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How solar energy and electrochemical technologies may help developing countries and the environment

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ABSTRACT

The policies of curbing CO_2 emissions have worked poorly on a global scale and an economically sound proposal of bringing electric power to Europe from an Algerian solar hub has just been dismissed. With reference to the Algerian – European relationships, we analyze the broad context where an environmental policy benefitting both developing and developed countries can be put in place. We then discuss the connection between anthropogenic CO_2 emissions and acidification of Oceans along with a geo-engineering proposal aimed at solving these pressing problems with large-scale solar-powered chloralkali plants. While the cost of sequestering a ton of CO_2 with dedicated chloralkali plants is unacceptably high, it is economically and environmentally sound to replace an existing European Cl_2 plant (consuming fossils) with a solar-powered plant in Algeria. If the Algerian plant uses a new, more efficient chloralkali process, it will be competitive with existing European plants even at the current low market value of the carbon emission credits. We finally explore the possibility of coupling Cl_2 production with CO_2 reuse and syngas production through a novel electrochemical process.

1. Introduction

After several millions years, carbon dioxide concentration in the Earth atmosphere has now reached again 400 ppm. In a geological time-scale, this rise of about 100 ppm over the characteristic level of recent interglacial periods has been anomalously fast, and fully due to human activity [1]. Science has been trying for decades to predict the medium term and long term effects of the anthropogenic production of greenhouse gases, a daunting task due to the complex and partially unknown interactions between Oceans and atmosphere [2]. The most immediate dangers for the biosphere and its biodiversity are probably related with the phenomenon of Oceans acidification [3], the likely release of the CO_2 captured by Oceans triggered by a temperature rise [4], the expansion of the oxygen depleted areas in the Oceans [5] with long term effects upon the biosphere [6].

The perceived urgency of curbing the production of greenhouse gases is pushing, on one hand, towards the replacement of fossil fuels with renewable energy sources, in particular, with those using directly the solar radiation [7] and, on the other, towards the development of innovative ways of carbon dioxide capture and reuse, one of the hottest themes in material and environmental sciences. As a matter of fact, Elsevier has launched a new magazine: *Journal of* CO_2 *utilization*.

However, even the best technology and the most brilliant concepts born out of this research efforts will not translate into large scale applications and environmental benefits if appropriate "boundary conditions" are not present. It is therefore important to analyze first the broader context in which technological contributions to solve the greenhouse emissions problem have the possibility to be adopted.

To illustrate this point, we will first discuss the demise of DESERTEC, an economically and technically sound proposal for a solar hub in the Algerian desert to supply Europe with electric energy. We will also discuss the possibility that a country like Algeria produces renewable energy in the form of biofuels and solar hydrogen.

We will then summarize the basic science relating the increase of atmospheric CO_2 and the Ocean acidification in order to analyze the feasibility of an interesting geo-engineering proposal [8] designed to solve these problems through a chloralkali process. Using the data of DESERTEC we demonstrate that this proposal is economically untenable.

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On the other hand, we find that, by adopting an advanced electrochemical technology of chlorine production, Cl_2 can be conveniently produced with solar power in Algeria, and shipped to OECD countries to partially replace the output of plants using fossil energy, thus achieving a substantial reduction of global emissions. Finally, we suggest that the environmental and economic benefits would be higher if solar power is used to produce Cl_2 and syngas from CO_2 and recycled HCl with a novel electrochemical process.

2. The broader economic and political context

2.1. Developed and developing countries

About 85% of our energy needs are covered by fossil fuels. Developed countries are mostly importers of fossil fuels, with a level of consumption which has flattened, or decreased, in the past decade due to stagnating OECD economies and their policies primarily aimed at decreasing their energy imports by developing their own sources (renewable or not) and increasing their energy efficiency . The above is particularly evident in the directives of the European Union concerning energy [9]. On the other hand, many developing countries are exporters of fossils with rapidly expanding economies and energy needs [10]. The situation is unlikely to change substantially in the next decade [11]. Part of this expansion is related to transfer of factories from developed countries which try to put a ceiling to consumption of fossils and, as a byproduct, to their CO_2 emissions. Since developing countries have weaker regulations and can hardly afford advanced technologies, this transfer resulted in a worsening of the global CO_2 budget.

The increased rate of global emissions is one of the consequences of the asymmetric relationship between developed (OECD, mostly energy importers) and under-developed (mostly exporters of energy and raw materials) countries. After the second world war, the US helped rebuilding the economies of Japan and several European countries favoring a diversified commercial exchange with them. The ensuing affluence produced political stability and essentially banned wars between OECD countries.

Nothing comparable is seen today in the policies of OECD towards developing countries, where the wealth often comes from the export of few commodities controlled by the ruling elite; social unrest and political instability often lead to open conflicts which cost enormously in human, economic and environmental terms.

2.2. The Algerian case

As a case study of the interactions among economics, politics and technologies we will consider Algeria, where the government takes about 90% of its revenues from export of fossils, mostly to Europe. Over the past decade, exports have not increased while internal consumption of oil, gas and electricity has risen between 4.5% and 7.5% per year keeping the production of fossils nearly flat [12]. No major upgrade of the production facilities has taken place: in 2010, 5.6 Gm^3 of natural gas (3% of the total production) have been vented causing the same greenhouse effect of 0.1 Gton of CO_2 [13]. Relevant changes in the natural gas market (development of non-conventional sources) are decoupling the prices of oil and natural gas; this works against the favored position Algeria had with European clients, which have committed huge resources in the costly gas lines connecting Algeria–Tunisia with Spain and Italy [14].

Algeria owns a substantial portion ($\sim 2 \cdot 10^6$ km^2) of the Sahara desert with nearly ideal conditions to exploit solar energy, but has only ~70,000 km^2 of arable land. The possibility that Algeria grows energy crops to sell transportation fuel to Europe cannot be considered for lack of fresh water and unused fertile land. In addition, the environmental benefits of biofuels are not always beyond doubt: a recent review indicates that among renewable energy sources, biofuels from dedicated crops may not be the best environmental option for transportation [15]. According to Crutzen [16], the emission of NO_x from the fertilizers used for energy crops balances the reduced CO_2 output associated with replacing fossils with biofuels.

2.3. The DESERTEC proposal

DESERTEC [17] is the failed initiative of a distinguished international consortium which planned in building a 17,000 km^2 concentrated thermal solar power hub in Sahara delivering up to 100 GW_{el} (or ~70 GW_{el} in average) to European countries, which currently have a combined power need of about 500 GW_{el}. A completed DESERTEC project would have satisfied ~15% of the current power needs of the European Community. Predicted total cost in 2009 for hub and power lines was ~500 billion €, which would have generated a gross revenue of ~60 billion €/year (at the assumed bulk rate of 0.1 €/kW h) and a saving of 350 Mt-CO_2/y relative to thermoelectric methane plants producing the same electric energy with 33% efficiency (see Fig. 1).

Considering financial and operating costs along with the legendary red tape of Algerian bureaucracy, the return time of investment under most scenarios would have been measured in decades, substantially more than for renewable energy plants built in Europe. The proponents of DESERTEC were hoping in a political decision in favor of Algeria from the European Union (EU), a very unlikely decision since the main aim of the energy policy of EU is the reduction of the dependency upon external suppliers [8]. The European Commission will never trade reduced emissions against reliability of a strategic supply such as electricity; this, in our opinion, was the fatally weak point of DESERTEC. Long before its demise in the Spring of 2013 [18] it was clear to us that DESERTEC was not politically and economically viable. However, its idea of using an unexploited resource (land and solar energy) to reduce emissions is much appealing.

Many proponents of the "Hydrogen Economy" (see next subsection) have argued for export of solar hydrogen produced by photovoltaics (PV) in sun-scorched regions; we argue that this proposal has essentially the same political flaw of DESERTEC and, in addition, is untenable from the scientific and technological points of view.

2.4. The hydrogen alternative

Analyses of the potential benefits of solar hydrogen production in countries like Egypt [19] and Saudi Arabia [20] applies to Algeria

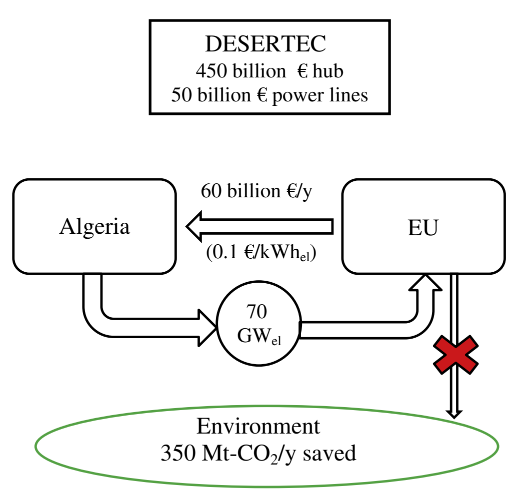

Fig. 1. Economic and environmental summary of the DESERTEC proposal.