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Energy for Sustainable Development: A systematic approach for a badly defined challenge

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ABSTRACT

Energy for Sustainable Development is analyzed as a Technology challenge with a very large set of possibilities both in energy generation and energy consumption. The portfolio of emerging technologies in both domains is very large but also very demanding. Their learning curves show very different features, and inherent difficulties in each technology can be identified. Additionally, energy sustainability conveys rigorous considerations about Global Warming and ancillary subjects, which are not yet properly defined in terms of requirements on the energy sectors. Moreover, the evolution of energy generation sources in the first decade of this century clearly shows a mismatch between the theoretical boost to combat climate change, and the actual facts in energy markets. However, emerging technologies in the complete energy sector could give a suitable answer to a challenge not very well defined so far.

1. Introduction and background

In elementary Physics, Energy is defined as the capability to make a work.

For Society and Economics, Energy is a special good, indispensable for personal well-being, and even more indispensable for the economic activity and competitiveness of a country, a region, a continent or the World as a whole.

Energy is thus a two-sided subject: its demand has to be satisfied for not to hamper social and personal welfare, what conveys the need of very complex and sprawling energy markets; but the main laws governing Energy are not commercial ones: they are laws of Physics, and must utterly be complied with. Any exploitation of a source of energy is limited by those laws, totally unchangeable. On the contrary, markets can be changed by taxes, subsidies, loans, take-or-pay contracts and other trade tools. Energy markets are a problem, no doubt about it; but the actually binding problem is Physics, in a double stage: Physical Sciences, for studying the relations among the relevant magnitudes of a given source of energy, or for studying energy sources in general; and Physical Technologies, to materialize the exploitation of a source. Any real advancement in this field has to pass through these stages, and the largest part of this book will be devoted to them, because they actually are the hard part of the problem. Other considerations will also be treated for the sake of completeness, in a subject where wishful thinking is a current tool to shape the future on paper, not on real facts. And it is the facts what matters.

In the turn of the Century, Energy was in the very center of a badly defined dispute on Global Warming [1] and Sustainable Development [2]. It is a fact that the increase in the atmospheric inventory of greenhouse effect gases, notably CO_2, is mainly caused by combustion of fossil fuels, but its true influence on Climate Change is still to be established with adequate soundness, even if the Intergovernmental Panel on Climate Change has stated that there is an unambiguous relation between said increase and the planet warming. What warming?, we can ask. How can we distinguish the evolution of climate with and without such increase? By means of numerical simulation [3,4], but this is not an ordinary problem, is highly chaotic, and the natural evolution of the climate along millions of years shows enormous variations, without clear triggers from one phase to the following [5–8].

In this paper, an attempt is made to clarify the alternatives we have to give an answer to the Energy Problem, which has three main objectives:

- Security of supply
- Environmental quality
- Low cost

Those alternatives can be grouped in two sides; the energy generation portfolio [9,10], and the users' technologies, which constitute the final objective to be covered [11]. In that chain from generation to consumption, a very important thermodynamic principle is always present, even if the energy forms are not of a thermal nature: unlike matter, which is recycled with some consumption of energy either in natural or artificial mechanisms, energy cannot be recycled. Energy is always in a process of degradation, which leads

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to entropy increase and isothermalization. Hence, energy sources are indeed sources, and all of them are exhaustable, including the renewable ones, most of which are secondary energy forms from the Nuclear Fusion energy generated in the Sun by the continuous consumption of protons. Geothermal energy and tidal energy have a different origin, but they are marginal in the full energy budget of our planet.

In the users' side, new technologies are emerging in these years, particularly the Electric Vehicle [12–14]. The full energy picture will deeply change if we are able to harness these emerging technologies, but this is not an easy challenge.

In the next section, Sustainability will be analyzed on the basis of actual energy data. Section 3 will be devoted to identify where Energy can come from, not in geography but in Physics. This analysis gives us the floor to address the subject of Renewable Energy Sources in Section 4; and to deal with the Nuclear domain in Section 5. Section 6 is devoted to the emerging technologies which consume energy, particularly for transportation. Some conclusions are expressed in Section 7, trying to pave some ways for the future.

2. Carbon economy vs. Global Warming

Going back to the facts, fossil fuels essentially are solar energy of ancient times, accumulated as coal or hydrocarbons in processes lasting million of years. The CO_2 captured by plants, plankton and the like from the biosphere in remote times, is being released very rapidly nowadays. Artificial emissions of CO_2 in 1 year are around 1% of the current inventory in the atmosphere, and natural CO_2 sinks cannot follow the growing emission rate. The result is therefore an increase in the contents of atmospheric CO_2 which was about 250 ppm (parts per million, in volume) one Century ago and has risen to 390 ppm by now [15].

The balance of CO_2 is currently as follows: the inventory in the atmosphere is 2.5 teratons (Ttons) and the content in the seas is estimated at 125 Ttons. The natural circulation in the CO_2 cycle is 400 Gtons, 50% of which is resent to the air by plants, and 50% approximately goes through the general food chains and putrefaction mechanisms. The artificial perturbation caused by fossil fuel combustion is 30 Gtons/year.

It must be said that the CO_2 contents in the air along the geological history of the planet has been higher and very much than the current value, and the climate has been warmer, although not always. In our current Age, covering about 1 million years, very cold periods, called Glaciations, lasting many millennia, were interrupted by warm periods, the interglaciations, and such tremendous climate change did happen without any type of human intervention. We are living now in an interglaciation which started about 13,000 years ago, and it is lasting too much, according to the geological recordings and the way we understand them. In fact, the threat of a new glacial period freezing the full surface of Earth but the tropics was a non-negligible possibility, but it was not possible to forecast when such a big problem would start [16,17].

At the end of XIX Century, the great Swedish chemist Svante Arrhenius [18] was the first person establishing a link between the CO_2 content in the atmosphere and the temperature on the surface of the planet, but he was not concerned with Global Warming as we understand it nowadays, but just the contrary: he considered massive coal combustion as a tool to keep the planet warm, if a new Ice Age started to freeze it. At that time, the radiation balance on the Earth could not be measured as we do now with satellites and pyranometers, but the greenhouse effect was approximately understood with the household example of gardener's greenhouses, where the glass roof lets the sunbeam go in, but it does not let the inner radiation go out. This difference stems from the difference in wavelength between the photons of the solar beam and the photons of the inner radiation. Solar photons are packed around 1 μm, while thermal radiation photons from the surface of the planet are packed around 20 μm; and standard glass is transparent for the former pack, and backscatter a high fraction on the latter. Arrhenius could not use this explanation because his idea was earlier than Max Planck's quantum theory of electromagnetic radiation, but the greenhouse phenomenology was evident, and Arrhenius extended it to CO_2 at a global scale.

Atmospheric greenhouse effect is caused by molecules with 3 atoms or more, and it is very beneficial for life in our planet. Its present worth measured in temperature is almost 34 °C; which means that the current average temperature on the surface of the planet, 15.5 °C, would go down to 18 °C below zero in absence of the greenhouse effect and most of the Earth would be frozen.

The increase of atmospheric CO_2 inventory in last century is well recorded, from 250 ppm (volume) to 390 [15] and Earth's average surface temperature has increased by about 0.8 °C , with about two thirds of the increase occurring since 1980. The coincidence seems very strong and suggests a cause-effect fact. However, there are other independent variables and boundary conditions in this problem, which cannot be controlled to make a proper experiment *ceteris paribus* (the Latin sentence for stating that the rest of the problem was unchanged, and only the variable under study was modified). This is not possible in our case, because there are a number of magnitudes affecting the climate, as Sun's activity. It is true that solar radiation values are recorded and exact boundary conditions can be used in updating climate simulations, but in a non-linear problem, a change in the main variable can send the evolution of the performance in a totally different branch. Additionally, volcanic emissions of aerosols and gases can also change the background of the problem, and it is not easy to properly record those emissions [19–23].

In the 2007 Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC), computational simulation estimates were given indicating that during the 21st Century the global surface temperature is likely to rise a further 1.1 to 2.9 °C for their lowest emissions scenario and 2.4–6.4 °C for their highest. The bracket is very wide because uncertainties recognized by the scientists do not allow higher accuracy.

In spite of all voiced concerns, the consumption of energy products worldwide [24,25] along the first 10 years of 21st Century registered the highest increase in coal, jumping from 2.4 Gtoe in 2000 to more than 3.5 in 2010 (the main reason for that being China, rising from 0.7 Gtoe to 1.7). Another salient feature has been the commercial explosion of unconventional gas (mainly, shale gas) in the USA [26] under President Obama's Administration [27]. Neither the so called Nuclear Renaissance nor the deployment of Renewable energy sources has undergone a comparable evolution in that country. All these facts point out that Energy is in general dominated by short-term economics, because long-term strategies are not embodied in the energy prices. This is one of the key points for shaping the future of energy, but it is not straight forward to apply it. Even the price to be paid for CO_2 has to be established by a still immature market, and the real fact is a substantial increase in global CO_2 emissions, rising from 25.6 Gton in year 2000 to 33.1 in 2010 [24].

In the USA, 45% of electricity generation was produced by coal, 24% by gas (which was the fast rising source) 20% by nuclear; 10% by renewable and 1% from others. For 2035, it is expected to have 39% by coal, 27% by gas, 18% by nuclear, 16% by renewables and 1% by other sources [27].

Hence, the current global trend contradicts to a large extent the political principle of moving to a lower dependence on oil and the rest of fossil fuels, but it does not mean that we can forget our obligations for shaping an Energy sector with a broader variety of energy sources, taking advantage of all physical mechanisms found in