expensive, but Europe is considered a developed country, thus it would be entirely possible for European countries to afford wet scrubbers. (Skipka & Theodore 2014.) Nitrogen has similar environmental effects to sulphur and every 1,8 million tonnes of coal consumed 23 million tonnes of nitric oxides (NO_x) are released (Vujic et al. 2012). There are many trace elements and heavy metals released in coal combustion, lead (Pb), Mercury (Hg) and Arsenic (As) being some of them.

Particulate matter (PM) is another negative environmental impact that can impair visibility, impact on plants ability to photosynthesize and even change soil pH thus affecting vegetation other ways. There are dry scrubbers or ESPs available to capture particulate matter (PM), but they have a high energy requirements according to Hanania, Stenhouse & Donev 2018). Dry scrubbers are more effective when coal is high in sulphur (S), which can be removed via wet scrubbers, essentially preventing sulphur (S) and particulate matter (PM) from being released into the atmosphere. These obviously come with a higher cost, which still should be economically possible for European countries and many already have them. If dry and wet scrubbers are truly as effective as stated, this could help coal to compete with nuclear power and other energy sources. However, in the case of nuclear power there is no sulphur-, nitric emissions nor trace elements, heavy metals, particulate matter (PM) or organic compounds. There is not much to compare here between nuclear and coal power in terms of emissions. There is essentially no need for wet or dry scrubbers in the nuclear power plant, thus proving in terms of emissions, nuclear power is superior to coal power.

There is plenty of natural radiation that living beings on Earth are subjected to everyday and cause no harm. Nuclear power and coal power emit radioactivity as well. This is where proper comparisons of coal and nuclear power can resume, while environmental impacts were rather one sided as stated above. Coal emits radioactivity, because it often has trace amounts of uranium (U), thorium (Th), radioactive potassium ($^{40}\mathrm{K}$), radium (Ra), 210-polonium ($^{210}\mathrm{Po}$) and radon (Rn) according to Lerner et al. (2012), Munawer (2017) and Vujic et al. (2012). Uranium (U) and radon (Rn) can dissolve in the water thus polluting it. According to Miller (2016) and Munawer (2016) large amounts of radiation can cause multiple types of cancers on living beings, and even cause genetic mutation. However, Miller (2016) also states that radioactivity emitted from coal power plants is very small. When compared to nuclear power, coal power emits 100 times more radiation in the nearby coal power plant environment compared to nuclear power plant environment according to Vujic et al. (2012), which was not mentioned in any other literature. McCombie and Jefferson (2016) states that nuclear power plants release radioactive gases such as Krypton-85 ($^{85}\mathrm{Kr}$), Xenon-133 ($^{133}\mathrm{Xe}$) and Iodine-131 ($^{131}\mathrm{I}$). However, the amount is not disclosed by McCombie and Jefferson (2016), but states that these released gases would subject humans to small doses of radiation.

Nuclear waste consists of uranium (U), plutonium (Pu), cesium-137 (^{137}Cs) and strontium-90 (^{90}Sr) according to Lerner et al. (2012), but it is important to note that these are highly radioactive and in larger quantities compared to coal radioactive trace amounts. That is what makes nuclear power stand out compared to coal radioactive nuclides. Essentially, these radioactive materials coming from nuclear power plants are in lethal even in smaller amounts. Smaller amounts just require longer the exposure time according to Breeze (2017).

Coal waste is perhaps the biggest advantage of coal power. Fly ash, bottom ash, boiler slag, fluidized-bed combustion ash and flue gas desulfurization material are considered as coal waste. Essentially, 1,8 million tonnes of coal consumed in a 1 GW coal power plant generates 272 thousand tonnes of ash (Vujic et al. 2012, 36). McCombie and Jefferson (2016, 763) provides another example, where a 1 GW coal power plant generates 400,000 tonnes of ash in a year. Nuclear waste is perhaps the biggest disadvantage of nuclear power. Essentially, 27 tonnes of nuclear fuel generate 26 tonnes of uranium (U), 0,27 tonnes of plutonium (Pu) and 0,8 tonnes of fission products in a 1 GW nuclear plant (Vujic et al. (2012, 36). Essentially, even though nuclear waste is generated less, it is more dangerous than coal waste. Vujic et al. (2012) provides great comparisons of both coal and nuclear power waste, which makes accurate comparisons easier. It is clear that more coal waste is generated compared to nuclear waste. However, nuclear waste is highly dangerous, even though Vujic et al. (2012, 36) and Breeze (2017, 90) state that only 3% of nuclear waste is actual nuclear waste as uranium (U) and plutonium (Pu) can be recycled. But recycling nuclear waste has not been designed in all nuclear power plants such as closed through nuclear power plants of older generations. Closed fuel cycle nuclear power plants and breeder fuel cycle nuclear power plants essentially recycle the nuclear fuel to make more fuel for nuclear power plants (Touran 2009).

The main benefit of coal waste is that it can be recycled into other useful materials such as road-building materials, cement additives, as pellets to rebuild oyster beds, roofing, waste stabilization etc. Europe in fact utilizes 92% of the coal waste. There are some worries of the radiation dose increase on humans, but according to Miller (2016) it is not a source of concern, when compared to other building materials that emit some radiation as well. Coal waste products carry also numerous elements, but in small amounts they can be even considered as nutrients. Groundwater contamination is possible as well, though Miller (2016) mentioned that EPA concluded the risk to be very small. Nuclear waste can be recycled to an extent, but in the end, it will continue to be highly radioactive for centuries. McCombie and Jefferson (2016, 763-764) stated that nuclear plant’s lifetime 1500 tonnes of nuclear waste are generated, where 5% of the waste is high-level waste. Decommissioning will also be more expensive compared to coal power plant, which is one of the disadvantages of nuclear power. This is because over the years the nuclear power plant has been become contaminated due to being exposed to radiation, whereas coal power plants do not have such a problem.

Both coal power and nuclear power require large amounts of water to be used. In coal power wastewater effluent includes fine coal particles, which require clarification systems to avoid water pollution, which can be damaging to aquatic species that are sensitive to chemical and physical water conditions. If the water effluent is not stored in a proper way, landslides and dam failures are possible. The literature does not provide the amount of water required by coal power, but McCombie and Jefferson (2016, 760) claim that nuclear power water consumption is less than coal. Literature on nuclear power provides water amount usage of 1500-2700 l/MWh or 32 $\frac{\mathrm{m}^3}{\mathrm{s}}$. Skipka and Theodore (2014) mentions coal wastewater and nuclear wastewater to increase temperatures of the local water source. Breeze (2017, 92-93) suggests monitoring the water sources to see if increase in water temperature has negative effects on the aquatic species.

However, nuclear wastewater is just water, it does not require clarification process as coal wastewater does. Water cooling process is however, required. Released nuclear wastewater is not radioactive and in fact, has increased wetlands. Wetlands in turn have attracted wildlife and even endangered species, which is not the case in coal wastewater. (Lerner et al. 2012).

9.3. Politics and technology

Politically both coal and nuclear power suffer through a considerable amount of scrutiny. According to McCombie and Jefferson (2016, 764) coal had a public approval of 48 % and nuclear 38 % in 2011. Nuclear had the lowest approval rating and coal the second lowest. This means general public prefers coal over nuclear, which could be a good indicator of voting choices in the future on nuclear power. However, the poll was done in 2011, right after the Fukushima nuclear plant accident in Japan. It would be strange if nuclear power did not see decline in approval. Coal has also higher death rate compared to nuclear according to McCombie and Jefferson (2016, 761-762). Coal has 35 deaths to every TWh, while nuclear has less than 3 deaths to every TWh produced. It is intriguing that although nuclear has far less deaths than coal does, yet the general public often considers nuclear power less safe. However, accidents are always possible and when a catastrophe happens, it is usually much worse in case of nuclear power than coal power. As earlier discussed in chapter 8, Vujic et al. (2012, 41) stated that coal power has been under-regulated, while nuclear power has been over-regulated. This correlates to risks and death rates among the two energy sources, which would explain the low death rates in nuclear power industry.

New technology is the future of coal and nuclear power. Coal gasification's only main advantage is the environmentally friendliness. Efficiency unfortunately goes down as the costs increase. Coal gasification does not seem to be a realistic energy source as long as natural gas is easily available. Coal liquefication and coal pulverization are other possibilities in the future. Coal scrubbers are expected to increase in efficiency as well as fluidized bed technology and hydrosizers can be used to extract the trace coal left in the mining waste. (Lerner et al. 2012, 43-48.)

In the case of nuclear power, smaller power plants would make nuclear power more accessible to different regions due to lower costs. Safety and efficiency are increased as the Generation levels go up, where even the amount of nuclear waste could be diminished considerably. Even nuclear waste can be decayed in just few hundred years instead of thousands (Lerner et al. 2012, Vujic et al.

2012). Perhaps, one of the most exciting technology would be the molten salt reactors enabling the use of thorium (Th), which would increase nuclear fuel reserves significantly whereas nuclear fusion seems to be still in distant future.

10 DISCUSSION

Nuclear power is clearly superior in terms of energy density, power density and efficiency. As Europe is a highly populated continent, nuclear power could help save space due to its high-power density. Even though Europe does not possess much uranium (U) reserves, the high energy density enables the economical long-distance transportation into Europe. Nuclear power also has a higher operating efficiency, which translates to lower production costs, thus making energy less expensive for European citizens. However, building costs and labour costs are lower in coal power plants. Building a large nuclear power plant is expensive and can take a very long time. During that time other energy sources would have to be used. Coal would be the best baseload option until then, granted wet and dry scrubbers are used, which could be supplemented with renewable energy.

What was exceptionally surprising was the large differences between four coal ranks of lignite, subbituminous, bituminous and anthracite in carbon content and heating value. While the average variable for coal is often used, depending on the coal rank, the energy produced can be more than the average. This can in turn do disservice to coal power and give people an inaccurate presentation of coal’s energy characteristics. Also, brings a question, why anthracite is not used more in electricity generation, since it has the highest heating value?

Environmental impacts are generally the lowest in nuclear power, except nuclear waste. Nuclear waste is still a problem for many countries to solve and using underground repositories might not be a possibility for all as they are required to be in an area with no earthquakes, tremors, or volcanic activity, which is rather a problem for south Europe. This would leave future underground repositories to be placed in northern Europe, except Iceland, which has volcanic activity. This could pose a problem in nuclear waste transportation as well as the general public in north Europe accepting such loads of nuclear waste from other countries. Considering that Europe is trying to make their energy industries more environmentally safe, nuclear power would have most of the environmental benefits. Nuclear has basically no direct emissions, some via fuel cycle, but this can be considered negligible when compared to coal’s direct emissions. People generally want to distance themselves from nuclear power plants, which would be beneficial for wildlife as well.

Future technology seems also very promising for nuclear power, even though the poll results in 2011 were not very promising. However, humans forget and move on over time, so chances are that today and, in the future, results of a poll could be different. Especially, depending on a country in Europe as some are positively increasing nuclear power, while others are not. Additionally, the heat dissipated in cooling towers is often wasted, instead of using the heat for other purposes, until released back in the water source. In the future, there would definitely be potential using the heated water for other industries or as central heating, rather than releasing it to another water source and increasing the water temperatures of the said water source.

However, even though nuclear power is generally superior to coal, there is still a risk of nuclear power plant accidents, leaching of radioactive material to sea, groundwater, near human populations or even wildlife populations. It would be devastating environmentally if an accident were to happen, and endangered species were to die at fault of the accident. Genetic mutations would also be a considerable risk and to see full effects of nuclear plant accident on the environment and humans can take decades. Thus far short-term effects have been devastating and long-term effects would be that the land would be unusable for many years. This could, however, provide a safety zone for animals over years as humans would stay away from these areas.

While you can find many statistics on coal and nuclear power production and consumption in Europe, there is a lack of recent environmental effects on specifically in Europe among literature. This would be crucial as European countries tend to have more advanced technology in general in their power plants thus estimating real environmental effects of especially coal would be crucial to determine if coal could be used more in the future while environmental effects can be diminished. Generally, however nuclear power does not have significant environmental impacts compared to coal power, but there is also a possibility that those are simply not researched enough in the literature. This would seem especially the case in mining uranium (U), although it is claimed to be similar to coal mining, more information should be available.

Some of the literature was rather old, while other was new. Depending on the country that released the literature can have large differences in statistics. Some of the literature was from the United States, while some from Europe and one from Pakistan. For example, one study released in Pakistan pointed out that life expectancy increases the further away people are from coal power plant. This was not mentioned by any other literature and thus would be difficult to see if the case would be same for Europe. This is where literature could differ depending on the geological location of the literature released, as developed countries tend to have newer technology than undeveloped countries. Potential bias from the authors is possible, as it was quite hard to differentiate the environmental impacts of coal in developed countries and undeveloped countries. Essentially, if wet scrubbers and dry scrubbers are working that excellently then how much would this diminish coal environmental impacts exactly? It makes sense that under developing countries have a higher emission rate, but it does not help to understand how much coal technology has improved in developed countries over the years. The literature showed the wet and dry scrubbers efficiency but not how much it reduces the coal emissions. This could lead to people having an unwarranted bias against coal power, when people are still associating today’s coal industry to what it was 50 years ago.

Last, but not least this study is a narrative literature review, which leaves possibilities on the author bias. Author bias can affect the choosing of literature pieces in the study as well as the text that is included and is not included in the study. Additionally, author could analyse the literature wrong. This could give the reader inaccurate presentation of coal and nuclear.

11 CONCLUSION

The purpose of this study was to analyse the literature available in coal and nuclear power to review the current information as well as compare the literature with each other. The literature analysing method in this study was narrative literature review. The aims of the study were to answer the research questions which were to identify and compare the energy production of coal and nuclear power, environmental impacts, and determine which energy source would be better for Europe in the future.

From energy production point nuclear power is significantly superior in electricity production compared to coal power. This is due to the high energy density, power density and efficiency of nuclear power. Nuclear power has been found to be a cheaper option to produce energy after carbon taxes have been factored in, but without it, coal power would be cheaper option. However, carbon taxes differ among European countries and if carbon taxes are low, then coal would be more superior price wise.

There was a consensus with the literature of 115-150 years of coal left with current consumption, whereas literature on uranium (U) reserves had drastic differences from 50-1000+ years. Germany, Russia and Ukraine have the highest coal reserves consisting mostly of lower rank coal, while Russia and Ukraine are the only European countries with high uranium (U) reserves. This would most likely require European countries to look for uranium (U) outside of Europe, but due to high energy density and high reserves of uranium (U), uranium (U) would be a superior option to coal.

Nuclear and coal mining have similar environmental impacts that require large amounts of water, which in turn generate large amounts of wastewater. Nuclear power, however, can use in situ leaching as well, which is a less invasive process. Coal power uses a considerable amount of water in their coal preparation plants, while nuclear power uses for cooling. Literature concluded that both would raise the water temperatures of the nearby water sources, thus requiring monitoring. This would require coal power plants to have clarification systems to remove the coal waste out of the water or otherwise pollute the nearby water sources. Nuclear power uses also large amount of water to cool down the steam turbine condenser, though less than coal power. In fact, cooling water released back into water sources is not radioactive and has created wetlands to support wildlife, even endangered species.

In environmental impacts nuclear power plant is superior in emissions, as nuclear power plant emits no carbon oxides (CO_x), sulphur oxides (SO_x) nor air pollutants, besides the initial construction phase and fuel cycle. Coal power plants in turn emit carbon oxides (CO_x), sulphur oxides (SO_x), and nitric oxides (NO_x) and others. However, age of the coal power plant as well as the technology in it has a massive influence on the emissions emitted from the plant. New technology such as dry and wet scrubbers can lower coal power plant emissions significantly, but the literature never mentioned how much the coal power plant emissions were reduced once wet and dry scrubber technology was put in place. If the whole Europe would use dry and wet scrubbers in their coal power plants, could coal emissions be significantly reduced as of now? If that would be the case, then new coal environmental impacts study should be conducted and assessed. This could mean that coal power would have a more positive prospects compared to now.

Nuclear power is superior to coal power in almost every aspect, except nuclear waste. Coal waste can be recycled to other products, while technically majority nuclear waste can be recycled as nuclear fuel, but the nuclear fuel at the end of its lifecycle cannot be used further. This waste must be stored in a way to prevent leakage until they do not pose a danger to the environment anymore, which can be hundreds of years. Europe can use underground repositories, but this would be only an option to North Europe due to low seismic activity. Coal power plants emit generally more radioactivity than nuclear power plants due to the construction not made to obstruct radioactivity, while nuclear power plants emit some radioactive gases, but the amounts are considered to be negligible.

New technology wise coal is going to be more environmentally friendly, but more expensive, while nuclear power plants are expected to become smaller, safer, more effective. New nuclear power technology is supposed to answer the nuclear waste problem, which in this aspect nuclear power has a brighter future. Nuclear power has a higher energy production, lower environmental impacts, better prospects to look out for, which suggest Europe should invest in a nuclear power rather than coal power as a baseload.

More recent studies would be needed on environmental impacts on coal and nuclear power as some of the literatures were quite dated. This could also lead to the author of this report having a bias in choosing and analysing the literature, which can give the reader an inaccurate information of the two energy sources.

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APPENDICES

Appendix 1. Themes of the literature

	Coal energy			Nuclear energy			Coal env. Impacts						Nuclear en. impacts						Coal Future		Nuclear power	
Authors	Coal fuel characterics	Production & Consumption	Coal reserves	Nuclear fuel characteristics	Production & Consumption	Fuel reserves	Mining	Transportation	Emissions	Radioactivity	Water	Waste	Mining	Transportation	Emissions	Radioactivity	Water	waste	Politics	New technology	Politics	New technology
Lerner, K. L., Lerner, B. W., et al. (2012	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x		x
Miller, B. G. (2016)	x	x	x		x		x	x	x	x	x	x										
International Energy Agency (2019)		x	x																			
Skipka, K. J., Theodore, L. (2014)	x	x	x	x	x		x	x	x		x	x	x					x				
Vujic, J. et al. (2012)		x		x	x	x			x	x		x			x	x		x	x		x	x
Munawer, M. E. (2017)								x	x	x												
Breeze, P. (2017)				x	x	x										x	x	x			x	x
McCombie, C., Jefferson, M. (2016)	x	x		x	x	x			x			x			x	x	x	x	x		x	