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THE PRAGMATIC DICHOTOMY OF ENERGY IN THE WORLD

A DICOTOMIA PRAGMÁTICA DA ENERGIA NO MUNDO

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ABSTRACT: Energy is important to humanity. Today, countries routinely trade their energy reserves. The world and humanity have formed an alliance with indissoluble and practically unquestionable sources of energy for continuity of human development. Nevertheless, strategies adopted by several nations made them absolutely dependent on energies of other nations through commercial means. The dichotomy of dependence between nations for a good as valuable as availability of energy makes countries that do not have exploitable energy sources need to trade energy. However, globalized trade can be a long-term trap. This can be seen in armed conflicts in which certain countries fail to supply energy to others for their own benefit. Pragmatism in use of energy sources in the world and understanding of the nature of relationship between energy and human beings, allows us to understand why long and tireless research into energy is carried out. The relationship between nations of the world must be different after establishment of first nuclear fusion reactors, which will bring a new balance to countries, even those that today are heavily dependent on their nation's natural resources. This paper aims to show how is relationship between human beings and energy, their dependence, their needs and their relationship between nations and, finally, to present in an objective way possible transformation and distribution of energy in the world with use of energy nuclear fusion reactors.

Key Words: Energy; Source Energy; Electric Energy; Nuclear Fusion; Controlled Thermonuclear Fusion; Tokamak.

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RESUMO: A energia é importante para a humanidade. Hoje os países comercializam de forma rotineira suas reservas de energia. O mundo e a humanidade formaram uma aliança com as fontes de energia indissoluvel e praticamente inquestionável para a constinuidade do desenvolvimento humano. Contudo, as estratégias adotadas por diversas nações as tornaram absolutamente dependentes de energias de outras nações por meios comerciais. A dicotomia da dependência entre as nações por um bem tão valioso como a disposição de energia faz com que os países que não possuem fontes exploráveis de energia, necessitem da comercialização de energia. Entretanto,o comércio globalizado pode ser uma armadilha a longo prazo. Isso pode ser observado em conflitos armados no qual determinados países deixam de fornecer energia para outros em benefício próprio. O pragmatismo no uso das fontes de energia no mundo e o entendimento da natureza da realção entre a energia e ser humano, permite compreender o porque as longas e incansáveis pesquisas em energia são realizadas. A relação entre as nações do mundo devem ser diferentes após estabelecidos os primeiros reatores a fusão nuclear, o que trará um novo equilíbrios aos países, mesmo aqueles que hoje são fortemente dependentes dos recursos naturais de sua nação. Este artigo tem o intuito de mostrar como é a relaçõa do ser humano com a energia, sua dependência, suas necessidades e sua relação entre as nações e por fim, apresentar de forma objetiva a possível transformação e distribuição de energia no mundo com a utilização de reatores a fusão nuclear.

Palavras-chave: Energia; Fontes de Energia; Energia Elétrica; Fusão Nuclear; Fusão Termonuclear Controlada; Tokamak.

INTRODUÇÃO

The current world, despite being in constant evolution, has still not been able to find in dialogue a civilized way of dealing with serious problems between nations. There are countless examples of disputes with military intervention that almost always consume a huge amount of lives and vital resources for planet and for human development.

In this context, energy plays a very important role, both in form of interaction between nations and in dependence on use of certain energy sources. Currently, world energy production is spread among different energy sources and different forms of transformation, some efficient and others not so much. The fact is that whatever amount of energy is produced, it will still not be enough for an equal distribution among peoples of the world. The more energy available, greater will be its consumption given predominant characteristics of strategies and tactics used to provide humanity with constant development (FRIGO, 2018; FELTRIN, 2018).

The diversification of energy sources has always been important for composition of energy matrix of a given nation, that is, composition of different forms of energy transformation helps in diversification of energy consumption for each type of application.

Different geographic and geological characteristics allow use of different forms of energy in each country. This is an important determinant in diversification of energy sources, and in planning of use and exploitation of these sources by countries in the world. Another important factor is cost of exploring certain geological energy sources and their investments in short and long term, given estimated reserves. This will basically depend on strategies adopted by each country, and also on form of concession chosen to allow exploitation of resources.

Each country in the world chooses form of governmental regime that is most suitable for its nation, often in a general way, and in a few times in an authoritarian and autocratic way. The world has always found a strong cultural difference in countries called Western, and countries called Eastern. These differences, despite being tenuous and very consistent with cultural traditions, end up imposing a relative barrier between the nations of both hemispheres. Currently, a way of observing the dichotomy between so-called western countries with so-called eastern countries is noted by government regimes adopted in each of these countries. And cultural, economic and commercial differences end up reinforcing differences.

These differences can be interpreted as a form of pragmatism adopted by countries with democratic or partially democratic government regimes as opposed to hybrid or authoritarian government regimes and vice-versa. The fierce dispute for power in any governmental regime is always a sad reality, and energy forms an important part due to economic values arising from exploration, storage, distribution and sale of this important resource.

The fact that some countries have an abundance of a certain energy source to detriment of others, constitutes a problem for countries with few natural resources for energy transformation and exploitation. These differences provide a very big barrier between nations in the world, and each one can still be aggravated with the cultural and governmental characteristics of each nation.

With all this, the important thing is how to find adequate solutions for equalization of energy distribution between different nations with different natural resources. One of main forms of energy exploited by humanity, which can be transformed into different forms is electricity. If a certain piece of equipment, or device, allows the generation of huge amounts of energy at affordable costs, this could bring an unprecedented balance between nations around the world, regardless of their location and their cultural and governmental characteristics.

One of ways to dispose of this energy is through nuclear energy (MURRAY, 1993). In which the world knows only part of it called nuclear fission energy. Nuclear

fission energy, as name implies, needs to be fissioned, that is, broken. Then heavy atoms of radioactive elements must be broken down so that part of their atomic binding energy can be harnessed in form of heat for heating and generating steam used by conventional steam turbines to drive conventional electrical generators and produce electricity. This type of machine can almost always be built in different countries with or without oceans, or even large reserves of water available for cooling. However, the world, after devastating effects of nuclear weapons of mass destruction, and some accidents with nuclear power plants, chose to avoid expansion of this energy source, including its reduction in several nations such as Germany.

In this paper, source of nuclear energy that will be presented, and discussed, is other part of nuclear energy. It's nature's way of producing huge amounts of energy in the Cosmos, nuclear fusion (McCRACKEN and STOTT, 2012). Nuclear fusion, as name implies, is way to unite light atoms and hydrogen isotopes, causing them to break through electrostatic Coulomb barrier, and produce a new element in which union process gives off a significant amount of thermal energy, many times superiors to nuclear fission process. In a similar way to nuclear fission process, thermal energy of nuclear fusion will be used for heating, and generation of steam in traditional way in turbines and electric generators, as in case of nuclear fission, but with an efficiency many times greater (HIWATAR and GOTO, 2019).

In paper, there is existing and pragmatic dichotomy of nations in relation to use and exploitation and sale of energy between countries, their characteristics and their peculiarities. The need for energy available in more significant quantities in order to provide a better quality of life for the world population and its constant development. Analysis of amount of energy produced and consumed in the world and its growing deficit, in addition to existing options and alternatives with current technologies. Finally, nuclear fusion will be presented and the expectation for operation of the first nuclear fusion reactor in the world and way to distribute energy equally among nations in order to reduce inequalities and rivalries that almost always lead to armed conflicts and/or military.

THE ENERGY DEFICIT BETWEEN THE NATIONS OF THE WORLD

To this day, the world remains trying to meet growing energy demand of the world's population. The fact is that the supply of energy has always been an insignificant fraction of what demand requires. This is what motivates search for more efficient energy sources and all development in area of energy generation.

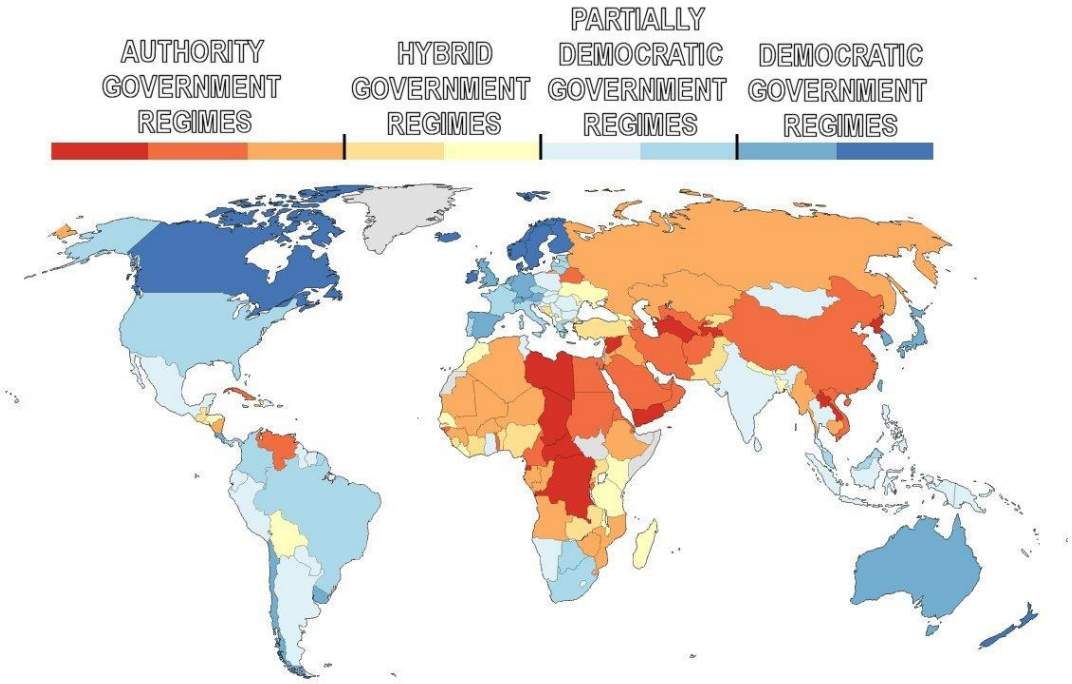
Science seeks to find solutions that can, at same time, supply energy deficit without impacting nature and environment, and that still allow it to be economically competitive and can be distributed equally across nations. As can be seen, task is not simple and not easy to be met.

According to difference of each government regime of each nation, information about energy production can be misinterpreted, or easily modified for other strategic reasons. The division of economic power in the world undoubtedly allows emergence of several chasms with enormous proportions which world diplomacy almost never manages to cross without damage to both sides of these chasms. Democratic or partially democratic government regimes try in vain to allow the dilution of powers and economic concentrations, because competitiveness is human nature.

The search for economic resources so that a particular nation can stand out from other, almost always harms the balance. This fragile balance allows for unbelievable disparities such as lack of access to electricity. It is not uncommon in today's world to see countries in which their populations do not have access to electricity, which often seems unlikely to happen, but it does happen. This shows great difference between the world's economic powers, which affects and favors emergence of disputes and conflicts.

Figure 1, its possible to notice different types of government regimes distributed around the world and their intensities (extreme red - absolutely authoritarian regimes and extreme blue - absolutely democratic regimes).

Figure 1 - Types of government regimes around the world in year 2020.



Source: Adapted from Global Democracy Index (2020).

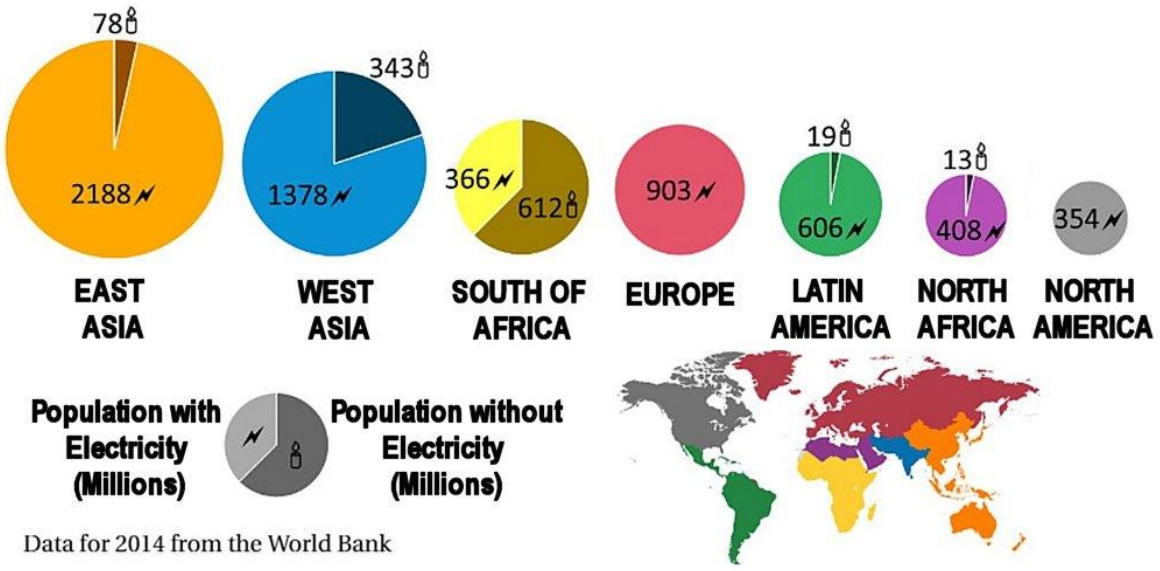
Figure 1, its possible to observe that there is a territorial division of similar proportions between democratic and authoritarian regimes. This undoubtedly feeds classic division of dichotomy between western and eastern, intensifying their socioeconomic, cultural and governmental differences.

This division of the world worries future world negotiations for an impartial consensus of conduct and harmonious coexistence between nations. In this scenario, energy is an important factor in power disputes, and its commercialization can be a powerful form of dependence between nations, which can lead to serious conflicts of great magnitude. Everything that the world has been trying to avoid since the end of Second World War in 1945. There have been several initiatives to put the world and all nations together to constantly provide world peace, especially after development of long-range nuclear devices constitutes a of main modern threats in military conflicts.

The sad reality today, in which differences are still dealt with without dialogue and with military oppression, exacerbates situation in which refugees have to spread to several other countries, aggravating situation of world balance. Whatever reason for military interventions, it is a fact that all efforts undertaken since 1945 fall to ground and show how weak humanity is in defending and guaranteeing the life of its own species.

Figure 2, its possible to observe in different locations around the world division of populations that are largely served by electricity and those that do not receive the minimum amount of electricity. Showing that situation is absolutely serious in Africa (southern region), in which in 2014, just eight years ago, almost half of the population of this region did not have minimum amount of electricity. Something of smaller proportions, but equally worrisome, also occurs in West Asia, where ~1/4 of population does not have electricity (SMITH *et al.*, 2013; SHOBANDE, 2020; MOHAMMED and AKUOKO, 2022; HAY *et al.*, 2019).

Figure 2 - Populations with and without access to electricity in the world.



Source: Adapted from World Bank (2014).

In this previous figure, it is clear current inability of the world to provide electric energy in order to meet real human needs regarding the continuity of development and evolution of the species in different regions, and also, it is clear disparity in amount of electric energy coming from a given region when compared to others. It is easy to notice that since 2014, Europe and North America have almost all of their services and availability of electricity for the population. However, it is also clear that among seven regions presented in this study, that five of these regions still suffer from unavailability of electricity to supply all nations and their peoples.

The lack of energy balance in the world is a serious socioeconomic problem, which greatly exacerbates situations and relationships between different nations. Nations with greater purchasing power, even when not served by natural resources that can be converted into energy, are able to acquire energy from other countries. In short term this seems like a solution, but in medium and long term they create a dangerous dependency, which almost always leads to disputes.

Energy in general almost always has great value when transformed into form that a given nation needs, fuels, heat, electricity, among many others. One of only energies capable of transforming into almost all needs of a nation is electricity.

Electricity can be used as “fuel” in means of transport, as “heat” for heating homes and as electricity for operation of various equipment for domestic and industrial use. In this way, electricity may play an even more important role for world society than it does today. When the efforts of international scientific community give expected results for 2025 with the nuclear fusion processes, it could be beginning of a new era of energy in the world, with affordable costs, with decentralized production and with amount of demand never seen before (MISHRA and ANITHA, 2020).

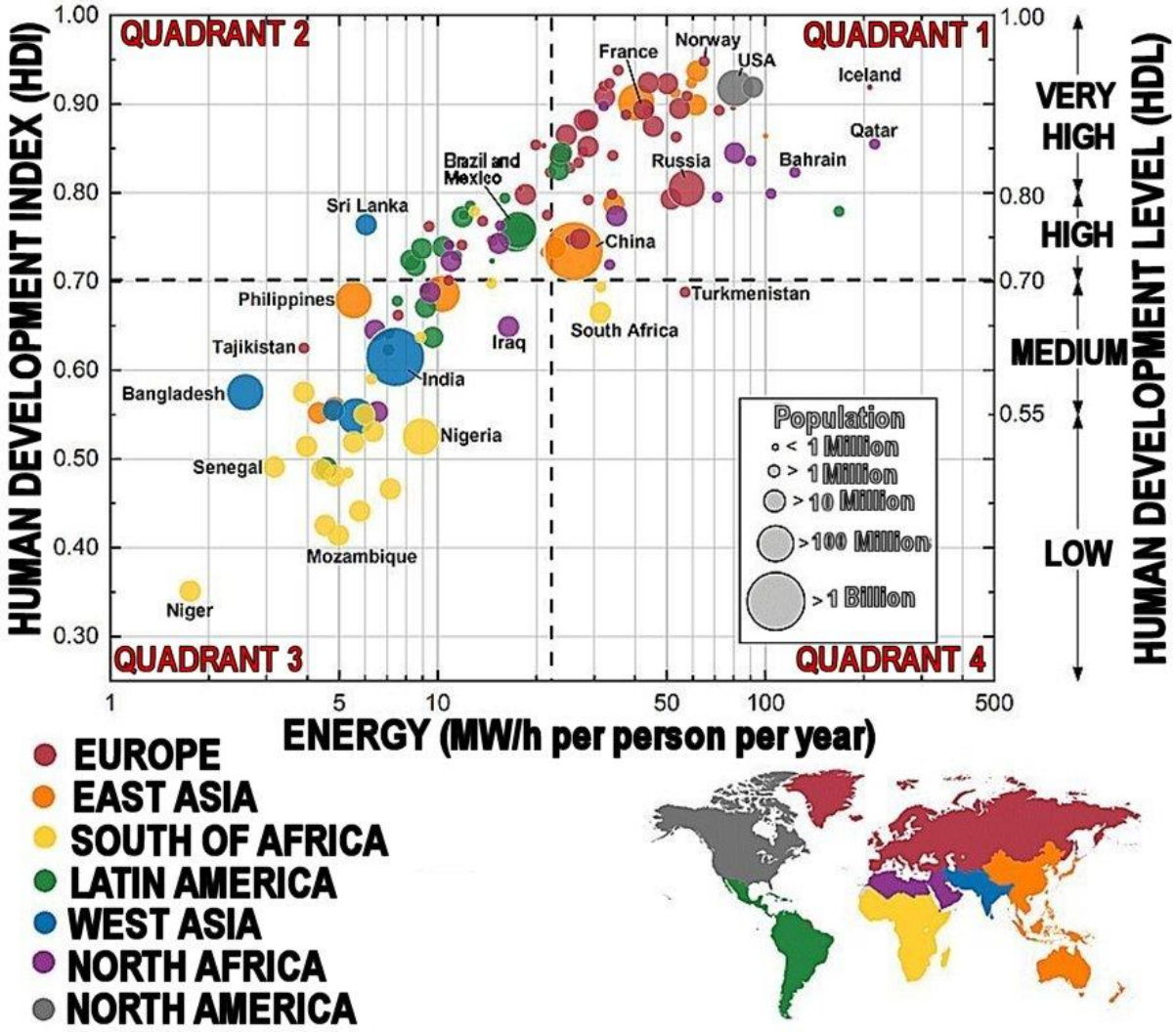
Figure 3, its possible to observe relationship between the Human Development Index (HDI) when compared to available amount of energy (MW/h year per person) in different countries around the world (PASTERNAK, 1998). Whose colors are again related to regions of the planet and sizes of points circumscribed in figure related to number of people in each nation. Note that Mexico and Brazil appear almost overlapping and have HDI between 0.7 and 0.8 with energy close to 20MW/h year per person, located in second quadrant that distinguishes it from nations that have high HDI's and relative amount of energy available. Brazil and Mexico are still classified as having a high level of development (region to right of figure).

In the first quadrant are nations that have highest HDI's and vast amount of energy available and high or very high Human Development Level (HDL), such as USA, China, Russia, France, among many others. The fourth quadrant is characterized as a region of passage between nations that have a large amount of energy, and medium HDL and HDI still below 0.7. In the third quadrant are all nations that have difficulties in providing significant amounts of energy and with HDI below 0.7, also characterizing low and medium HDL. Note by the colors and sizes of dots, that vast

majority are countries located in southern region of Africa, a few in northern region of Africa and western Asia, with very few countries in eastern region of Asia, and finally some countries from South America. Note that among the population sizes of these nations, only India stands out with a large population, HDI close to 0.6, low energy availability and medium HDL.

The vast majority of nations in the third quadrant are small in population size, with a low HDL and HDI of less than 0.6 (TRYGGESTAD, 2019, FISCHER, 2018, HAY *et al*., 2019; SHOBANDE, 2020; MOHAMMED and AKUOKO, 2022).

Figure 3 - List of the Human Development Index (HDI), Human Development Level (HDL), number of nation's population, and availability of electricity (MW/h year per person) in the world.



Source: Adapted from Fischer (2018).

The huge discrepancies observed in Figure 3 demonstrate need to find medium and long-term energy solutions that can be distributed more equitably across nations.

THE QUANTITY OF ENERGY PRODUCED AND CONSUMED IN THE WORLD

Despite the large amount of energy produced by the world (electricity alone is more than 25,000TW/h year), it is only a fraction of energy demanded. The greater energy supply, greater its use and human development. This has an impact on people's health, both in form of crops for food and in form of production of medicines, it impacts on quality of medical and hospital care, impacting on reduction of infant mortality, on access to education, on costs of families and especially on significant increase in people's quality of life (HAY *et al*., 2019; SHOBANDE, 2020; MOHAMMED and AKUOKO, 2022).

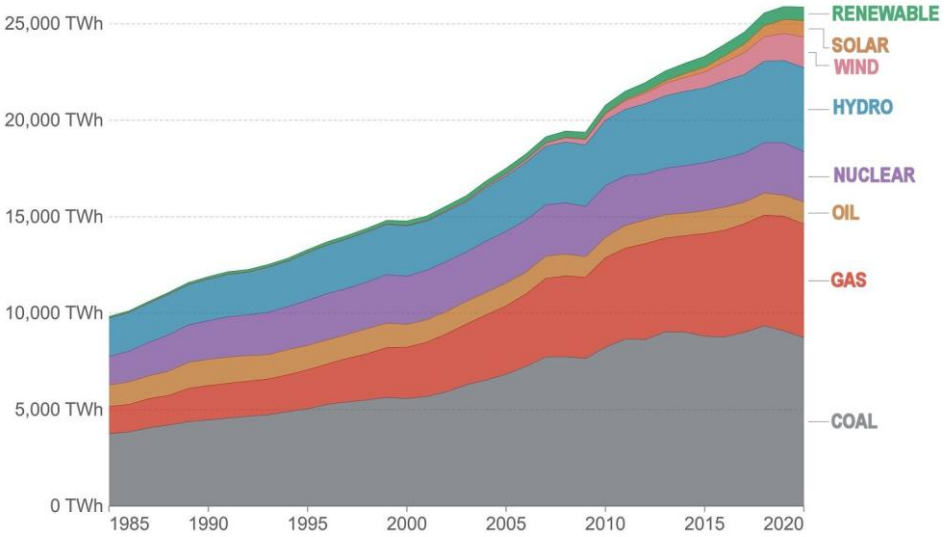
Access to energy is one of key factors for quality of life, not only in terms of health and social well-being, but also with guarantee of jobs and employability, whether as an employee or as the owner of a company. Abundance of energy allows reduction of fixed costs of manufacturing and services, which impacts on entire production chain of a nation.

Among these ways of producing energy, the world today classifies into eight different types and most significant forms of energy. Among these are: Renewable Energy (broad aspect), Solar Energy (photovoltaic), Wind Energy (all types of generators), Hydroelectric Energy (all sizes), Nuclear Energy (nuclear fission) and Fossil Energy (Oil (fuel), Gas Natural (fuel) and Coal (fuel)).

Figure 4 shows transformation of different energy sources into electricity with contribution of each source to total electricity produced in the world in 2020. It is surprising to know that ~1/3 of the world's electricity production still depends on coal burning. And that ~1/4 of electricity production depends on other two fossil fuels (Natural Gas and Oil), with oil being about six times smaller than Natural Gas. In this way, more than 50% (fifty percent) of electric energy produced in 2020 is of fossil origin. If the reserves of this fuel for some reason suffer economic sanctions, or wars, or economic crises, or even shortages, the world would lose more than half of its annual electricity production, which would lead to a socio-economic disaster of unthinkable magnitude and with dire consequences for humanity (KIES *et al*., 2021).

The decision to reduce nuclear power plants around the world may have been too hasty, given current insignificance of promises of renewable sources (all types including solar and wind energy) which, despite being potentially interesting, fail to achieve efficiency and availability necessary for meet current world energy demand, let alone future demand.

Figure 4 - Relation of total production of electric energy by type of source in the world in year 2020.



Source: Adapted from *World Data* (2021).

In previous figure, it is important to realize that source of electricity from hydroelectric plants is still almost one and a half times amount of energy from all renewables, and this is due to potential of wind energy installed today, and its growth in recent years. The production of wind energy has grown even with incredible difficulties of installation (especially of off-shore type (at sea)), maintenance and interruptions in production. The cost and time of large hydroelectric plants make it impossible to quickly build large units. In addition, like wind power, hydropower also suffers from constant climate change, impacting the rainfall regime at headwaters of rivers, bringing inconsistencies in volumes of reservoirs and directly impacting the production of hydroelectric plants.

Of all forms of energy available for production of electricity shown Figure 4, nuclear based on nuclear fission is one that is most independent from climate and political will of nations. But his past brings sad memories of accidents in nuclear power plants and military artifacts used at end of Second World War of mass destruction. This coupled with constant production of radioactive waste used as fuel for reaction, with very slow decay (forcing very long storage), makes up all problems that seem to dismantle all its intrinsic advantages.

In item of renewable energy (Figure 4), there are sources of energy from biomass, tidal energy and geothermal energy sources, which can help certain nations. In first case, those of biomass, countries with a large volume of animals raised for food can be successful in their use, especially in large animals (swine and cattle), their use as fuel without transformation into electricity can be a way of gradually replace use of natural gas. Tidal energy is also promising, however there are numerous technical solutions to obtain electricity via tides and almost all of them are still in prototype

stage, but there is a great chance that they will be part of worldwide effort to obtain a diversity of energy sources. This also includes research into submerged turbines to generate electricity via flow in rivers.

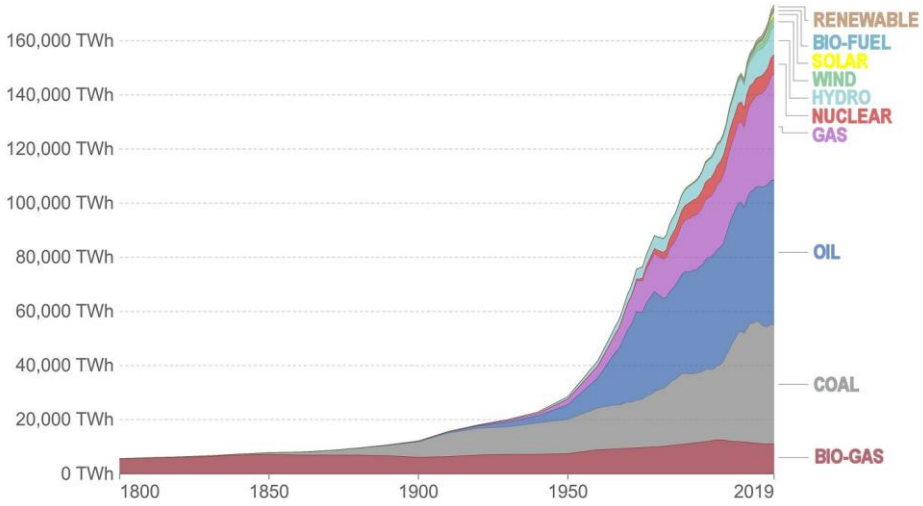
The form of energy which must be considered as an absolutely natural source without questioning is geothermal, whose use is based on the heat of planet Earth itself. This energy is used in heat exchanger circuits that are used to produce steam for conventional turbines, and thus generate electricity via conventional electricity generators, as a nuclear fission plant does. However, nations that can benefit from these resources need to have volcanic activity in their territory, as cost of very deep drilling makes their use unfeasible.

All that remains is to hope for a turnaround in energy research in such a way as to make it possible to find viable solutions for electric production with reduced values and a large independent abundance of natural resources specific to each region.

Figure 5, the primary energy consumption in the world from 1800 to 2019 is presented. Note that until ~1850 energy source that was available was only natural biogas. From the 1850s onwards use of coal burning became prominent until in mid-1920s use of oil as a fuel began, followed by natural gas in ~1940s. After 1945, with end of Second World War, several energy sources became accessible, the first being use of kinetic energy from waterfalls in large hydroelectric plants, and then other energy devices, nuclear, wind farms, first photovoltaic panels and everything else.

See Figure 5 that amount of primary energy consumption in year 2019 was around ~165,000TWh year. This is about ~150,000TW/h year greater than all energy consumption in year 1900 (119 years earlier). This study makes clear dependence and exponential growth of energy use and consumption by humanity. It is possible to extrapolate these values following this exponential growth and imagining that there is energy production to meet this future demand for year 2035. In 2035 consumption should be ~245,000TW/h year, about ~1/3 of total energy produced in 2019.

Figure 5 - Primary energy consumption in the world in year 2019.

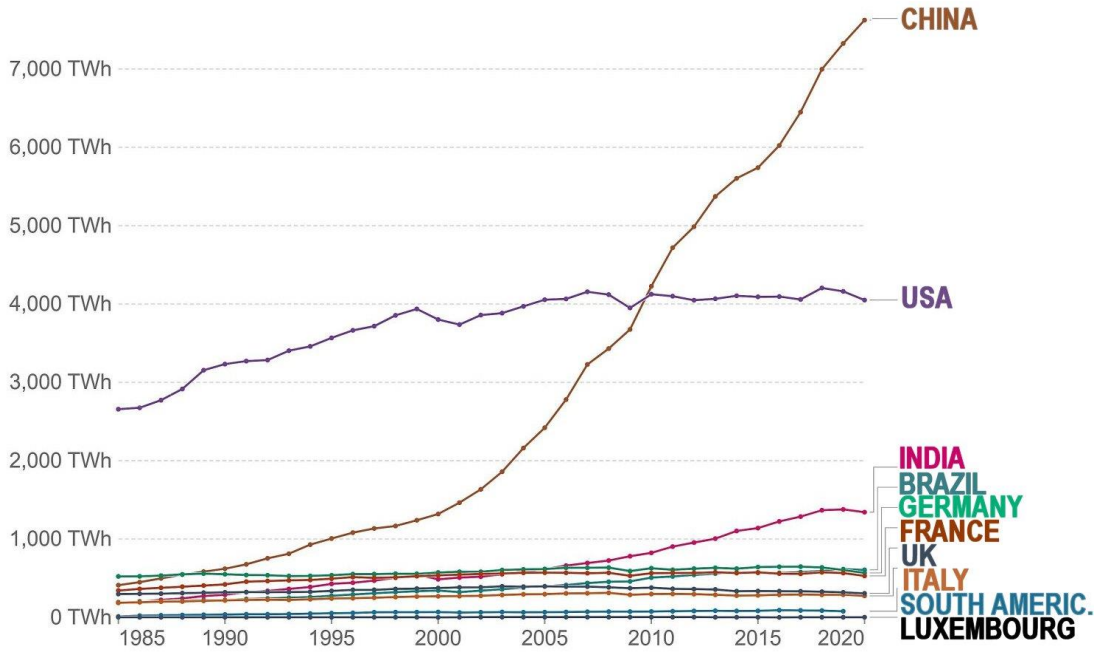


Source: Adapted from World Data (2021).

Figure 6 its possible to analyze the history of electricity generation by country from 1985 to 2020. Note that in this figure, the largest electricity generating nation is China with ~7,800TW/h year. These values for China are about ~50% higher than those for US (~4,000TW/h year). Then there is India (~1,400TW/h year) and Brazil tied with Germany and France (~700TW/h year).

In this figure, it is possible to see that China became the largest country in electricity generation between 2009 and 2010, noting that in 1985 (~35 years) China was third country in electricity generation and producing about ~400TW/h year (~20 times lower than today).

Figure 6 - Electricity generation by countries in year 2020.



Source: Adapted from *World Data* (2021).

ENERGY OPTIONS AND NUCLEAR FUSION ENERGY

There are several options of energy generation sources available in the world, many are capable of generating significant amounts of energy over time, each with different characteristics of efficiency and lifetime. The energy options that can be important sources of energy, mainly to generate electricity through physical transformation, are: wind (wind), waterfalls in rivers (hydroelectric), sunlight (photovoltaic), tidal force (tidal force), wave force (tidal force), ocean force (oceanmotive), decomposition of matter (organic or plant - biomass), heat of the planet Earth (geothermal), breaking of atoms (fission nuclear) and union of atoms (nuclear fusion). Of these transforming energy sources, only biomass and nuclear (fission and fusion) are independent of climate and geographic location, but nuclear fission is

dependent on radioactive material reserves and their enrichment, and biomass energy depends on quantities significant amounts of organic and/or plant material.

Photovoltaic energy, despite suffering interference with shadows (clouds, buildings and geographic location) and requiring light incidence (generating energy during some hours of day) is an option that can also be used anywhere in the world, with different electrical generation efficiencies due to latitude and longitude. Sea related energy sources (ocean motive, wave motive and tidal power) depend on nation's access to the sea, and not all nations of the world have easy access to the sea. In a way, access to the sea also allows use of wind energy, which due to coastal (on-shore – on land) and even ocean (off-shore – at sea) winds to generate electricity. Geographical features are essential for energy of hydroelectric plants that use height difference of geography of place to take advantage potential energy water of rivers (reservoirs) in kinetic energy by waterfall to drive turbines and generate electricity. As well as for geothermal energy that depends on proximity of magma to surface (volcanic regions) to be able to harness heat and generate electricity.

There is also energy obtained from fossil fuels, which can be exploited if a nation has these natural resources available in its territories (oil, natural gas and coal). These fuels can be used in vehicles, for residential and industrial heating and even for generation of electricity. Of all these energy sources, only one capable of generating a sufficiently large amount of energy, with sustainable fuel for transformation, regardless of climate and location on planet Earth and without prejudice to its efficiency is nuclear fusion (FELTRIN, 2018; CHEN, 2011; McCRACKEN and STOTT, 2012).

Nuclear fusion as a source of electrical energy has been extensively researched since the 1950s. The machine most studied in nuclear fusion research by magnetic confinement of plasma is known as the Tokamak (CONN, 1983). The Tokamak is a complex machine, but it is device that today is closest to becoming a nuclear fusion reactor (WILTGEN, 2021; WILTGEN, 2022D; WILTGEN, 2022E).

Nuclear reactions release enormous amounts of energy when they break down or when they melt. The process of fusing atoms together (fusion) produces a much greater amount of energy than breaking an atom (fission). Furthermore, the energy needed to break an atom is significantly less and much easier to obtain than energy needed to fuse atoms together. On Earth, the physical state of matter conducive to fusing atoms through nuclear fusion is plasma (WILTGEN, 2022A; WILTGEN, 2022B; BOYLE, 1968; CHEN, 1974; ELIEZER and ELIEZER, 1989; BOYD, 2003; BELLAN, 2008; BIEL, 2017). Plasma, although common in the Cosmos, is rare on Earth. To achieve the physical state of plasma, it is necessary to raise temperature a lot, and thus, degree of thermal agitation particles until they can dissociate into ions and electrons. When this occurs, the environment for achieving nuclear fusion is formed. However, there are some limitations of temperature, confinement time, and density that need to be

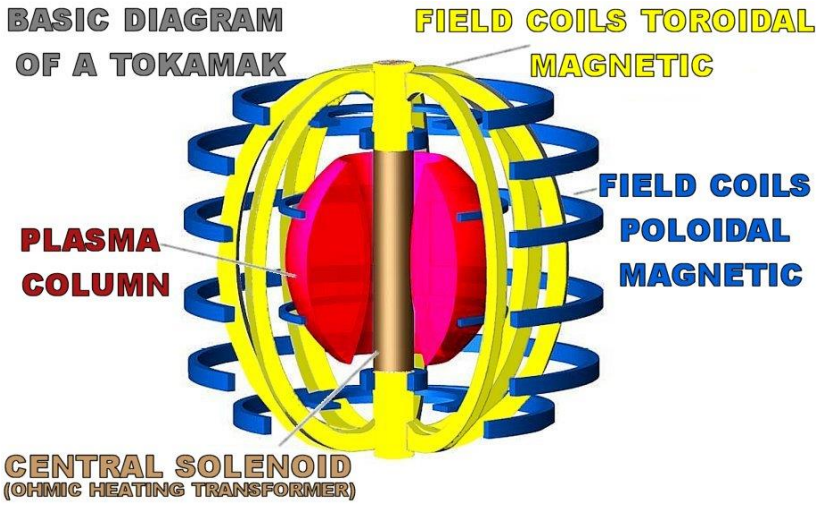
achieved in plasma in order for conditions conducive to nuclear fusion to occur (HAMACHER and BRADSHAW, 2001; CHEN, 2011; WILTGEN, 2021, PESTANA, 2015; McCRACKEN and STOTT, 2012). The plasma temperature required for nuclear fusion is on order of millions of degrees Celsius, much higher than surface temperature of the Sun (BOYLE, 1968).

This directly implies the engineering needed to keep this plasma away from any material existing on Earth. That's why they use a vacuum chamber and magnetic coils capable of keeping plasma at this enormous temperature away from walls of the vacuum chamber, confining it to a central region of Tokamak machine in shape of a ring, which is called a plasma column, as can be seen Figure 7 (WILTGEN, 2018, SAXENA, 2016). The easiest nuclear fusion reaction to obtain on Earth occurs with use of two isotopes of hydrogen (Deuterium and Tritium), these two elements are used in research on controlled thermonuclear fusion in Tokamak machines. When breaking electrostatic Coulomb barrier, a huge amount of energy is released in form of heat, in addition to high kinetic energy neutrons and composition nuclear fusion product of Deuterium (*D*) with Tritium (*T*), which is Helium (*He*) (ARTISIMOVICH, 1972; CLARKE and CAI, 2012; CHEN, 1974; WILTGEN, 1998; MISHRA, 2020).

Due to shape of this nuclear process, amount of fuel needed for nuclear fusion is very small and it is capable of generating an enormous amount of energy, and so it is extremely efficient, more than any other process used to produce electrical energy. The proportion of nuclear fusion fuel (Deuterium and Tritium) is much smaller than proportion of nuclear fission fuel (Uranium or Plutonium) needed to produce same amount of electrical energy. If comparing nuclear reactions (fission and fusion) with other conventional ways of producing electricity, it is possible to see that proportions are significantly smaller due to high efficiency of nuclear reactions (WILTGEN, 2022C; YICAN and SUMER, 2018).

To obtain a nuclear fusion reactor it is necessary that machine can produce an amount of energy greater than amount of energy used in process. On a Tokamak this is called "*critical ignition point*", i.e. threshold that turns a nuclear fusion experiment into a nuclear fusion reactor. As energy required in process of operating a Tokamak is very large, due to need to produce high confining magnetic fields (WILTGEN *et al*., 2001), at very high plasma temperatures to obtain nuclear fusion, it is possible to perceive that a Tokamak to function as a nuclear reactor will need an enormous amount of energy produced by nuclear fusion just to reach ignition point, and even more so to surpass limit of Lawson's criterion and function as a reactor (LAWSON, 1957; COSTLEY, 2016; COSTLEY *et al.*, 2019). The ignition barrier that relates the triple condition (Temperature, Density and Confinement Time) and temperature reached in whole process (WILTGEN, 2022D; HORVATH and RACHLEW, 2016; YUSHMANOV *et al*., 1990).

Figure 7 - Basic diagram of a Tokamak machine with its main components.

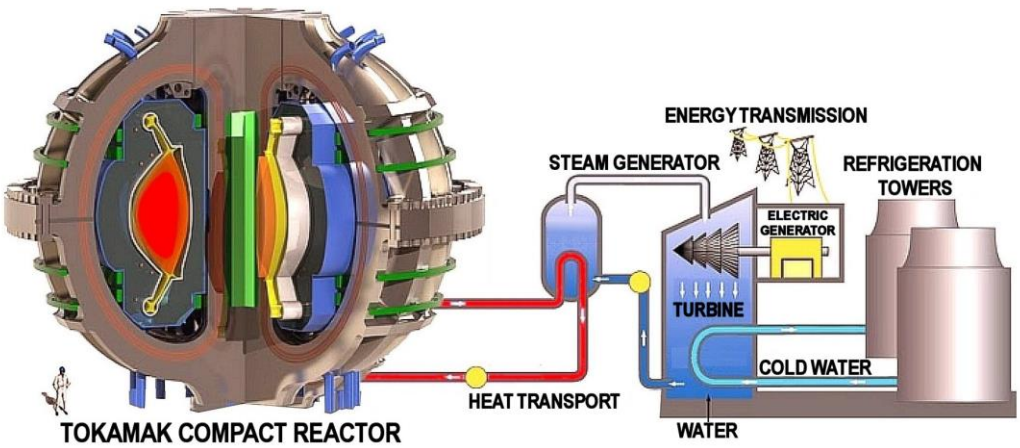


Source: Wiltgen (2021).

The Tokamak machine needs very efficient heat exchange systems to remove excess heat generated by nuclear fusion process, which in addition to thermally heating Lithium (*Li*) coating, which is used for production of Tritium (*T*), it must transfer energy to other heat exchange circuits until it reaches turbines that drive generators for production of electricity (ZOHM, 2019).

The expected result of a nuclear fusion reactor is to produce a lot of electricity with little nuclear fuel and with efficiency superior to any other existing energy source. Figure 8, it can be seen this process that takes a Tokamak to stage of a controlled thermonuclear fusion reactor. For this, the spherical (compact) Tokamak reactor must (SCHOOFS and TODD, 2022; MENARD *et al*., 2016), through nuclear fusion reactions, heat a refrigerant liquid so that heat can be conducted through several stages of heat exchangers until it can generate water vapor for activation of conventional turbines coupled to electric generators (WILTGEN, 2021; El-GUEBALY, 2009; DEAN *et al*., 1998).

Figure 8 - **Compact Spherical Tokamak machine like a nuclear fusion reactor.**



Source: Adapted from *MIT NEWS* (2021).

DISCUSSION AND FUTURE PERSPECTIVES

Given constructive and operational form of a Tokamak machine, and its evolution to a nuclear fusion reactor, it will very soon allow us to imagine in the future that several machines similar to this will be able to compose a strong source of electrical energy for nations of the world.

This action can provide a solid and important condition for there to be a better division of electric energy sources around the world, and thus, significantly and definitively modify distribution of large amounts of energy to several nations without natural reserves available for energy generation.

A Tokamak machine such as a nuclear fusion reactor can be built anywhere in the world. Allowing to reach regions previously inaccessible for installation of a source of electrical energy on a large scale. The first reactors will not be able to be installed in many places due to need for engineering and development for more diversified solutions to be assumed by companies that will manufacture this type of nuclear reactor.

The ease of use of fuels in a Tokamak type fusion reactor, combined with non-existence of accumulation of radioactive material to be stored and/or confined for many years. Although in a speculative way, it allows us to perceive enormous opportunity provided by nuclear fusion insedimentation of sustainable development of the human species on Earth regarding constant and growing need for electrical energy.

The opportunity to be able to provide electricity in such a widespread way will, in more distant future, allow a large electricity grid between nations in a similar way to what happens with digital communication. In a world ruled by constructivist ideals and peaceful harmony, it will not be surprising that breadth of electric power source based on nuclear fusion is not main source of energy on planet Earth.

Allowing remote locations with precarious financial conditions to enjoy a favorable condition for their development, raising their natural and cultural gifts as goods and services offered to the world, in order to fortify their population and solidify their economies, health, safety and comfort.

The very natural pragmatic dichotomy in energy exploration and generation will go through a new phase, in which dichotomy will be less emblematic and pragmatism firmly accepted, in sense of guaranteeing and following right path traced by science for many decades.

The persistence of nuclear fusion researchers will finally be recognized and will allow a new world order, in which energy will be a good of humanity and not something to be coveted. Despite human vanities, it is possible that this opportunity to supply large amounts of electricity to the population can reduce lack of food, health and safety worldwide.

It remains to remember that the impetus and inventiveness of future engineering will undoubtedly allow reduction in scale of fusion reactors, making them more compact, with lower cost, with greater construction options and facilitating their installations and operations. This is all moving towards reducing values of modern reactors intended for nuclear fusion and costs of generating electricity via nuclear fusion.

It is a fact that electric energy is one of preponderant factors for development of a nation, allowing to extract the best of it cultural and socioeconomic characteristics, valuing and encouraging it professional aspirations and it financial resources of interest to other nations and peoples. The ease in use of electric energy, it diffusion, it availability, it reduced cost, allow a country to use different types of machines to constitute a strong and stable industrialization, improvement of medical and hospital equipment and thus, meet needs of treatments of health, food production and storage, education, research and development, which can lead to a better HDI (Human Development Index) condition, which also improves the minimum conditions for survival and progress of the nation.

Science will not stop at nuclear fusion reactors, but without a doubt achieving this feat is one of conditions for science and technology to be able to go beyond what science fiction writers imagined. Having unimagined amounts of electrical energy available will make previously inaccessible ideas become reality in near future, new forms of energy storage, as well as locomotion, special travel, artificial life and tactile holographic remote communication will be the first breaks from paradigms arising from energy availability achieved with nuclear fusion.

However, engineering cannot wait for good results of research in nuclear fusion, it is imperative that all technological efforts are committed to developing new forms of energy transformation that can help development of humanity, any and all sources of energy until today employed, will have their share of importance in constitution of an energy matrix. This makes it essential to continue technological innovations and constant improvements in efficiencies and in way of employing engineering in solving captive and common problems of various forms of energy that are used today.

Ensuring that energy is a factor of development and not of dispute between nations can lead the world to a never-before-seen reality in which balance is most important of lessons to be learned and applied by the human species.

All these paths meet need to guarantee the human species a favorable condition for its evolution and intellectual, cultural development and in harmonious balance for union between nations. The peaceful coexistence of the human species on the planet will be able to put an end to divisions and current dichotomies that distance one nation from another so much, and thus, allow world development in a state of lasting peace.

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