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ENERGY AND SUSTAINABILITY

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ABSTRACT

The energy flux toward the Earth is presented, showing the primary energy sources and their annual flux. These primary sources provided the energy stock that our society regards as "sources" of energy. Energy from this stock is converted into energy usable by our society through a chain of converters constituting an energetic system. The converter chain must fulfill simultaneous requirements of quality, location, and time, and is interrelated with the ecological, social and economic systems. The course of the human species from its cradle to the occupation of the whole planet is sketched. Along this path, the importance of animal and plant domestication, and the concept of time, developed during the Neolithic revolution, becomes evident. Ironically, the question of time would haunt us: the problems we face today show our huge difficulty in thinking and acting in the long range. Thermal converters enabled human society to draw from a huge energy stock accumulated over millions of years. This massive use allowed all our development but also brought with it a plethora of problems. A study of supply alternatives seems to indicate that a substantial reduction in demand will be necessary in order to achieve sustainability in the future.

1. ENERGY SOURCES

For an understanding of the link between energy and sustainability it is necessary to observe the Planet as an object of study and carry out its energy balance. Thus it can be seen that the Earth continually receives energy in the form of radiation -- of all wavelengths -- and emits energy by long-wave radiation, as shown in Fig. 1. Jancovici [1].

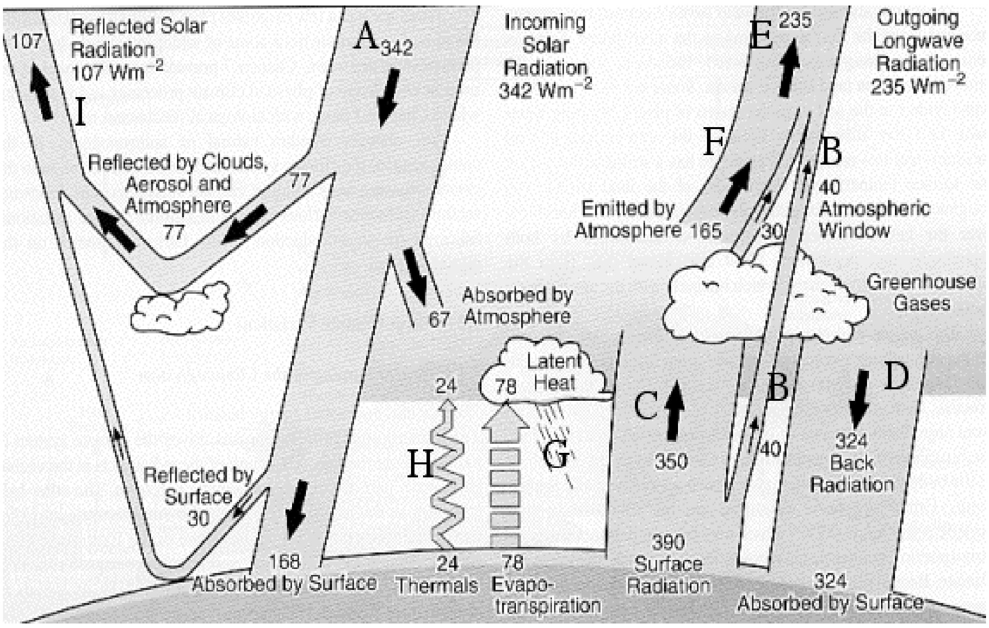

Figure 1. Earth energy balance

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It is also subjected to the gravitational force, essential for the atmospheric cycles. The energy of tides is supplied mainly by the gravitational attraction between Earth and Moon. The Earth also has a stock of nuclear energy resulting from its process of formation. Part of this stock of fissile elements is available and can be used to feed nuclear reactors for the production of energy. Another part is inside the Earth in a process of radioactive decay, and is responsible for part of the geothermal energy. Table 1, Annual flux of energy to the geo-biosphere, shows the magnitude of permanent energy fluxes on an annual basis. Odum[2] and PB Statistical Review[3].

Table 1. Annual flux of energy to the geo-biosphere

	kJ/yr	% by source	How much solar is bigger
Solar	$3.93\ 10^{21}$(a)	99.96	1
Geothermal	$6.72\ 10^{17}$(a)	0.017	5848
Tide	$5.20\ 10^{16}$(a)	0.001	75577
Geothermal + Tide	$7.24\ 10^{18}$	0.018	5428
Total	$3.93\ 10^{21}$	100.00	-
World consumption 2003	$4.21\ 10^{17}$(b)	-	9339

(a) Odum, H.T. – 1996 (b) BP Statistical Review of World Energy 2004

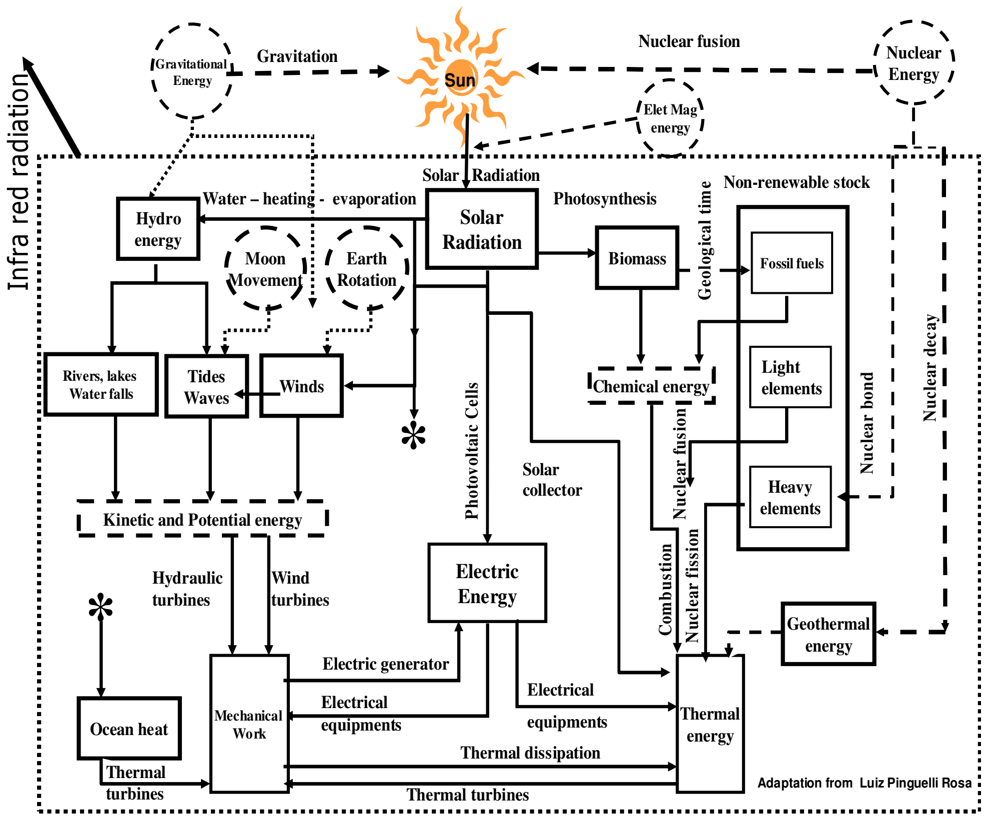

Figure 2. Energy transformations chain

Also available are light elements that could be used in fusion reactors -- not yet operational -- for the same purpose. According to Table 1, solar energy is by far the most abundant source, and from this perspective it is a sustainable source. However, solar energy reaches the Earth in a diluted form and is subject to atmospheric conditions.

Because it comes diluted and intermittently on a given point of the Earth, it does not fit the demand patterns of our society, requiring a concentrated supply of energy 24 hours a day. Fig. 2 shows several energy transformation chains for obtaining energy for final use. However, the most important energy stock in use is that of fossil fuels, that originated in living processes which, in turn, relied on solar, tidal and geothermal energy -- in addition to nutrients and suitable atmospheric conditions, of course.

2. ENERGETIC SYSTEM

An energetic system is necessarily composed of a chain of converters that must simultaneously fulfill three requirements in supplying energy: quality, location and time. Energy must be available in the required quantity and quality, and at the time and place where needed. The energetic system always interacts with three other systems: social, economic and ecological. Primitive man could only rely on the energy of his own body -- and of other humans used as slaves. After domestication of animals, he could also count on their energy. Table 2 shows the efficiency of the main biological converters and also of exosomatic sources. The superior efficiency of humans as converters, and their ease of communication, have certainly been a powerful incentive to slavery. Social incentive for the development of machines powered by forms of energy other than human was weak or non-existent in the Roman Empire.

Table 2. Efficiency of conversion of energy into work

Biological converters	**Exosomatic converters**
Human being ~ 20%.	
Horse ~ 10%.	Thermal < 40%
Ox < 10%.	Hydraulic/Wind < 100%

Any discussion of the role of human engines in Rome's energy system must start from the fact that a society with access to a source of energy whose costs of reproduction it need not assume, but attend only to its upkeep -- as the strict biological minimum -- will not feel compelled to produce more. The social incentive to develop machines powered by sources of energy other than humans was weak or non-existent. Debier[4]. In the early Christian era there were 3 million slaves and 4 million free men in the Roman Empire. In a simplistic way one could say that human society experienced two distinct energy models: the Chinese model and the Medieval European model. The Chinese model was characterized by the absence of slavery as a source of energy. Their option was to invest in endogenous reproduction. Technological advancement in China was surprising and in many cases predated their European equivalents by centuries. Another characteristic of the Chinese model was their stability and the long-range planning supported by a central power. In contrast, the European model massively used slavery as a source of energy, and never evolved a unified nation. The existence of many nations without a centralized control made possible the appearance of successful initiatives in many places and their dissemination.

3. A GLANCE AT THE HISTORY

The course of the human species from its cradle --Africa – to the occupation of the whole planet is closely related to the mastery of energies stronger than its own. Probably the first of these energies was the fire. The first signs of use of fire date back to more than 700,000 years, Brown[5]. Mastery over fire certainly had an important symbolic meaning and a deep influence on the socio-psychological level, and has been a factor of humanization and socialization. Plant and animal domestication has also been essential for the development of civilizations. Fig. 3, the spread of humans around the World, shows the slow evolution process and the difficulty of adapting to adverse conditions.

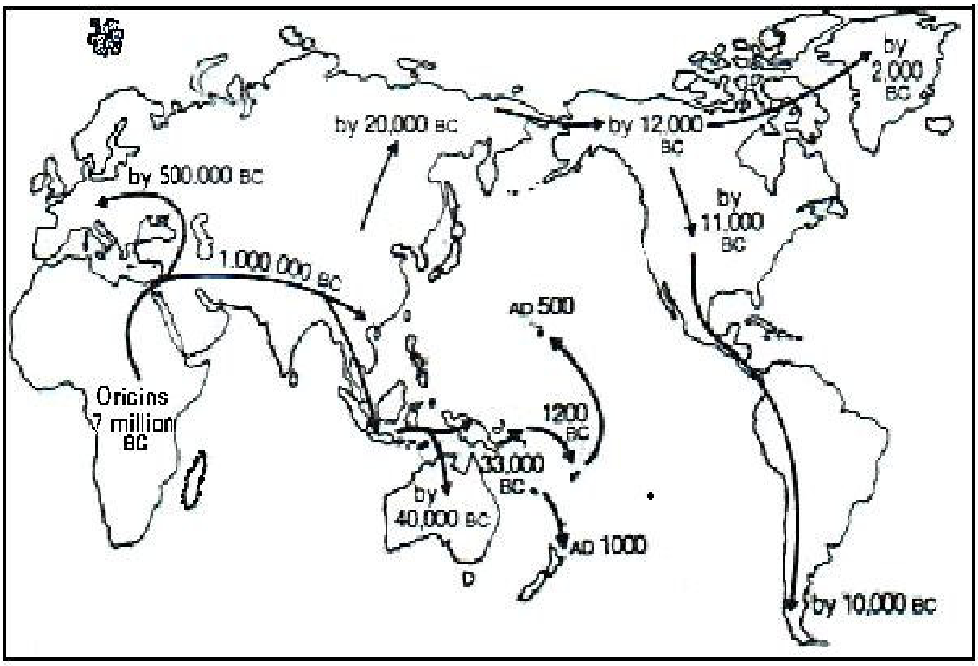

Figure 3. The spread of humans around the World

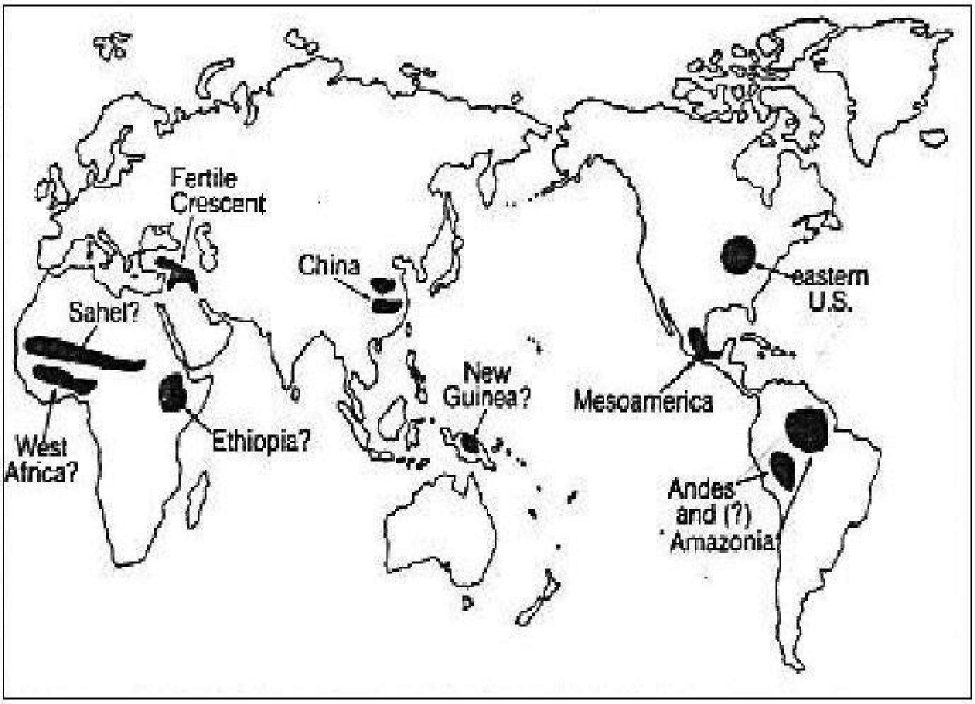

Figure 4. Centers of origin of food production

Fig. 4, Diamond[6], shows the centers of origin of food production. A question mark shows areas where there is uncertainty about the influence of neighboring areas. Human groupings that were unable to domesticate large mammals before causing their extinction either could not advance in the development process, or else became dependent on the development brought by invasions of other groupings.

The concept of Neolithic revolution does not refer exclusively to plant and animal domestication; it can be understood as the mastery over a whole food-energy chain by a human population as a result of a long process. Productive forces can be schematically characterized as follows:

- knowledge of cultivation and storage techniques; mastery of production and reproduction of plants, large-scale storage, and food preparation techniques;
- use of soil as a work medium where energy investment would result in much larger harvests than in the foraging system;
- human energy, the only source of mechanical energy, is an investment that will yield dividends only much later, at the end of the agricultural cycle.
- regarding animals, the Neolithic age knew the confinement for meat production; specialized animal breeding, which presupposes a complex economic system for the exploitation of all animal products and an active species selection, would only come much later.

Apparently, from among all these characteristics, the notion of time, represented by investments with a future perspective, is the one that least took root in the human species. We, as a species, have a huge difficulty in thinking, planning and acting in the long range. This probably led to the disregard of environmental questions along history and up to this day. The most glaring instance of this is the refusal of some nations to sign the Kyoto Protocol, despite all the evidence that CO2 emission will cause a temperature rise in the planet and all the attendant consequences.

In the Brazilian case, deforestation of the Amazon Region for the expansion of the agricultural frontier, mainly for bovine production, is another example of this difficulty. Philip Fearnside, in his presentation "Sustainable Use of Tropical Forests" in this workshop, showed that 3.4 trillion cubic meters of water are transported annually by wind currents from the Amazon Region to the South of the continent, according to Table 3.

Table 3. Water flux in the Amazon Region

	Water volume trillions of m^3/year(a)	**Comparison with of flow of Amazon river (%)(b)**
Transported from Atlantic Ocean into the region by “Aliseos” winds – (Trade winds)	10 ± 1	152%
Average flow of Amazon River at mouth	6,6	100%
Precipitation in the Amazon River basin	15,05	228%
Evapotranspiration	8,43	128%
Water vapor transported by wind to other regions	3,4 ± 1	52%

(a) Values of the Salati (2001) revision, except last item.
(b) Percentage of average flow at mouth.

Deforestation will influence this balance since in areas transformed into pastures water infiltrate into the soil 10 times less than in the forest area. Deforestation in the Amazon Region will certainly cause a drastic reduction in the amount of transported water, with disastrous consequences for the huge area marked in Fig. 5. Knowledge of this does not seem sufficient for decisions and plans to be made to preserve the forest. On the contrary, the Multi-Year Plan of the Brazilian Federal Government (2004-2007) is based on a series of infrastructures that will lead to significant losses to the forest, Fearnside[7].

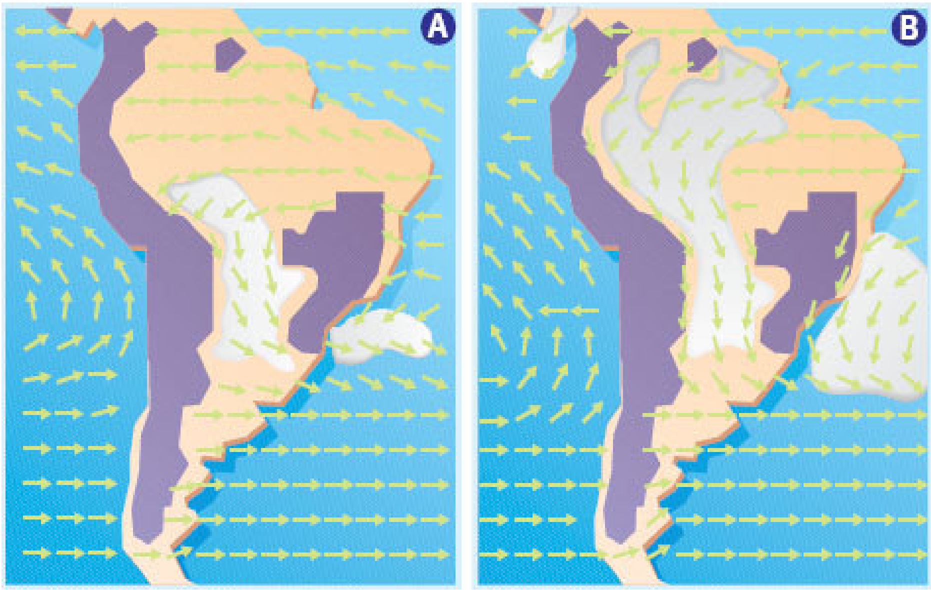

Figure 5. Water route from the Amazon Region to the South of the continent.
A) June-August and B) December-September

Another example. Egydio Schwade developed what he calls the Fruit Forest in his property near the city of Presidente Figueiredo, 140 km north of Manaus in the state of Amazonas. Instead of felling trees for conventional agriculture, he plants fruit trees alongside the forest trees, breeds fish and produces honey. Under a 50-year-old sucupira tree (Bowdickia nitida Spruce ex Benth) he keeps bee-hives of native bees and Apis mellifera. From each flower cycle of the sucupira tree he obtains about 10 kg of honey. This tree is coveted for the production of furniture because of the texture of its wood, and sells for R$ 10 in the forest. With honey production Egydio earns R$ 120 per year. By selling the tree he would receive R$ 10 and would then have to wait for another 50 years to get R$ 10 again.

4. TOWARD SUSTAINABILITY

After the Industrial Revolution the alliance between technology and science accelerated the progress of our society. The energetic support for this progress has been and still is provided by the fossil energy stock. Fig. 6, PB Statistical Review[3] shows that in 2003 dependence on fossil energy were 87.7%.

Much has been said about alternatives such as hydrogen, but it is worth remembering that hydrogen and electricity are energy vectors rather than sources. Both need energy sources in order to be produced. In this work, production of hydrogen will not be discussed, either from fossil fuels, or biomass or water electrolysis.

The projected consumption for 2025, EIA[8], as shown in Fig. 7 - World Consumption of Primary Energy - History and Projections, EIA, 2004 - projects for 2025 practically the same figure, in spite of a greater supply of renewable energies.

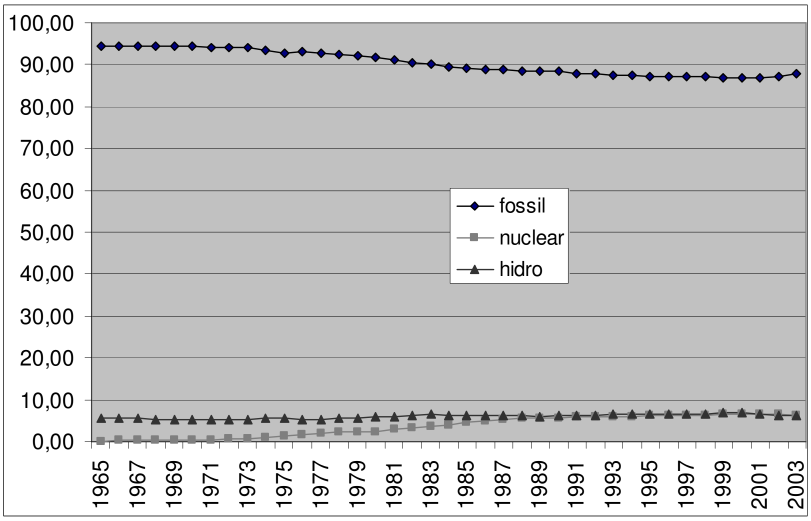

Figure 6. World Consumption of Primary Energy

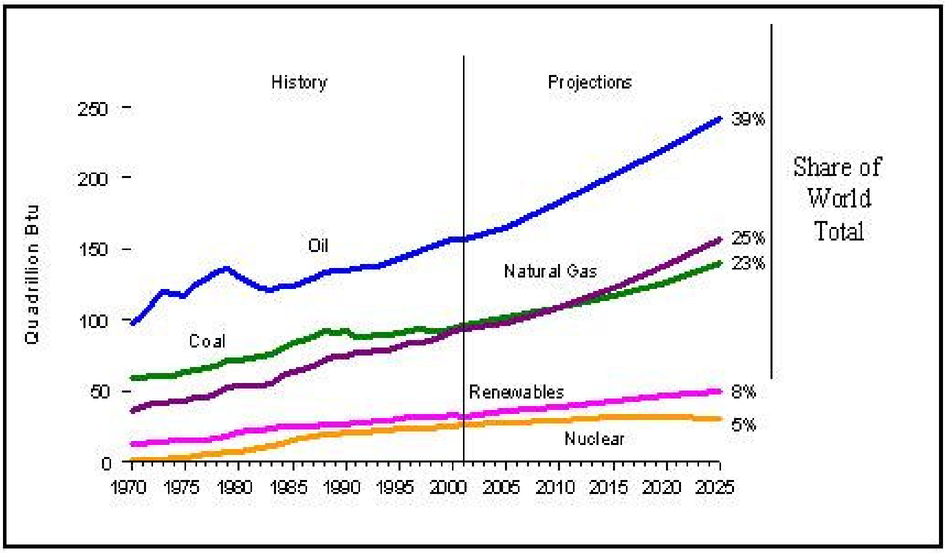

Figure 7. World consumption of Primary Energy – History and Projections

5. RENEWABLE ENERGY

Imagining an extremely optimistic scenario where it is possible to double the amount of hydro energy, obtain electricity from wind energy in the same amount of hydro energy, and keep the nuclear production expected for 2025, reliance on fossil energy would still be 63% in 2025. In this scenario, direct use of solar energy, either by photocells or biomass, was not considered.

Considering the production of biomass, and based on current technology in Brazil, 1.94 10^8 kJ/ha-year are produced by growing sugar cane for energetic purposes. The traditional method of harvesting that consists in burning the leaves of the standing cane before harvest is being gradually replaced by harvesting without burning, and the use of the leaves for energetic purposes. This will raise the amount of energy produced per hectare. The environmental effects of the sugar cane monoculture are not being taken into account. This scenario is shown in Table 4 - Energy production from sugar cane.

Table 4. Energy production from sugar cane. Compiled by the author

		Brazil	World	World	World	World
Fossil energy replacement		100%	100%	100%	10%	10%
	units	2003	2003	2025	2003	2025
	toe	$1.09\ 10^{8}$	$8.55\ 10^{9}$	$1.24\ 10^{10}$	$8.55\ 10^{8}$	$1.24\ 10^{9}$
	kJ	$4.70\ 10^{15}$	$3.69\ 10^{17}$	$5.37\ 10^{17}$	$3.69\ 10^{16}$	$5.37\ 10^{16}$
Planted area	ha	$2.42\ 10^{7}$	$1.90\ 10^{9}$	$2.76\ 10^{9}$	$1.90\ 10^{8}$	$2.76\ 10^{8}$
% Brazil	%	2.8%	222.4%	323.4%	22.2%	32.3%

Note that in order to replace 10% of fossil energy to be consumed in 2025 an area of 32% of the Brazilian territory will be necessary. The area of Brazil is $8.55\ 10^{8}$ ha (8,547,000 km^2). Even then we would have in 2025 a dependence of 53% on fossil energy. It seems evident that finding new energy sources is not enough; rather, it is necessary to invest in more efficient technologies and equipments, and above all establish the basis for a less energy-voracious society.

6. CONCLUSIONS

The dependence on fossil fuels is and will remain very great in the next decades. The reduction of this dependence is a global imperative, mainly by the necessity of CO_2 emission reduction. The ease of access to the stock of fossil fuels and its availability had led our society to the construction of an energy-greedy model of development. This is reflected in our economy, infra-structure, habits and culture. The data collected above indicates that it will be not possible to sustainably produce the amount of energy demanded today by our society. Therefore, in addition to improvements in efficiency of equipments and processes, it will be necessary to rethink our economic model taking into account the carrying capacity of the Planet.

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