University of Piraeus

Department of International & European Studies

Master in Energy: Strategy, Law & Economics

NUCLEAR POWER

CRITICAL ASPECTS, GEOPOLITICAL GAME CHANGERS AND FUTURE SCENARIOS

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Grigorios S. Gkizas

gr.gkizas@gmail.com

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Abstract

Nuclear energy is reported to possess both good and bad qualities. In particular, it may be used for both the production of weapons and for peaceful purposes. This research aims to discuss both sides, focusing on the game changers of technology and geopolitics; regarding the effects those two can have for the development of the sector. As this research showed, the dynamics of international relations are in stalemate, while the current issues in the management of geopolitics will decide whether a new era of more significance or less importance for nuclear energy will emerge.

Nuclear power's energy mix shareholding is rising steadily but is yet far from reaching high levels in the world energy mix. Some countries abandoned it after tragic accidents occurred like Chernobyl in 1986 and Fukushima in 2011 while other strengthened their support, aiming at further developments in the security around of its power generation technologies. Apart from the issues one can note in terms of nuclear power use, the same case does not apply when one is looking into the environmental aspect. It is understood that nuclear power can considerably lower the environmental damage that other forms of energy produce.

Therefore, in this thesis we attempt to further elaborate and point out nuclear power's advantages and disadvantages, on the level of politics, society, and technology bearing in mind society's emotional terms. In fact, technology plays a huge part in this categorization and it promotes the whole research into a new level of game changing effects that will render nuclear power either more widely accepted and used or completely bottlenecked in today's low energy mix values.

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1. Introduction

1.1 Introduction

Article 2 of the IAEA statutes states that: "The International Atomic Energy Agency shall seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the World. It shall ensure, so far it is able, that assistance provided by it or at its request or under its supervision or control is not used in such a way as to further any military purpose (Ragheb, 2018)." These few lines that form an article of an international organization that deals with nuclear energy, offer us the whole picture of this form of energy. It is widely known that nuclear energy can be used both for good and for aggressive purposes. Hiroshima and Nagasaki bombings back in 1945 showed the world the enormous catastrophic power of nuclear energy (then called atomic).

Nuclear energy started in war. Albert Einstein and Leo Szilard first provoked the US government to seek after the guarantee of nuclear energy by speaking to then-president Franklin D. Roosevelt to think about Nazi Germany having a nuclear bomb. Nuclear innovation—both for weapons and for regular social applications—was at that point impelled on amid the Cold War as a method for hindering war among the superpowers and their politically adjusted alliances of states. It was additionally a method for giving advancement help to nations rising up out of hundreds of years of neediness and colonization. Indeed, even with the end of the Cold War, nuclear issues keep on assuming a significant role in worldwide undertakings. While worldwide environmental change goals have incited a resurgence of enthusiasm for nuclear power as a potential wellspring of carbon-impartial power, security and waste administration issues remain and still intrigue. Regardless of whether nations renounce nuclear power, the poor wellbeing practices of a state can spill crosswise over fringes and compromise other whole areas.

However, the geopolitical directions of energy security being a dynamic field it greatly changes through time. Moving past the demand and supply security of hydrocarbon, the developing energy security issues are going to be characterized by worldwide basic concerns, be the UN affirmation on Reasonable Energy for All or the promise by in excess of two hundred nations to cut down carbon discharge to confine the temperature increment to 1.5 °C above pre-mechanical dimensions. Clearly in its changed terms and reference, energy security is inserted in a progressively perplexing biological system of change which is required to guarantee accessibility, availability, reasonableness, and worthiness on the direction of low-carbon energy framework. It likewise calls for returning to the issues, for example, the security for whom, security for which esteems and security against what dangers (Cherp and Jewell, 2014). In its all-encompassing characterize, it is likewise seen as a decision of energy framework (Debaz, 2016 according to G. Pant). This could not have yet been considered for the advancement, in innovation, possibilities and guarantees of the “digitalization of energy infrastructure” guaranteeing “greater energy security at a local, regional and national level (Molinaroli, 2016).”

Unquestionably, every nation even though being part of a worldwide context, needs to settle on its own decision of its mix. Clearly, the new energy mix is perceived in favor of clean and cleaner fuel. Nuclear is cleaner when compared with coal, oil, and gas. It needs to be the part of a larger scheme. In any case, views are split concerning the role of nuclear into achieving a free carbon era. There are individuals who realize nuclear in relation to coal and oil and suggest it as substitute in the power sector, while others perceive it as far as low-carbon bridge technology. It is contended that “Even if you want to be using 100% renewables, which not everyone does, it’s going to take many decades to get there, probably sixty or seventy years at least. So, nuclear is an essential low-carbon bridge technology for those decades (Leggett et al., 2011).” It is intriguing that with regards to the setting of environmental change, nuclear now enjoys a new acknowledgment. Under the umbrella of Nuclear for Climate initiative of French Nuclear Society, American Nuclear Society and European Nuclear Society, aggregate endeavors are made to reposition nuclear power in the standard planning of the energy security agenda as some extent of the arrangement’s solution (SFEN, 2016). This part means to break down the repositioning of nuclear sustainability not simply as advantageous but rather in the more extensive setting of economically sustainable security. Nuclear energy is cleaner and has a role in relieving negative ecological outcomes of triumphant energy mixes. It has a place in this transition, yet the decision in its support is affected by numerous factors other than funding and the time lead, as will be further elaborated in later sections.

The aim of this thesis is to contribute to the discussion of using nuclear energy in order to produce useful final energy. It will focus on the contemporary agenda of nuclear power, recent developments and the disassociation of nuclear as a form of destruction, but as one for peaceful energy purposes. Furthermore, this thesis aims to project a future perspective for nuclear energy, and its use in the world energy mix.

In conclusion, there are colossal focal points to either expanding interest in nuclear energy or keeping on the current track. Policy makers more specifically should wrestle sincerely and transparently with these inquiries so as to devise the best arrangement as to nuclear energy, both for their very own nations and for the worldwide network all in all (Blasio and Nephew, 2017).

1.2 Thesis Structure

The structure is as follows: Firstly, a short assessment is being made concerning the double nature of nuclear energy and its current state in the world energy mix. Secondly, in the literature review chapter that is following, we confront a big amount of issues that are currently engaged in nuclear energy sector's growth. More specifically, we analyze the geopolitical landscape and contemporary issues while we engage into a discussion about the role and potential game changers that could revolutionize its use. Finally, the literature review focuses on France's exemplary nuclear energy cycle and nuclear power's environmental impact while it discusses the energy market, the biggest competitors involved in it and seeks nuclear energy's spot in that huge market. Thirdly, at this point of our thesis, the methodology of analysis is being introduced, followed by the results section where our findings finally take form with an emphasis on future projections, thus leading us to the thesis's final remarks.

2. Literature Review

2.1The overall picture

Existing projects are ageing while some other functional nuclear power plants follow the path to shutdown, because of political outlook or non-sustainable economics. Targeted subsidies would be able to boost this energy generation form in order to render it more competing against other sources of energy since the private sector is non-existent due to the size in many levels of such an investment (risk, size, long time lag payoff, image), (Levite, 2018).

2.2 Nuclear power in the world energy mix and electricity demand projections

According to World Energy Outlook of 2017, “When China changes, everything changes.” Such a statement clearly shows us the length and the importance of this country’s ability to swift the world politically. Energy investments are fundamentally politically connected as it is projected by the Chinese president’s call for an “energy revolution,” the “fight against pollution” and the transition towards a more services-based economic model, which means moving the energy sector in a new direction, in 2014. At this point we should also mention the fact that he called for the acceleration nuclear reactor program on the eastern coast, therefore showing a commitment to his general statement with any means necessary (WEO, 2017). This commitment was first reported by David Stanway and edited by David Holmes for Reuters on June 2014 (Stanway and Holmes, 2014).

Furthermore, electricity demand will keep increasing, reaching up to 40% rise in final consumption as shown in the figure below. This significant growth could use nuclear power for its electricity generation in order to fill in gaps from the inconsistent renewable sources and thus be seen as a solid alternative option, especially in such cases where energy security is aligned with national security (Figure 1).

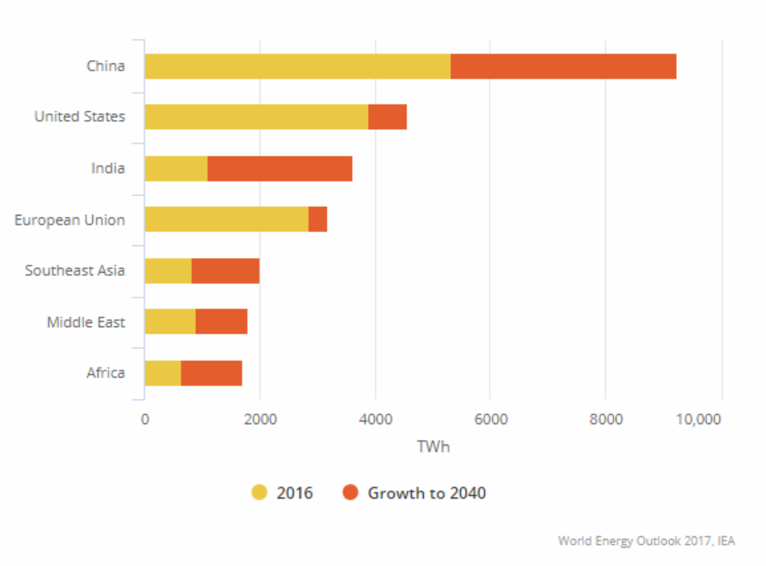

Figure 1. Electricity Demand by region (WEO, 2017).

Finally, through IEA's projection of the global average annual net capacity additions from year 2017 to 2040, we witness abandonment of coal (heavy decrease), stability on the gas sector, an increase of 6 GW in renewable sources in comparison with years 2010-2016 and a 50% rise in nuclear energy from 2GW to 4GW in the same comparison (Figure 2).

While it may be a rather small difference in terms of absolute GW power, the fact is that doubling its previous sectorial capacity could mean a distant future's potential development in energy generation. It could be forming a small, yet not unnoticeable beginning, of a reliable answer to society's needs. Based on a gradual development and given that certain game changers will come in place, this current analysis will try to depict the future of the nuclear sector and to pinpoint whether it forms an emerging giant that could overtake the reins through the lens of technological turnaround when all our other known energy sources are rendered impractical or scarce (WEO, 2017).

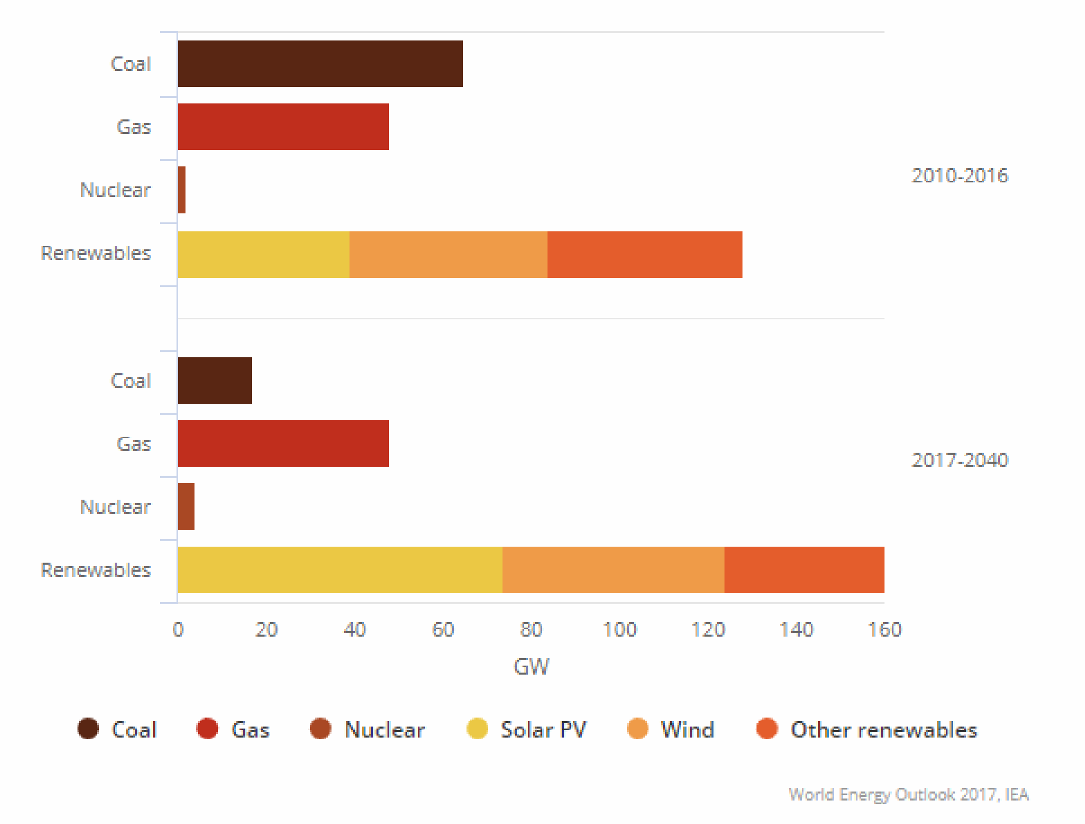

Figure 2. Global average annual net capacity additions by type (WEO, 2017).

2.3 Geopolitical Landscape

After noting the two sides of the same coin as far as nuclear energy is concerned, we should examine how interconnected they are with each other and how does this affect reality. In fact, because of the reason that weapons production and peaceful purposes, mainly electricity production, can be mixed with each other (dual-use) (Revesz, 2015), thus the need for understanding the geopolitical landscape, the dynamics and the fears in an international level about the proliferation of this technology. However, how is it possible to share the required technology for electricity production while avoiding giving away means of weapons production? In order to address these issues we will discuss nuclear geopolitics and the 'game-changers' of the nuclear sector, both inside and outside of the field (Marvel and May, 2010).

2.3.1 Nuclear Weapons Proliferation – Non Proliferation Treaty securities and insecurities: Key factors for future development

Prestige-seeking can sometimes lead to a dangerous situation where a certain state is inspired to assemble and test nuclear weapons. In the nuclear setting, the characteristics related to notoriety are generally advancement and freedom, which translates to power and the ability to confront different states. The definition clarifies why a distinction is passed promptly on additional strategies by using nuclear weapons than by societal advancement, for example, improved social welfare, education or equitable public administration. Nuclear tests can be made into "public events," in the sense that they can create knowledge that they have taken place as well as gather information about their interpretation from the world. It is more attractive to make a case if there is a conspicuous limit isolating its accomplishment from its non-accomplishment, and a nuclear blast enforces such a limit. On the other hand, successfully using nuclear for peaceful purposes would suggest a "semi-nuclear" capable state and therefore a potential threat that would be deterred. It is demonstrated that a limit is critical in light of the fact that prestige includes the second dimension of convictions. Apart from the fact that the international community realized that nation “A” owns nuclear weapons as of that moment, an open nuclear test also advises every international player that everyone else will have to consider this new reality, thus reinforcing esteem. Since the end of the Cold War, stresses over nuclear over-expansion have surfaced, and the issues with different methodologies, like bans, approvals or military interventions have turned out to be apparent. To separate weaponry from prestige, it takes away a significant motive for the process of proliferation (Barry O’Neill, 2006).

Prestige is regularly viewed as an issue of feeling and demeanor, yet the concentration here is its vital significance. Early pragmatist essayists like Herz, Morgenthau, Nicholson, and Niebuhr were correct in that sense of directly addressing it. It possibly becomes the most important factor particularly in bandwagoning events when a state seeks support from other states whose activities are key elements - the potential supporters discover a union increasingly alluring a greater amount of them. Assuming that seeking that kind of prestige is deliberately reasonable, it cannot be isolated by advanced reasoning (Barry O’Neill, 2006).

2.3.2 Current Geopolitical Issues

Issues nowadays concerning nuclear energy, have gone passed nuclear proliferation and competition between great powers. Focus is shifting to energy security, climate change and development. It is believed that if nuclear energy is to increase its share in the world mix, the most significant upsurge would come from the developing world. Non-OECD energy demand will nearly double the demand from OECD countries as shown in figure 3 (Blasio and Nephew, 2017). As the IAEA estimates North America and Europe will face decline in nuclear capacity in comparison to China’s emerging plans that seem to follow a path of growth (Paraskova, 2017). “According to the IAEA, reduced competitiveness is the main reason for planned premature shutdowns ‘low natural gas prices, particularly in the US, caused by a rapid expansion of shale gas production, have fundamentally transformed the energy economy’ (Blasio and Nephew, 2017).”

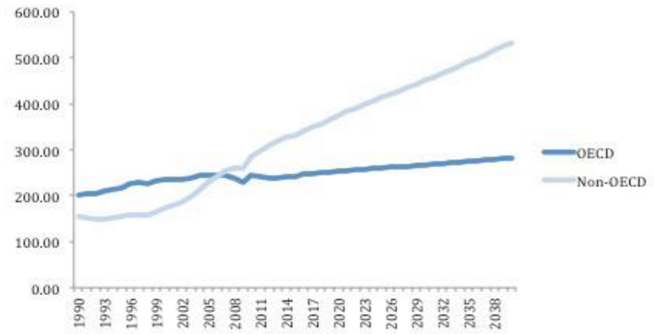

Figure 3: World Energy Consumption, 1990–2016 (Quadrillion Btu). Figure taken from EIA (Historical Data 1990–2012, Projections 2013–2016).

2.3.3 Nuclear energy’s role

From the analysis up to this point, it is clear that priority needs to be provided to the Research and Development of the sector (R&D). There are reactor designs which will be discussed later on our research paper and that more efficiently and effectively satisfy the aforementioned issues, such as the interest of enhanced safety, mitigated waste and risk reduction of nuclear weapons proliferation. Policy makers around the world should consider developing mechanisms to help prioritize further research and development on these types of reactor designs while addressing uncertainties of regulatory acceptance, and therefore deal with increased associated costs that come along with these uncertainties. “In other words, a technology down-selection and standardization by the international community is needed in order to reduce R&D and licensing costs and truly leverage economies of mass production” (Blasio, and Nephew, 2017). In parallel IEA has used strong language while trying to describe all this perplexity of the nuclear energy sector: “The closures on both sides of the Atlantic represent a blow to an industry that for years talked about the prospect of a ‘nuclear renaissance’ based on the merits of large-scale, low-carbon energy. They show how Western governments have waffled in their support for the technology, opting to subsidize renewables rather than putting a real price on carbon emissions that would more heavily penalize dirtier fuels, such as coal and gas, and thereby promote nuclear energy. The closures also highlight how green NGOs, many of which were created to oppose both military and civilian use of nuclear energy, have influenced the debate on nuclear power. Many greens still see it as an evil akin to global warming (IEA 2015a, b)."

Therefore, the contradictions that fill the nuclear energy sector are now visible and careful attention has to be attributed to the public opinion, "Funding and safety will be crucial to the development of nuclear energy as IAEA puts it:

'The safety performance of nuclear installations is crucial to the future of nuclear power, as a strong safety record is essential for its public acceptance,' *the IAEA commented, noting that* 'The financing of nuclear projects is challenging, given the highly capital-intensive nature of such projects, their resulting sensitivity to interest rates and construction durations, and the nature of the uncertainties' (T. Paraskova, 2017)."

2.4 Game Changers

There is a growing need to assess nuclear power's role in the future energy mix. It began from the 1960s conventional wisdom which supported the idea that nuclear power could dominate the electricity sector of developed countries. Unfortunately, forecasts cannot offer a stable perception for the future as shown in Figure 4, and thus the need for 'game changers' approach. This approach brings in factors that can increase or decrease nuclear power's popularity as an alternative source of energy generation, and therefore any event that is not considered in the conventional planning assumptions (Marvel and May, 2010).

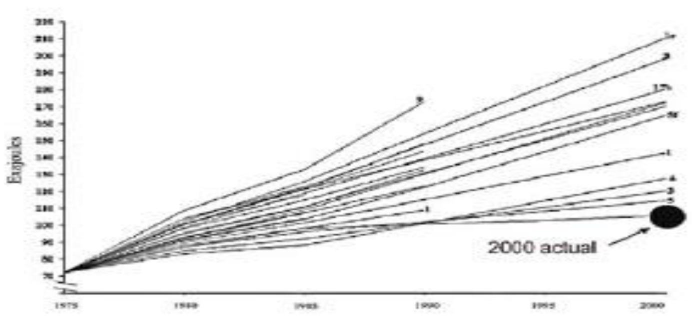

Figure 4. Several forecasts of US energy use by 2000, made in the 1970s, dramatically overestimate total demand. Figure taken from Craig et al. (2002).

2.4.1 Technological Game Changers

At first, as we are entering the technological aspect of nuclear power, it is desirable to discover the availability of reactors' raw materials. Consequently, mining and milling of natural uranium seem to be sufficient for a significant future development in the nuclear energy sector, according to a 2003 MIT study (Craig et al, 2002).

Enrichment of the uranium processes does not necessarily make for a game changer since clandestine enrichment already existed for example in the case of Iran. The concept is that enrichment technologies at the moment need state involvement because of their large scale. If however, there was an advancement that would render the enrichment of the uranium possible in a sub-state level then the proliferation risk would highly rise since the know-how would reach a wider variety of players. Finally, sustained nuclear fusion technology would drastically change the course of the sector since it could potentially be able to address most of these technological issues. Solving and narrowing down tech-issues in nuclear energy sphere, translates into fighting off current overwhelming political issues as well (Marvel and May, 2010).

2.4.2 Nuclear Geopolitics

On the other hand, there can be traced game changers outside the field that are connected with geopolitical factors such as national politics and attitudes to nuclear energy. Three are the major areas where a game changing effect can surface from. Accidents, terrorism and war and proliferation.

To begin with, we should expect accidents over considerable amount of time (Marvel and May, 2010). In their paper, Kate Marvel and Michael May wrote specifically: "We should expect accidents over the 50 year time horizon of this study." Just one year later, a major level 7 accident of the International Nuclear and Radiological Event Scale (INES) occurred in Fukushima in 2011 (IAEA, 2011). Even though a significant number of accidents have happened, the actual rate and damage to health and environment are lower for nuclear energy compared to any hydrocarbon generation.

In the field of terrorism and insurgence, any terroristic act against reactors that would release radioactivity or a state's attack against another one with which they are in a conflict, would drastically change the whole scenery.

The Non Proliferation Treaty (NPT) that entered into force in 1970 is a worldwide effort – with few exceptions - to contain proliferation of weapons or the means to produce them such as the enrichment of uranium, the reprocessing of plutonium and in general any technology that can be considered as dual-use, meaning the ability to be used both for peaceful and military purposes (Revesz, 2015). The challenge for the future lies to the potential production of technology that facilitates covert activities, since any efforts for military purposes have come to light with the current technology that needs big scale milling as mentioned above.

Another game changer comes outside of the nuclear field. High competition of other sources that are used to produce electricity, namely hydrocarbons and renewable sources. Carbon dioxide, a greenhouse gas that is emitted by burning fossil fuels could promote the use of the proven low-emission generating technology of nuclear reactors, given that this need of environment management is prioritized politically and aligns with nuclear developments, able to address the issues of cost, safety and proliferation.

2.4.3 The Dynamics of International Reactions

Putting down the scope the reality of the U.S. in contrast to Russia, China and India, the latter ones have formed a more pro-oriented nuclear power policy. We have to bear in mind the growing need they have for power compared to the developed countries. On the other hand, even if a nuclear accident were to happen in the U.S. it would definitely set back planned expansions but we would not witness a complete abandonment since nuclear sector feeds 20% of the total energy production in the country.

The same case applies for other countries like France (73%), Japan (2% from 30% before Fukushima accident, 2011) and South Korea (28%) (IEA, 2016 b, c, d), that heavily depend on nuclear energy in their energy mix. Japan for example has committed that until 2030 it would have reached back to around 20-22% in its total energy mix, as Paris agreement's obligations are increasing the pressure. This shows that accidents can slow down sectorial development but not abandon it, when energy security comes as top priority (Silverstein, 2017), unlike some northern European countries like Germany that orientate in a complete phase out (Staudenmaier, 2017).

Such was also the case with the 'Three Mile Island' nuclear plant in Pennsylvania in the U.S. in 1979. Design deficiencies and a human error led to a partial meltdown of the nuclear core. In the end however, minimal health impacts were found in the surrounding area and nothing outside a few-mile radius (Blasio and Nephew, 2017). The U.S. is still the state with the most nuclear reactors in the world (WNA, 2018).

Similarly the then Soviet Union that faced the devastating accident of the Chernobyl station's fourth reactor of a level 7 INES in 1986, constitutes a major player nowadays that is also 'exporting' nuclear 'know-how'. The Russian Federation not only did it not change its course nuclear wise, but it provided it with a new dynamic, of safer and more challenging technologies. As Reuters expressed it during June 2017: "Rosatom - Russia's State Atomic Energy Corporation - has sold several nuclear reactors to developing countries under a model by which Russia finances, builds and operates the nuclear plant and sells power to its customer - a model that has also raised questions about Russia using energy policy as a means to political ends" (Reuters, 2017).

In conclusion, many developing countries have expressed interest in nuclear power which could potentially alter the future debate around it. A possible expansion in any of them could trigger a whole new era, in a series of game changing events that would either reduce the use of nuclear power or give birth to a nuclear renaissance.

2.5 The energy market in an interconnected world

The world energy market is seeing progress and change altogether. It is tremendously swarmed, seeing challenge inside the hydrocarbons and with clean energy. The geopolitics of energy will be taking place in a double dimensional field. One on the territory of substitution where the old energy players (hydrocarbon) would cease the passage to new players through energy choices and inside the area of the hydrocarbon between old players, in particular OPEC, and new providers for example, US, Canada, Australia and Russia and inside energy choices themselves, for example local trade war among nations. This is additionally convoluted by state strategies forming request "by promoting consumption of certain fuels and restricting consumption of others (Makenzie, 2015)." It is very apparent that unlike years ago, the change will be basically affected by the power of rivalry among the distinctive powers. The force of rivalry is going to be dictated by the mechanical advances affecting on near costs and the administrative system by the legislatures. Incidentally energy market has never seen a dimensional playing field. Endowments have been the wellspring of never-ending showcase twisting (IEA, 2014). The present change will likewise be seeing a routine of endowments. Critically, transformational innovation is empowering crucial fuel substitution in energy end use. This has been most striking in power generation also, distribution and is probably going to be in transportation chain too. Similarly, basic factor has been the effectiveness improvement over the production network. In total, the effect on interfuel substation is progressively noticeable in volume and scale. It is contended that "As interconnectivity among energy markets grows, so will the complexity confronting players across the energy value chain. Not only will the pace of change accelerate, but price shocks, regulatory changes, or technological breakthroughs in any given space will pose a much greater threat now than they used to as disruptions ripple across interconnected markets (Brognaux and Ward 2015).” Patterns show a progressively fragmented market as far as energy blend is concerned. It is no big surprise it is alluded in plural—Global Energy Markets (EIA 2015).

The OECD inclination is for renewables and gas, and the developing markets impulses are to keep on depending on hydrocarbons extensively coal alongside renewables. The geography of energy utilization has changed as well as energy supplies. It is stated that “Trade patterns will evolve as commodity demand growth shifts to emerging markets. North America will disrupt traditional trade flows as it becomes an energy export province, with oil imports declining and eventually going into reverse. North America will also compete with Russia and the Caspian to become the world’s foremost natural gas supplier (EIA, 2015).” The geography of energy utilization is likewise moving with mechanical changes. Subsequently, the geostrategic situating of market is moving. It is turning to Asia, despite the fact that Yergin makes the distinctive point that “We are experiencing a movement from the BRIC era to the Shale era, from a time of great demand and scarcity to a time of abundance in supply and weaker demand.” Ascent of clean energy regardless of the dominating hydrocarbons is the rising truth of the energy showcase. This is reflected in the flows of investments and capacity expansion. “In 2015, renewable energy set new records for investment and new capacity added. Investments reached nearly $286 billion, more than six times more than in 2004, and, for the first time, more than half of all added power generation capacity came from renewables (UNEP-Bloomberg, 2016).” The diagram below demonstrates that the power sector energy mix will be changed profoundly in support of clean energy as in figure 7 (Pant, 2017).

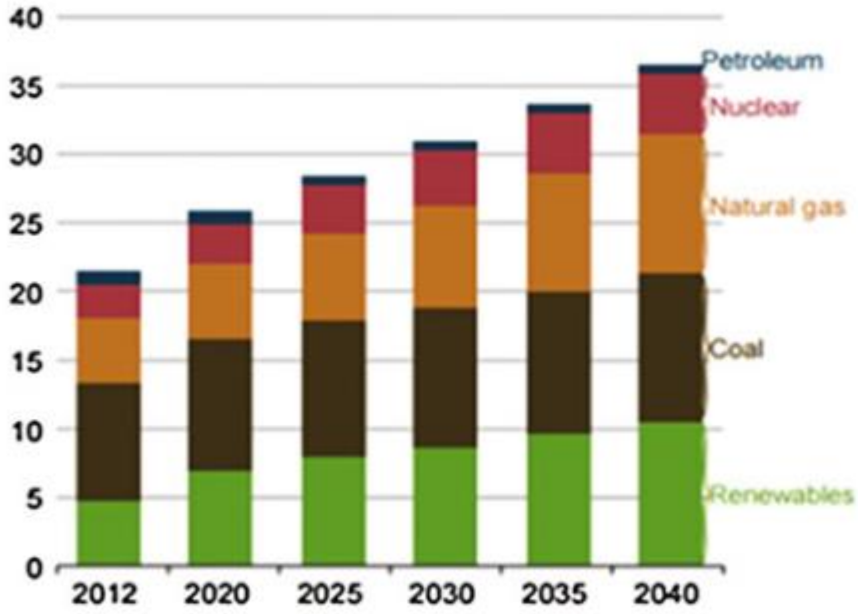

Figure 7. World electricity generation, 1990-2040. Source: US, EIA. International Energy Outlook, 2016.

2.6 Energy Cycle - The French Energy System paradigm

In this part of our research we will go through France's nuclear energy system in order to grasp how such a system functions. France chose to follow the path of nuclear energy after the primary oil emergency in 1973. The principal PWR (pressurized water reactors) began in 1977 (Fessenheim) and 58 PWRs were dynamically associated with the framework up to 1999. This has enabled France to build the extent of power originating from nuclear reactors up to generally 80%, diminishing its reliance on fossil fuels. Hence, it has enabled France to diminish its CO_2 outflows for power creation by close to a factor of five, with a mean CO_2 emanation in the range of 70-100 gCO_2/KWh since 1993 (OECD, 2009). A value of 79 g/KWh is given for 2010, to be contrasted with the normal EU discharges of 347 gCO_2/ KWh (ibid.). The nuclear introduced limit in France in 2013 is of 63 GWe for a complete creation about 400-420 TWhe/year (CEA, 2012). To continue with, based on two great industrial operators, EDF and AREVA, France has created and aced a total fuel cycle which is totally situated in France aside from the metal mining activities. Studies are likewise on-going for a potential land storehouse to be opened in 2025 in Meuse/Haute-Marne site. Finally, figure 5 is expected to portray the explicitness of the distinctive fuel cycle steps, where it orchestrates the fundamental ventures of the French fuel cycle with the reference yearly motions (Poinssot et al. 2014).

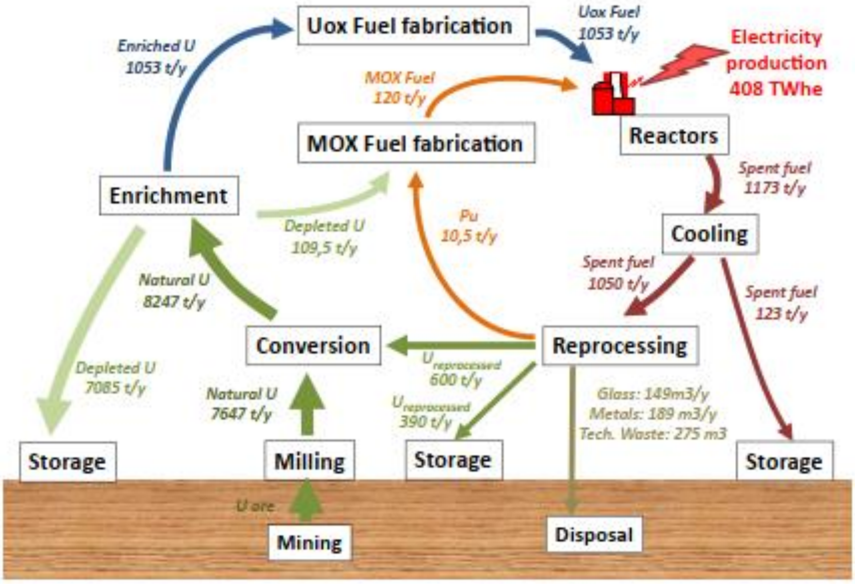

Figure 5. French reference fuel cycle and its representative streams (year 2010), (Poinssot et al. 2014).

2.6.1 Fuel cycle front end: from metal mining to fuel manufacture

Uranium is a characteristic and somewhat radioactive metal accessible under various structures all through the Earth's shake just as in most waterways and in ocean water. In explicit geographical conditions, uranium fixation is sufficiently high to make the extraction in fact also, financially attainable. In-situ methods (In-Situ Leaching method ISL) are for the most part utilized for poor uranium mineral (<0.1%) and at the point when the metal mineralization is sufficiently penetrable and inserted between two impermeable land layers. In different cases, established removal procedures are utilized, basically open pit for shallow surface store (<120 m profound) and underground digs for more profound stores. France generally imports yearly 8000t of uranium metal to feed its fuel cycle from these various types of mines. In the wake of being mined, uranium metal is processed nearby or near the uranium mine. Uranium goes first through a mechanical treatment, pulverizing and granulating. At that point, the uranium is separated from the mineral by filtering either with a solid corrosive or soluble arrangement. Processing produces a uranium oxide (U_3O_8) concentrate (yellowcake) which for the most part contains over 80% of uranium. The yellowcake is additionally cleansed in France (Malvesi Areva site), changed over into vaporous UF_6 in two stages (Malvesi and Pierrelatte destinations) and afterward improved in fissile isotope, ^{235}U (Tricastin site, close to Pierrelatte site). Up to 2012, the improvement was finished by vaporous dispersion (Georges Besse I plant, GB I); it is currently done by ultracentrifugation (Georges Besse II plant, GB II). Uranium is improved in the range 3.5-4.5% of ^{235}U (to be contrasted with the underlying 0.7%) and respects the generation of 7e10 occasions bigger volume of drained uranium which isn't USble with the present reactor park and is put away as a key reserve in Pierrelatte and in the Bessine site (Central part of France). In this investigation, just the previous advancement by vaporous dissemination was considered. It devoured a ton of energy: 2.4 MWhe/ SWU (A SWU is a Separation Working Unit which measures the work expected to deliver improved uranium at a given ^{235}U%, as a capacity of the ^{235}U% in the exhausted uranium). Be that as it may, since this advancement utilizes nuclear power created by the neighbor PWRs, its GHG emanations are substantially more constrained than some other advancement plants around the world. The advanced UF_6 is then changed over back to UO_2 for the consequent fuel creation at the Romans plant (Isère). Fuel pellets are made from squeezed UO_2 (uranium oxide) sintered at high temperature (>1400 C). The pellets are then encased in Zirconium compound (Zircaloy-4) cylinders to frame fuel poles, which are orchestrated into fuel gatherings prepared for presentation into the reactor (Poinssot et al. 2014).

2.6.2 Water utilization and withdrawal

Reactor cooling is the principal consumer of water utilization (97%) and withdrawal (99.9%), in spite of the fact that on the reactors with cooling tower (53% of the French reactors) are the main ones with net water utilization (1500 L/MWhe). The front-end tasks (mining, processing, change, and advancement) are the principle second-order benefactors (around 45 L/MWhe, for example, 96% if reactor cooling isn't considered) though water utilization and withdrawal are insignificant at the back-end (<2 L/MWhe). Be that as it may, water utilization from front-end exercises must be cautiously considered since these exercises are frequently situated in dry regions where protecting accessible water is a key issue. Moreover, contingent upon the sort of mining exercises, these figures can be a lot higher since the utilization of ISL strategies devour a bigger measure of water (Catchpole and Kuchelka, 1993; Poinssot et al. 2014).

2.6.3 Radioactive vaporous and fluid discharges

Amid the whole fuel cycle activities, radionuclides are discharged in the climate and in fluid media. The primary benefactor is radon and other honorable gases; trailed by tritium, at that point C14 and different radionuclides (Table 1). Radon, which is at first present at low focus in the normal uranium metal, is viewed as just and completely discharged in the environment amid the mining and processing step (35 TBq/tUnat), (Dones et al. 2009).

	Radioactive gaseous emissions	Radioactive liquid emissions	Radioactive solid waste			
			VLLW	ILW-SL	ILW-LL	HLW
	(Bq/ kWhe)	(Bq/ kWhe)	(m^3/ TWhe)	(m^3/ TWhe)	(m^3/ TWhe)	(m^3/ tTWhe)
Mining	666744		3190			
Conversion	1E-04	53.8	1.97	1.19		
Enrichment	5E-05					
UOX fabrication	2E-05					
Reactors	162	2717	22.94	24.61	0.32	
Reprocessing	554628	24444	2.63	4.31	0.80	0.36
MOX fabrication	2E-05	6,4E-05	0.019	0.1	0.05	
Total	**1221534**	**27215**	**3217.59**	**30.21**	**1.18**	**0.36**

Table 1. Radioactive impact indicators for the French TCC. NELCAS results (Poinssot et al. 2014).

It speaks to 53% of the radioactive vaporous outflows (Figure 6). Honorable gases, tritium furthermore, C14 are delivered in the fuel by neutron responses amid reactor activity. The majority of these gases stay caught in fuel pins also, are chiefly discharged at the reprocessing venture, aside from Tritium, which is somewhat discharged in the reactor cooling framework because of its dissemination through the fuel stick claddings.

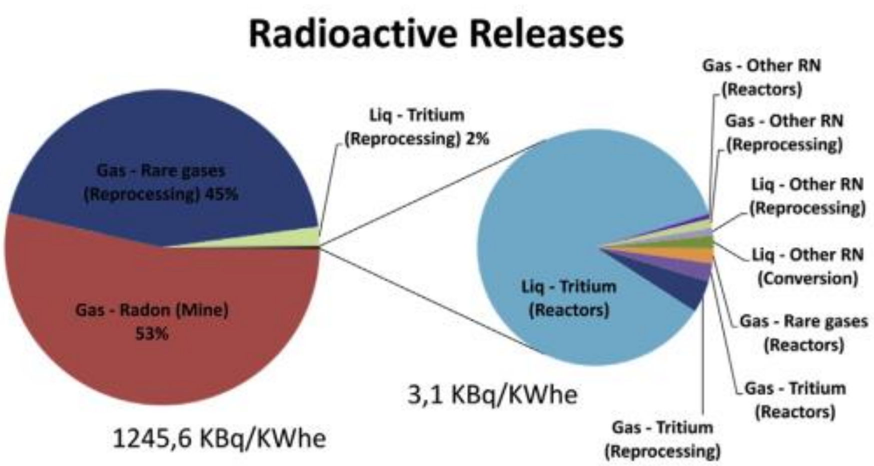

Figure 6. NECLAS results for the radioactive releases indicator for the French TTC (Poinssot et al. 2014).

Little measures of these gases are anyway discharged amid reactor tasks due to ruptured claddings. About 99.99% of the uncommon gases (554.5 kBq/ KWhe, 45% of the radioactive vaporous outflows) are discharged in the environment following the shearing and disintegration of the fuel poles while only 0.01% is discharged in reactors. On the other side, 99.2% of the tritium (27.1 kBq/KWhe) is discharged as fluidwastes and represent 89.7% of these wastes. The cycle as far as radioactive releases are concerned can be separated: While 10% is released during reactor operation the rest 90% is released during reprocessing (24.4 KBq/KWhe). Carbon-14 and other minor radioelements represent only 0.01% of the gaseous and liquid radioactive releases (146 Bq/KWhe). Furthermore, 50% is released during the reprocessing (73 Bq/KWhe, equally shared between gaseous and liquid waste). It is noticeable that 37% (54 Bq/KWhe) is released as a liquid waste during the conversion steps, during the yellowcake purification (Poinssot et al. 2014). Only 19 Bq/KWhe are released in reactors as gases due to breached claddings. It is noteworthy that these radioactive releases are well below the authorization and regulations thresholds and have a negligible effect on health as evidenced by the numerous health reviews around the La Hague Plant which demonstrates that the total impact is lower than 10 mSv/year (Groupe Radioécologie Nord Cotentin). In particular, noble gases are fully chemically-inert and do not interact with the biologic molecules: their environmental and human potential impact is therefore negligible around the plant (IAEA, 2012).

2.7 Environmental Impact

When it comes to electricity generation and the anticipated shift from fossil energy to other alternatives that is happening already but will rise even further until 2050, nuclear energy shows a clear face in terms of greenhouse gas emissions (GHG). More specifically nuclear energy is anticipated to have a range of 6-10 gCO_2eq/KWhe. To continue with, bearing in mind that the uranium has shown stability in a low price, this demonstrates the capacity of the first in producing base-load electricity in a predictable cost. GHG emissions come from mining, reactors operation and disposal steps. Mining operations drive water pollution and SOx and NOx emissions, while reactor operation steps are mainly depended on water consumption, withdrawal and technological indicators.

More specifically, in the area of atmospheric and water pollution the most important contributor being the relevant mining activities, accounting for 87% for SOx and 78% for NOx. The rest of the fuel cycle contributors by decreasing order are namely the reactors, the enrichment and the reprocessing. Mining and milling operations produce water pollution

(89%) by the releases of chemical hazards in water, with a significant contribution of sulphates.

2.7.1 The Global Market of Energy: Nuclear Energy's Spot

Truly, it was on 26 June 1954 that the first run through business utilization of energy from nuclear power plant initiated in Russia (ENS, 2016). In the US, President Eisenhower initiated the Shipping port Atomic Power Station on the 26th of May 1958. With the developing acknowledgment that nuclear can be safe and cleaner energy, it ended up being more acceptable. It was contended that in the fifties and sixties, "The amount of energy produced by the fission of a single uranium atom is approximately 10 million times the energy produced by the combustion of a single coal atom (EBSCO, 2016). The US Atomic Energy Commission commended the potential of nuclear by seeing that it would turn out to be "too cheap to meter": the oil emergency of mid-seventies formed a new catalyst, and nuclear was viewed as an alternative energy source. In the US under the Energy Independent Sentiment, President Nixon wanted to assemble 1000 nuclear reactors by 2000 to increase power production in the interior. The arranged development experienced mishap with accidents such as Three Mile Island (1979) and Chernobyl (1986). The market for nuclear restored in 2000 metaphorically depicted as renaissance. "A parallel trend during the last two years has been a rebirth of serious interest in nuclear power. Economic, environmental, and political factors are now aligning to drive a 'renaissance' in the use of nuclear power for electrical energy production. Based on economic factors in electrical energy markets and the fact that the current fleet of nuclear plants is rapidly approaching the end of their initial licence periods, a strong economic incentive exists for new plant orders during the next 10–15 years (Wood et al. 2001)." In 2011, the incident of Fukushima came as a shock, refocusing public opinion on the issue of safety and security. The discussion was once more initiated around the attractiveness of nuclear power. In any case, regardless of mishaps, the effect on the relevant market has been of mixed nature. While nations, for example, Italy and Germany chose to shut down their nuclear plants, numerous others, for example, China, the United Arab Emirates, France, Poland, the UK and the US chose to focus on upgraded safety and security instead of total phase out.

The development has been moderate to stagnation amid 1995– 2014 when reactors went up only by one, from 436 to 437. In any case, the World Nuclear Association is self-assured, as it visualizes the construction of 266 new power reactors by 2030 (Greens, 2015). IEA states that "nuclear is one of the world's largest sources of low-carbon energy (an average nuclear plant has the production of 4000 windmills), and as such, has made and should continue to make an important contribution to energy security and sustainability" (IEA, 2016). It additionally recognizes that nuclear power is the second-greatest origin of low-carbon power worldwide after hydropower and that the utilization of nuclear energy has maintained a strategic avoidance of the production of 56 billion tons of CO_2 since 1971, proportionate to just about two years of worldwide emissions at current rates. As indicated by World Nuclear Association (WNA, 2015), nuclear power procures significance in low carbonization process, since it is environmentally friendly and consequently could assume a vital role in meeting the environmental change target. It is evaluated that the power request which multiplied from 1990 to 2011 is probably going to develop from 19,004 to 34,454 TWh in the year 2011–2035. Essentially, it is Asia that the new flood is probably going to occur averaging 4.0 or 3.6% every year, separately, to 2035 (WNA, 2015). The future elements of nuclear power demonstrate two basic movements, one as referenced above: Asian flood for nuclear power; second, the upsurge of nuclear power in the world energy mix. This is substantiated by the World Energy Outlook 2015. In spite of the fact that nuclear gives 11% of world power consumption, its contribution in OECD nations is way beyond that point, reaching up to 21%. Furthermore, the worldwide power (IEA, 2015a, b) generation mix is moving away from coal. Its proportion is potentially going to decay from 41% since 1990 to 30% in 2040. This shift is additionally upheld by the fact that the offer of low-carbon innovations in total generation is to rise up from 33% in 2013 to 47% in 2040 (IEA, 2015a, b). The deviation is additionally obvious in installed nuclear capacities expected to develop from 543 Giga watt electrical (GWe) in 2030 to 624 GWe in 2040 out of an aggregate of 10,700 GW. The expansion will be amassed in China (46%), India, Korea and Russia (30% of it together) and the US (16%); however we might witness a decrease of 10% in the EU. Nonetheless, the development of nuclear share in the global energy mix is to be just 12%, well beneath its memorable peak (IEA, 2014a, b, IEA 2016)." As per IEA (2015a, b) a large portion of the new nuclear plants "are expected to be built in countries with price-regulated markets or where government-owned entities build, own and operate the plants, or where governments act to facilitate private investment (IEA, 2015a, b)."

2.8 Asian Region: A Big World Competitor and Nuclear Trader

The move in financial gravity to Asia deriving from the rising economies such as China and India prompts ascension in energy consumption in Asia. Assessments recommend that the future market of energy will revolve around Asia. It is likewise perceived that though hydrocarbon will stay fundamental to Asian energy mix, the Paris Agreement will force commitment on them as to expand their energy sources, thus resulting in supporting low-carbon energy. Even though Fukushima first and foremost affected the Asian region, it is with regards to the diversification of the energy mix that nuclear power has earned significance in that region. In spite of the fact that Asia has been delivering nuclear energy at low rates reflecting a low share in energy mix, today's resurgence is prompted by climate concerns. Notwithstanding the drive for nuclear energy still stays restrained by the cost, safety and security all the more so of disposal of high waste. The leakage of radioactive tritium from one of US's most established nuclear power plants—Indian Point Energy Center, owned by Entergy, only 25 miles north of New York City—levels 65,000% higher than typical has caused unease around the security question (Shank, 2016): Apparently the popular conclusion once again swinging against nuclear energy. US had not built another nuclear power plant in about 20 years when, in October of 2015, a plant in Tennessee was allowed. On the other hand, as Table 2 shows despite worries, nations are settling on decision for nuclear energy. From a geopolitical point of view, it is critical that the lead retained by the US is shaking and moving to China as it develops with even bigger number of nuclear reactors, as shown from a more recent table (3). It is also decisive that with the benefit of reverse engineering of Westinghouse AP 1000 reactor, "Chinese have come up with their own design that they soon hope to sell on the world market. Last month, the Chinese startled the world by signing a nuclear agreement with Great Britain whereby it will own 33.5% of the Hinkley Point reactor, Britain's first reactor in 20 years (Tucker, 2015)." China is allegedly developing as exporter of nuclear power plants. It has created indigenously planned Hualong One reactor which was openly exhibited by China General Nuclear Power Group, to the business officials from Asian countries targeting exports.

Country	Reactors operable	Reactors under construction	Reactors planned	Reactors proposed
US	99	5	5	17
France	58	1	1	1
Japan	48	3	9	3
Russia	34	9	31	18
South Korea	23	5	8	0
China	22	27	64	123
India	21	6	22	35
Canada	19	0	2	3
UK	16	0	4	7

Ukraine	15	0	2	11
World Total	437	70	183	311

Table 2. Nuclear reactors in the world (Anderson 2015).

Country	Reactors operable	Reactors under construction	Reactors planned	Reactors proposed
US	98	4	14	28
France	58	1	0	0
Japan	37	2	1	8
Russia	36	6	25	22
South Korea	23	5	0	0
China	45	13	43	170
India	22	7	14	28
Canada	19	0	0	2
UK	15	1	3	6
Ukraine	15	0	2	11
World Total	445	57	126	372

Table 3. Nuclear reactors in the world (WNA 2019).

The environmental agenda has promoted the idea of economies being sustainable as the energy security discussion reveals. The decisions are being made through a similar point of view of the energy mix which contributes in achieving the objective set by the Paris meeting in December 2015. The soil of the radioactivity emanation of nuclear energy is disappearing in support of its decarbonized nature. It is appropriately observed that “When you weigh the clean energy benefits against the dangers of air pollution from other forms of energy, it’s clear that nuclear energy is punching far above its weight class (Whitman, 2016).” Consequently, nations are repositioning the requirement for nuclear reactor to meet their particular responsibilities with controlled risk. President Obama has in his Climate Action Plan emphasized the positive side of nuclear energy towards clean energy change and guaranteed assistance to the struggling nuclear industry in US. “The President’s FY 2016 Budget includes more than $900 million for the Department of Energy (DOE) to support the US civilian nuclear energy sector by leading federal research, development and demonstration efforts in nuclear energy technologies, ranging from power generation, safety, hybrid energy systems and security technologies, among other things. DOE also supports the deployment of these technologies with $12.5 billion in remaining loan guarantee authority for advanced nuclear projects through Title 17. DOE’s investments in nuclear energy help secure the three strategic objectives that are foundational to our nation’s energy system: energy security, economic competitiveness and environmental responsibility (US Embassy 2015).”

With regards to geopolitical goals of nuclear energy, it is contended that (IEA 2014a, b, c) “Uranium resources are spread across five continents and are available to satisfy the needs of the global economy in the twenty-first century. However, geological availability of an energy source is not enough to guarantee the security of energy supplies: unpredictable interruptions of extraction and transport and a high level of uncertainty about future supplies due to the high market power of exporting countries can negatively affect the expectations of consumers about future access” (IEA, 2014a, b, c). Therefore, it is obvious that as low-carbon innovation is concerned, nuclear reactors should be made in a transitional regime, given that separated from cost, proliferation and waste disposal squander transfer and multiplication, it might be underlined that it is made out of numerous parts which require a dynamic, diversified and powerful worldwide production network (NEI, 2016). Obviously sourcing includes huge number of organizations and specialists as well as workers, for example “the current Areva project in Finland has more than 4000 employees on site from 55 different countries and their new French build has around 100 suppliers from the global supply chain (Hoggett, 2014).” As appeared in figure 8, the supply chain consists of a six tier pyramid “The top tier comprises the Technology Vendor, who is the main contractors for a plant. There are currently nine consolidated vendors operating in the global market, with four dominating the market (AREVA, Hitachi-GE, Toshiba Power Systems and Mitsubishi Heavy Industry). Tier two is off—System Integrators (e.g. reactor pressure vessel and steam generators); Tier three—Original Equipment Manufacturers (e.g. rod cluster control assembly); Tier four—Sub-component Suppliers/Distributors (e.g. control rods and heavy forgings); Tier five—Processors/Fabricators (e.g. alloys); and Tier six—Raw Material Suppliers/Miners (e.g. silver, zinc) (Hoggett, 2014).” Since these components require expertise and heavy investment, there have been a handful of players. There are just four enterprises all inclusive equipped for delivering design and production of such huge caliber, residing in Japan, China and Russia. The unpredictability of a nuclear power plan unmistakably draws out that with regards to The Paris Agreement pledges, the supply concerns could present issues. “From a supply chain perspective, risks appear to increase if a supply chain is reliant on a limited number of companies, technologies or markets, whereas resilience increases if the number of companies, networks, connections, etc., is large, as this creates alternative options for bringing forward a low-carbon technology at an affordable cost (Hoggett, 2014).”

Expansive innovations offer less versatility than littler scale advances. Development additionally seems, by all accounts, to be slower, with long life cycles between generations of plants, and once installed, they operate for decades, conceivably compelling the development of the system into different advances. Smaller scale advances however, show speedy rates on development and can be immediately conveyed and improved. Seemingly, at that point, from an energy security and low-carbon transition perspective, there is naturally something more secure about smaller scale innovations (Hoggett, 2014).

From the aforementioned, nuclear energy in spite of being clean it can also play its maximized efficiency role, in case it can be adjusted to other energy sectors, to be more specific renewables (solar power), extraction (hydraulic fracturing), storage (advanced batteries) and consumer efficiency (advanced thermostats), is engaged with technological innovation (Brinton 2015). It is contended that "without significant advances in nuclear reactor and fuel cycle technologies—advances yielding cost reductions, shorter cycle times, a greater focus on passive safety, and other improvements—nuclear is unlikely to play that role (Lester, 2016)," thus leading us to a suggested roadmap that will promote such needed advances.

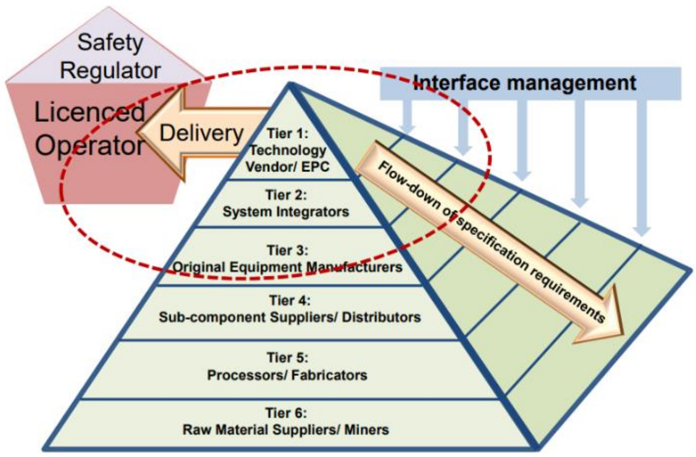

Figure 8. An overview of the world nuclear supply. Source: World Nuclear Association, September 2017 (WNA, 2017).

2.8.1 Suggested roadmap "Energy Collective 2016" follows the pattern mentioned below:

- Firstly, expanding the operational lifetime of the current fleet. The focus should be on innovations on cost control and efficiency. It covers today as far as possible the end of 2030s.
- Secondly, should form another larger fleet, based fundamentally on large and small light-water reactors, deploying them to the market to be used in power generation as an advanced nuclear technology. In addition these reactors would be used for desalinization, as heat processors and as means for fuels production for the transportation sector. This stage is calculated to start in the 2030s, extending to the end of the 21st century.
- Thirdly, build a next generation of cutting edge nuclear advancements in a time span after 2050 so as to be utilized more widely (Yurman, 2016).

3. Methodology

The previous chapter has informed us about current issues in the international agenda, concerning the use of nuclear energy for peaceful purposes, as well as the dangers of its use being redirected to WMD-connected activities (Weapons of Mass Destruction). It has also discussed the global market of energy and nuclear sector's position in it, along with its supply chains and more detailed information around its operational and environmental issues. Last but not least it reviewed a complete energy cycle based on the most developed system in Europe, France.

In addition literature review has pointed out the most important game changer that could significantly shift the tides, in the current game. Technological advancements could drastically change the electricity sector's pace. In fact, if any future factors should arise, technology should check and balance it. Finally, up to this point we have addressed nuclear power's resilience to any accidents that have occurred with very few cases of actual slowing down in growth. Therefore, bearing in mind the Asian tremendous rise in energy demand and supply and its up and coming nuclear role, the research questions that arise are:

- Which are the critical aspects of nuclear energy?
- Which geopolitical game changers exist in nuclear energy?
- Which future scenarios may be developed based on the findings of the previous two questions?

In order to answer these research questions qualitative methods will be used. Technology will hold a crucial spot in this discussion, along with geopolitics and the competition between the US and the Asian region. Focus will be given to an introduction to the latest cutting-edge technology of nuclear fusion, while trying to categorize some future scenarios concerning nuclear energy's sector.

4. Results

In this section, we will elaborate on our findings concerning the three aforementioned research questions, with a special focus on the industry itself and the dynamics that come into play within its structure. At the same time we will attempt to note some game changers that could lead nuclear power to having a more important role in the world's energy generation.

4.1. Nuclear Energy's Critical Aspects

Introducing many issues along this thesis, concerning nuclear energy and its aspects, we have reached the results section where we will look on this form of energy through the lens of its own industry and the developments taking place around it. Nuclear energy's aspects are namely two, which are also fully interconnected:

- Nuclear Energy for Weaponry

As mentioned above in the introduction, the very first use of nuclear energy that introduced it to the world, had taken place in the WW2 in Japan, when the Americans bombed Hiroshima and Nagasaki on the 6th and 9th of August 1945, respectively. People witnessed the so called "mushroom clouds" as well as the destructive power of nuclear weapons leading to a lightning fast surrender of Japan six days after the second bombing.

- Nuclear Energy for peaceful purposes

When one reaches to this point, what comes in mind is using the nuclear technology for non-weapons related actions (P.R. Lavoy, 2013). As Nicola de Blasio and Richard Nephew put it, (Blasio and Nephew, 2017): "This was enshrined in a 1954 revision to the original 1946 Atomic Energy Act (AEA), which allowed 'nuclear technology and material exports if the recipient countries committed not to use them to develop weapons."

4.1.2 The Industry and its developments

It is development and technological leaps forward: the cutting edge low-carbon advancements that are going to cartograph the geopolitical frontiers of energy security. "China's push into nuclear power comes as many nations have been re-examining the risks of nuclear energy and its costs compared with natural gas and other fuels. Two dozen reactors are under construction across China today, representing more than one-third of all reactors being built globally, according to the International Atomic Energy Agency-the scale and pace of building has given CGN and other Chinese companies the opportunity to bulk up on experience in the home market and gain skills in developing reactor parts, technologies and systems. That experience, combined with China's lower costs of labor and capital, makes the new Chinese reactor potentially attractive to international customers, industry experts said (Spegele, 2016)."

Chinese rise has pushed American nuclear industry into understanding that the nuclear market is shifting away. American disregard of the developing interest for nuclear energy in West Asia has led other competitors like Russia and China to participate in this race with lowered protective walls. Russian enterprise Rosatom is a main player of the nuclear energy market. The organization holds contracts worth $740 billion to manufacture 30 reactors in 12 nations, including Turkey, Egypt, Saudi Arabia, Iran, India, Argentina, Bangladesh, Nigeria, Algeria and others. It is discussed that both Russia and China enjoy a cost favorable position thus rendering them a cost advantage which could form overwhelming players in the relevant market. It is noteworthy that however the two nations competed with each other, they have also been cooperating. Rosatom is still working on a venture in Jordan in a joint effort with China. More specifically: "In 2013, Rosatom got a contract for the construction of the first nuclear power plant in Jordan. Then, it was planned that the Russian side will finance half of the project cost of $10 billion. However, in the autumn of 2015, it was decided that China will take on about 50% of the costs. So far, Beijing has only funded Rosatom projects, which were carried out in China. As can be seen, fearing competition, Rosatom is committed as soon as possible to take a free niche in the market of nuclear technology, even if it means resorting to the help of its rival (Bokarev, 2015)." The nuclear reactors apart from being an energy source, they pose instruments of political influence and a veiled step with weaponisation prospects. Under these circumstances will geopolitics be challenged once more, which forms an argument made by Mr. Nakahara, Director of the Office for International Nuclear Energy Cooperation at METI, while addressing the US– Japan Round Table: "The increased role that China and Russia are taking in the sphere, and expressed concern that the nuclear world has paid too little attention to the potential implications of such developments (Forum on energy, 2015)." Furthermore, based on the fact that building a power plant is very long in terms of time construction and the Russian contracts work to a great extent around a build-own-operate model, manufacturing possesses guarantees that these tasks proliferate Russia's diplomatic influence (Armstrong, 2015). The Jordanian case that is an ever expanding example of this success for the latter player, combining the supplier's increased influence with the technological advancements can find basis at the statement of the chairman of the Jordan Atomic Energy Commission, Dr. Khaled Toukan:

“We have been cooperating with Rosatom for many years, and we are going to build on this cooperation in various spheres. Today, a potential project to construct SMR-type NPP seems more relevant and more needed, so we would like to focus on it” (ROSATOM, 2018).

Nonetheless, we should keep in mind that this market is calculated to be a $1.2 trillion market, as well as that nuclear power has been an instrument of US foreign policy since its beginning (Pant, 2017). As stated by Koranyi: “American geopolitical, economic and technological leadership also predisposes the US to lead and benefit from the energy sector transformation abroad. The global transition to a lower carbon economy plays directly to the comparative advantages of the US: individual empowerment, innovation and engineering ingenuity (Koranyi, 2016).”

Being a pioneering state in innovation and technology, US have been in the market, long-lasting and keep developing until today. Given the tremendous involvement with nuclear energy's civil side and with the largest capacity available in the world, US have literally thrown off competition along the value chain (Gottemoeller 2013). Naturally, out of the 25 highest-performing reactors in the world, twelve of them are in US soil. Perceiving the rules of competition while bearing in mind financing, the state department has taken some actions such as "Team US.” The latter promotes the idea of civil nuclear engagement abroad so as to support the inner industry. Also along the same lines, Director of Nuclear Energy Policy position was created at early 2012. Correspondingly, “The Department of Commerce has established a Civil Nuclear Trade Initiative, the goal of which is to identify the US nuclear industry’s trade policy challenges and commercial opportunities and coordinate public–private sector responses to support the growth of the US civil nuclear industry (Gottemoeller 2013).”

In the European scene, nuclear energy discussion has taken another turn with the phase-out of EPR3 by the Finish government on the grounds of significant financial increase along with delayed construction. EPR under development, at Flamanville (AREVA 2016) in France, is additionally heavily postponed since its construction started during December of 2007 and expectations of completion were in 2013. Interestingly, in 2015 concerns were about the quality of steel in the pressure vessel (Eco Watch 2015). The damage done by that development is distinctively described by Eco Watch: “This is a serious blow to the pride of a country that is seen as the world leader in nuclear energy, with 75% of its electricity coming from 58 reactors (Eco Watch 2015).” Hence, while in 2019 after twelve years of construction and 6 years of delay with a big explosion in its background already during February of 2017 (BBC, 2017), it has finally been announced that hot functional testing will commence (WNN, 2019). However, it is also true that in parallel with this news, the plant still seems stuck to a never-ending cycle of arising technical problems that do not allow for its proper resumption of construction, with the latest addition of “faulty weldings” discovered on April 2019 (Reuters, 2019).

It is acknowledged that “where markets are freer, it is harder for nuclear power operators to make money, and too risky for them to build plants from scratch” (The Economist 2015). It is also being witnessed in Europe, where deregulated market exists; lower cost of electricity rendering the nuclear choice unfeasible (The Economist 2015). More specifically, the sector's economics and the way they are being handled propose that “Other things being equal, nuclear power’s front-loaded cost structure is less attractive to a private investor in a liberalized market that values rapid returns than to a government that can consider the longer term, particularly in a regulated market that ensures attractive returns. Private investments in liberalized markets will also depend on the extent to which energy related external costs and benefits (e.g. air pollution, GHG emissions, waste and energy supply security) have been internalized. In contrast, government investors can incorporate such externalities directly into their decisions. Also important are regulatory risks and political support for nuclear power. All these factors vary across countries. In the Republic of Korea, the relatively high costs of alternative electricity sources benefit nuclear power’s competitiveness. In China and India, rapidly growing demand for electricity encourages the development of all energy options (IEA 2015a, b).”

From a geopolitical angle, it is noteworthy that while West is not resting assured on the nuclear reactors as the form of clean energy that it strived for, Asia is pushing and proves a hungry giant for the sector's expansion, not affected by the Japanese experience. Moreover, four out of six trading nuclear countries are Asian countries. Namely all six of them are France (AREVA), US (General Electric, Westinghouse), Russia (ROSATOM), Japan (Toshiba, Hitachi), South Korea (KEPCO), China (CGNPC), with the four latter ones belonging to the Asian region. Table 4 below breaks down the dynamic situation of Asia (Pant, 2017).

Country	Power Reactors Operable	PRs Under Construction	Power Reactors Planned	Research Reactors Operable
Australia				1
Bangladesh		1	1	1
China	38	20	39	16
India	22	6	19	4
Indonesia			1	2
Japan	42	2	9	1
Kazakhstan				4
South Korea	24	4	1	2
North Korea				1
Malaysia				1
Pakistan	5	2	1	2
Vietnam			4	1
Total	131	35	76	36

Table 4. Nuclear Power in Asia (WNA 2018a).

4.2. Technological Game Changers

Having discussed the game changers above in the literature review, we will now focus on the two most notable ones that could heavily shift the world mix in favor of nuclear power. These are: The development of small modular reactors and the technology of nuclear fusion which could render current fission nuclear era, obsolete.

4.2.1 The Small Modular Reactor (SMR) regime

Moving on, the potential outcomes of small modular reactor have re-orientated the prospecting of nuclear energy. It is generally accepted that SMR's are going to form the cutting edge technology mentioned above. These SMR's are probably going to be ranging from 10 to 300 MW. These SMRs despite being small as far as size is concerned "are designed to have many components fabricated and assembled offsite, thus reducing the time and complexity of plant construction and increasing potential plant locations. SMR designs generally have their reactors buried in the ground away from weather hazards and are often designed to use passive cooling systems that are not vulnerable to power outages, further increasing the safety of the plan (BRIGGS, 2016)." They for the most part have their reactors underground, reducing weather condition threats. These structures mostly use cooling systems of passive nature that are resilient for example against blackouts, thus boosting the plant safety (BRIGGS, 2016). "Countries are investing on designs to gain the advantage of market. Britain has planned to spend 250 million pounds," so as to "position the UK as a global leader in innovative nuclear technologies" and pave the way "towards building one of the world's first SMRs in the UK in the 2020s." There is no shortage of contenders, with companies from the US to China and Poland all wooing the UK with their proposal (Carrington, 2015)."

Commercialization of SMR opens a way of various potential outcomes with special geopolitical sight. Such is the case with floating plants where "an SMR could be put on a barge, taken to a country, plugged into grid from the port and then, when its fuel was used up, sail back again. 'For newcomer countries [to nuclear], that could be a very attractive way to do it.' It has happened before: in the late 1960s a former US military nuclear-powered ship moored by the Panama Canal and provided onshore electricity (Carrington, 2015)." Russia has been working on an armada of submersible and floating nuclear power stations in order to take advantage of Arcticoil and gas reserves. Nuclear energy is coming back as an interesting competitor of the times; however it needs to develop through technological transition so as to end up less expensive, more secure and progressively versatile successors to the older enormous nuclear plants, thus meeting the energy security parameter. The geopolitics of energy security that is characterized by hydrocarbons control is now being unmistakably repositioned by the basic changes in the existential need to move towards low-carbon society. Therefore, low-carbon fuel will re-orientate energy security's preferred source. With regards to change in global geopolitical matters driven by technological advances with great impact, the virtual phenomena will turn into the key factor of geopolitical impact and power relations. The progress to low-carbon fuel will be the focal point of characterizing power connection among producer and consumer in light of the fact that hydrocarbon market is noting an interesting spike. Moving to a low-carbon energy reality fundamentally will rest upon the pace of innovative technology alongside institutional changes. Along these lines, it is the low-carbon innovation that will be playing out the geopolitics of low-carbon energy fuel. The argument that those who are focusing and contributing on such innovations would be the pioneers in the low-carbon market of energy clearly stands. Doubtlessly, the geopolitics of low-carbon energy security is going to race in a framework "to occupy and monopolize the low-carbon technology as well as its product market expresses the current new connotation of superpower's geopolitical strategy; that is, who dominates low-carbon technology would occupy the high ground (Wang et al. 2012)." In the low-carbon innovation period, nuclear has its own spot towards energy security, however as the EU report on The Sustainable Nuclear Energy Platform 2015 supports "The long-term sustainability of nuclear energy will be ensured by Gen IV fast neutron reactors and closing the fuel cycle, minimizing the nuclear waste and offering a transmutation option as well. This will require a large R&D programme for supporting the construction of reactors (prototypes, research facilities, demonstrators) and related fuel cycle facilities (SNETP, 2015)."

4.2.2 Nuclear Fusion Prospects

The long awaited nuclear fusion's development, the so called "holy grail" (Marvel, and May, 2010), is now more than ever a technological advancement tool that could boost nuclear energy's global influence and usage significantly. Once this form of energy production manages to sustain itself and produce more heat than the energy needed to fuel its plasma, it could mean the solution to today's various problems that revolve around nuclear fission, which is the current technology that reactors work with. Therefore, we should break down nuclear fusion's future perspectives along this section.

Firstly, to begin with, it is a fact that fusion can provide a source of energy almost inexhaustible. However in order for that part to be realized, huge technological leaps would be in order. It indeed poses an engineering challenge. Fusion is basically what powers the sun and the stars, by forming helium through fused atoms of hydrogen, where matter is converted into energy. When the temperature increases the nuclei can fuse, thus releasing energy. However such a function would normally not be feasible since the strongly repulsive electrostatic forces between the positively charged nuclei prevent them from getting close enough together to collide and for fusion to occur. This is the reason that justifies ITER's goal of producing 500 MW thermal energy for 400 seconds without any pauses. The important aspect is that the heat power input shall not exceed that of 50MW, which is what renders fusion challenging (WNA, 2019).

Secondly, what makes ITER a noteworthy collaboration project is the fact that so many nuclear powerful states are involved in its development and scheduling: "In an unprecedented international effort, seven partners – China, E.U., India, Japan, Korea, Russia and the United States – have pooled their financial and scientific resources to build the biggest fusion reactor in history. ITER will not produce electricity, but it will resolve critical scientific and technical issues in order to take fusion to the point where industrial applications can be designed (ITER, 2019)."

Furthermore, the use of fusion power could in theory serve humanity in every contemporary need following the international agenda of the climate change. Without sacrificing society's desire for continuous development, it could reduce the environmental threats that fission faces undoubtedly for many years, thus not contributing to the greenhouse effect or the phenomenon of acid rain. Another critical aspect that gets tackled by this technological breakthrough is the safety question, from which most negative arguments about today's nuclear power derive from, especially since the world has witnessed nuclear stations accidents. This time, the case is different since a runaway reaction is impossible and malfunction would only lead to rapid shutdown. Current concerns pertain to non-long-lived radioactive products unlike fission's procedure but to a short -term radioactive waste problem of the structure's materials. Finally, because tritium that is part of the procedure can be dangerous for the environment, hopes are now placed on the further development of the procedure with deuterium which is an isotope of hydrogen as well.

4.3 Future Scenarios

Since our focus in the two previous sections was around technological breakthroughs, we will now proceed into the categorization of technological factors that could lead to a more popular form of energy in political, financial and societal terms.

In terms of operation, four areas could promote game changing effects. These are namely, higher burnup, waste, proliferation resistance and grid compatibility (Marvel and May, 2010).

- Firstly, new reactors being able to higher burnup the fuel and therefore account for higher energy security and waste management concerns by not reprocessing spent fuel.

- Secondly, it is notable that many designs attempt to burn elements reducing the radiotoxicity of the byproduct with the example of Russian technology pledges: "The ultimate aim is to eliminate production of radioactive waste from nuclear power generation (WNN, 2016)."

- Thirdly, great interest is found in reactors being able to operate without the need of refueling and thus leading to containment of proliferation threats.

- Fourthly, existing electric grid may not have the capacity to handle new high-capacity generating sources. This means that a decision to adopt nuclear energy carries with it substantial up-front costs associated with grid expansion and modernization. Smaller modular reactors (SMR) may remove this issue, allowing for easier integration with existing infrastructure.

Moving on to another aspect that is heavily related with the sector's growth, we should mention the fact that according to BP's energy outlook, even though nuclear power is growing, this occurs less rapidly compared to the overall power generation, leading to a decline in its share. This also goes in parallel with the fact that ageing nuclear powers in OECD countries are decommissioned with limited to no investment in new capacity. However non-OECD and China follow a continuous development path, which could grow more and more into the future if most of the operational game changers become a reality. Finally, if through time the costs become more economically feasible we could see another rise in Europe that could boost the nuclear sector along with China.

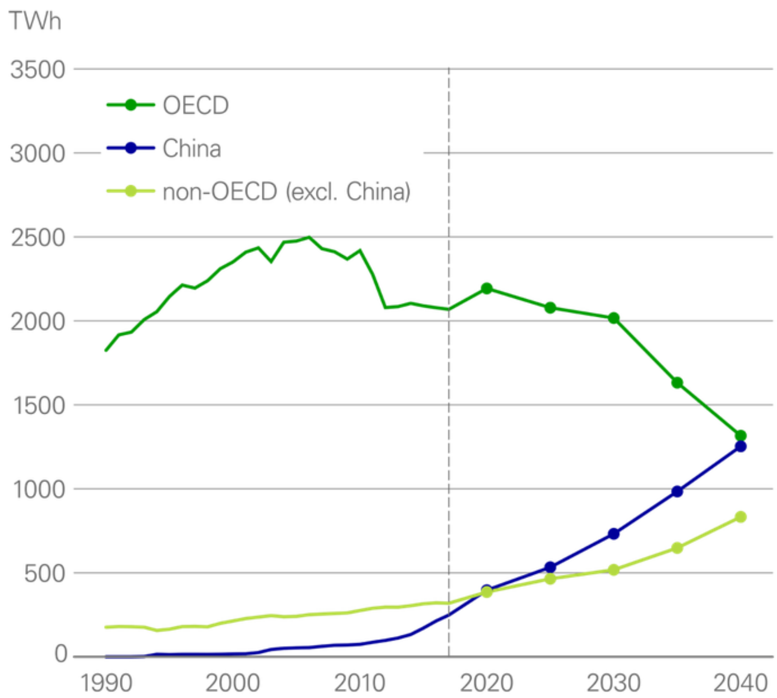

Figure 9. Electricity generation from nuclear energy. Source: BP energy outlook 2019.

5. Conclusion

In conclusion, what is apparent from this research is the fact that nuclear power is faced with various issues in terms of its growth and popularity. However, the international community on state level keeps its support on nuclear energy. Especially China and non-OECD countries seem to be more supportive than ever, while Europe is abandoning the sector. Furthermore, along this research, we have made a special case on technology as the most important factor of change. Given that technology could produce cleaner and safer reactors, this could also mean that a different perception around the whole industry could be adopted. Having analyzed the industry's scale, its environmental impact, the biggest competitors and its potential through advancements such as SMRs and nuclear fusion I would like to conclude this research with a note about nuclear energy's green perception, from Marvel and May that entails the whole reasoning behind humanity's need on nuclear, in order to tackle the environmental degradation.

When the discussion falls on energy sources, nuclear power is not yet perceived as a 'green source'. "The most likely game changer for the entire energy sector, including nuclear power, is a price on greenhouse gas emissions. If governments start to take the threat of climate change seriously, we should expect to see some form of emissions controls or direct subsidy of low-emission generating technologies (Marvel and May, 2010)." Such a development combined with a potential resurfacing of renewable technology's drawbacks due to future negative prospects such as the huge quantities of fresh water needed, the new transmission lines that have to be built to expand up to their far from centers locations and the fact that renewables are intermittent, could seriously reshape the world energy mix. Therefore, if nuclear power manages to enter the game and accepted as 'renewable' due to its reliable low-carbon baseload, we could witness a positive shift towards that kind of technology.

According to Kate Marvel and Michael May: "Our aim is to work towards a sustainable energy future, increasing the supply of reliable electricity worldwide and promoting development while reducing greenhouse gas emissions and environmental degradation. It is imperative to seriously consider all the options and it is important to decide what role nuclear power could and should play in the future energy mix (Marvel and May, 2010)."

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