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Regional Cooperation for the Energy Transition: The Role of Nuclear Power under Environmental and Technological Constraints

Engineering Limitations for Implementing the Energy Transition

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1. Introduction. Due to the increase in the concentration of greenhouse gases in the atmosphere, increasingly electricity will be used and this will drastically reduce combustion as the most utilized process to generate energy. A significant reduction in combustion processes from fossil sources will be necessary and this will lead to the replacement of fossil fuels by sources that do not emit greenhouse gases, such as renewable sources (like hydro, wind, solar, and biofuels), as well as nuclear and fossil fuels with carbon capture [1].

2. Renewables and Sustainability. Current technologies for solar photovoltaic and wind energy require a large number of units per installed kW. This implies an extremely large amount of materials per kWh produced. How this will affect sustainability? There is great concern about the possibility of early depletion of minerals such as:

- copper, lithium, nickel, cobalt and rare-earth elements when installing energy parks using such renewable energy technologies, and depletion of
- nickel and zirconium, for electrolysis in the production of hydrogen, and of
- platinum-group metals for fuel cells [2].

Minerals employed for offshore wind energy, use around 15 thousand 5 hundred kg/MW and for onshore plants around 10 thousand kg/MW. For solar energy, the value is around 7 thousand kg/MW. In comparison, nuclear power uses approximately 5 thousand kg/MW.

Among the sustainable development goals, the following have been defined: manage forests sustainably, fight desertification, halt and reverse land degradation, halt the loss of biodiversity, protect biodiversity and preserve indigenous populations' dwelling places [3].

Regarding Hydroelectric Power Reservoirs, these objectives impose new conditions for the installation of hydropower units. For example, the construction of hydroelectric dams with reservoirs that affect either biodiversity stocks, or the sustainable supply of river water, or indigenous peoples' rights, may be incompatible with these goals, requiring "run-of-river" type solutions. Under these conditions, hydroelectric power will be subject to climatic intermittence due to the lack of a regular supply of water to move the turbines.

3. Base Load. With respect to base-load power, the stability of the transmission lines by keeping the electric frequency constant is a necessary condition for their operation. Frequency variations, deriving from the inability to meet demand at a given time, may create blackouts. This problem could come up due to the intermittency of renewable sources. The existence of firm baseload energy guarantees a constant electrical frequency [3].

Currently, fossil fuel thermal plants, hydropower plants with important reservoirs and nuclear plants are used to generate baseload energy.

Consequently, for reasons of baseload energy demand to accompany intermittent generation, such as wind, solar and “run-of-river” hydraulic sources, the future trend will lead to the use of hydropower with reservoirs, biofuels and nuclear energy, as well as to the increase of interconnection of electrical transmission systems across countries’ borders [4].

Evidently, where adequate transmission networks do not exist, there will be no other alternative than to generate electricity by means of intermittent renewables and assume the risk of eventual blackouts in these regions.

4. Systems efficiency and transmission losses. Going to maximum electricity usage will diminish the efficiency of thermal energy consumption in terms of home heating and cooking processes, as well as electric cars usage. Entropy will be higher in the future human-life systems of the Earth planet. Efficiency of steam powered systems will also decrease due to higher condensing temperatures as a result of the increase of ocean, river and air temperatures produced by climate change phenomena. Power transmission from distant sites of solar and wind power sources will also generate energy important efficiency losses. Such effects will increase the amount of power to be supplied and will concentrate the production of electrical power near main consumption areas.

5. Nuclear as a clean energy. Actions for drastic reduction of carbon emissions lead to the use of technologies that limit the combustion of fossil fuels. This trend will lead to a more pronounced use of so-called clean energies - those without the release or with the retrieval of greenhouse gases - such as renewables, nuclear and biofuel combustion. For industrial, domestic and land transport uses, clean supply of power will be adopted. Utilization of fossil fuels will continue for some time for air, space and maritime transport.

Since power generation with fossil fuels will be gradually abandoned, baseload will be supplied by hydropower plants with reservoirs and by nuclear power plants. If the tendency is to build hydropower plants without reservoirs, there is no other alternative than nuclear power. Obviously, such a comment would be invalid if there were technologies that would allow to store adequate amounts of energy for baseload use when intermittent sources of energy could not satisfy the demand of power (low flow in rivers in the case of “run-of-river” hydro plants, or lack of sunlight for photovoltaic installations, or periods without wind for wind power plants).

The nuclear industry developed technologies to contain, process and control its solid, liquid and gaseous wastes before releasing them safely to the environment. In countries with intense use of nuclear energy, the annual amount of fission products - stored in controlled premises - is less than 0.004% of all wastes produced by its inhabitants in a year. For this reason, nuclear energy is considered a "clean energy".

Built near consumption centers, without long transmission lines, nuclear units require little space for installation. It is a technology that has the highest energy density per unit volume - between 45 million to 70 million times greater than that produced by fossil fuels, such as oil, coal or natural gas. This makes nuclear technology a highly suitable solution for installing baseload power plants close to consumption centers, occupying relatively smaller spaces [1].

6. Brazilian nuclear commercial advantages. Brazil has been internationally recognized as an exporter of enriched uranium for nuclear power plants, based on its process of centrifuge enrichment. Additionally, Brazil has large amounts of natural uranium mineral resources and the expertise of fuel element manufacture, as well as the knowhow for PWR nuclear power engineering, based on its continuous manpower development programs. This makes Brazil as one of the few countries in the world to be able to manufacture and furnish enriched fuel elements under regional and international safeguards treaties for the peaceful use of nuclear energy. Brazil is now the only Latin American country with such right.

7. Conclusions. Due to global warming, as electrical energy will be used more intensively, the supply of primary energy will be done by replacing fossil fuels with sources that do not emit or retrieve greenhouse gases, such as renewables (hydroelectric, wind, solar, biofuels), nuclear and, if economically feasible, fossil with carbon capture. In the short run, oil, coal and natural gas will continue to be used to supply energy by combustion in space applications and maritime and air transport. But the expansion of their use for construction materials, pharmaceuticals and other applications with organic compounds will substantially expand by means of advances in petro chemistry and coal-chemistry.

Pursuant to policies based on implementing the United Nations sustainable development goals, the installation of fossil fuel plants, as well as of hydropower plants with large reservoirs, will be discontinued or largely reduced.

Primary energy supply will drastically diminish combustion as the most used process to generate energy. Fossil fuels will be replaced by clean energy sources, such as renewables and nuclear. Due to the growth of greenhouse gases in the atmosphere, electric power will be used in large scale.

The stability of the transmission lines to keep the electric frequency constant is a necessary condition for their operation. The existence of baseload power guarantees a constant electric frequency. It will be necessary to ensure a generation of baseload power that accompanies generation by intermittent energy sources such as renewables. To provide clean baseload power in sufficient scale, near the consumption centers, the proven and available technology that exists is nuclear power.

Brazil is one of the few countries in the world to be able to manufacture and furnish enriched fuel elements under regional and international safeguards treaties for the peaceful use of nuclear energy. The expansion of the nuclear power industry in the country will generate new markets for exporting enriched uranium fuel elements which will appear following worldwide energy transitions.

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BASIC ELEMENTS FOR THE ENERGY TRANSITION ENGINEERING

- **Coping with greenhouse gases concentration increase in the atmosphere;**
- **Drastically reducing fossil fuels combustion as the most utilized process to generate energy;**
- **Replacing combustion processes by electrical power;**
- **Following up the UN sustainable development goals;**
- **Assuring the existence of firm baseload energy;**
- **Considering additional losses of efficiency and transmission.**

RENEWABLES AND SUSTAINABILITY

- Solar photovoltaic and wind energy require a large number of units per installed kW, leading to an early depletion of minerals like copper, lithium, nickel, cobalt and rare-earth elements, nickel and zirconium and platinum-group metals;
- Off-shore wind energy plants use ~15,500 kg/MW, on-shore plants ~10,000, solar energy ~7,000, nuclear ~5,000;
- UN sustainable development goals require among others the protection of biodiversity and the preservation of indigenous populations’ dwelling places;
- Hydroelectric dams with reservoirs may be incompatible with these goals, requiring "run-of-river” type solutions subject to climatic intermittence.

BASE LOAD

- **Assure the stability of the transmission lines by keeping the electric frequency constant;**
- **The existence of firm baseload energy guarantees a constant electrical frequency;**
- **Fossil fuel thermal plants, hydropower plants with important reservoirs and nuclear plants are used to generate baseload energy;**
- **The future trend will lead to the use of hydropower with reservoirs, biofuels and nuclear energy and to the increase of interconnection of electrical transmission systems across countries' borders.**

SYSTEMS EFFICIENCY AND TRANSMISSION LOSSES

- Maximum electricity usage will diminish the efficiency of thermal energy consumption (home heating, cooking processes, electric cars usage);
- Entropy will be higher in future human-life systems;
- Efficiency of steam powered systems will also decrease due to higher condensing temperatures as a result of climate change phenomena;
- Power transmission from distant sites of solar and wind power sources will also generate important efficiency losses;
- The amount of power to be supplied will be much higher.

NUCLEAR AS ONE OF THE CLEAN ENERGIES

- **The drastic reduction of carbon emissions will lead to the use of technologies that limit the combustion of fossil fuels;**
- **A more pronounced use of so-called clean energies (renewables, run-of-river hydro, biofuels and nuclear);**
- **Baseload will be supplied by hydropower plants with reservoirs and by nuclear power plants;**
- **The nuclear industry is the only one that contains, processes and controls its solid, liquid and gaseous wastes;**
- **Built near consumption centers, without long transmission lines, nuclear units require little space for installation.**

BRAZILIAN NUCLEAR COMMERCIAL ADVANTAGES

- Brazil has been internationally recognized as an exporter of enriched uranium for nuclear power plants based on its process of centrifuge enrichment;
- Brazil has large amounts of natural uranium mineral resources and the expertise of fuel element manufacture, as well as the knowhow for LWR nuclear power engineering;
- Brazil is one of the few countries in the world to be able to provide enriched fuel elements under regional and international safeguards treaties;
- Brazil is now the only Latin American country with such rights.

CONCLUSIONS

- **Due to global warming electrical energy will be used more intensively, replacing fossil fuels with sources that do not emit greenhouse gases;**
- **Electric power will be used in large scale;**
- **Pursuant to policies based on the UNSDGs the installation of fossil fueled plants, as well as of hydropower plants with large reservoirs, will be largely reduced;**
- **Combustion of fossil fuels will be replaced by clean energy sources, like renewables and nuclear;**
- **It will be necessary to ensure a generation of baseload power that accompanies generation by intermittent energy sources;**
- **Brazil is one of the few countries in the world to be able to manufacture and furnish enriched fuel elements under regional and international safeguards treaties;**
- **To provide clean baseload power in sufficient scale, near the consumption centers, the proven and available technology that exists is nuclear power.**