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A comparison of electricity production technologies in terms of sustainable development

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ABSTRACT

The electricity production sector has currently and for the past years been dominated by fossil fuel technologies, mostly coal, oil and natural gas. This has had various environmental consequences, such as increased gaseous emissions, soil and water pollution, global warming, as well as fossil resource depletion. As a result, the need to pursue Sustainable Development (SD), in order to reduce dependency on fossil fuel, to achieve Greenhouse Gas (GHG) mitigation and to reverse the effects of climate change has currently become imperative. SD is considered to be one of the most important factors for countries' energy policy today and efforts, such as the ones materialized through the Kyoto Protocol mechanisms, are being made to promote sustainable electricity production technologies globally. Nuclear and renewable energy technologies both have the potential of contributing to the increasing global energy demands, while simultaneously lowering GHG emissions and also having a positive economic and social impact. In view of their differences and the ongoing nuclear debate, this paper aims to compare specific promising and emerging nuclear and renewable energy technologies in terms of their contribution to SD and prospects for deployment. The comparison showed that each technology contributes in its own way to SD and that political decisions, individual country energy policies and public opinion will probably determine the future deployment of each energy technology.

1. Introduction

The energy and particularly the electricity production sector today is confronted with many serious issues. Global warming is one of the major environmental problems that the humanity is currently faced with and will face in the coming years [1]. The main factor which is held responsible for climate change is Greenhouse Gas (GHG) emissions coming mostly from energy production plants around the world, along with other sources. The majority of the world's electricity is currently produced via fossil fuels, mainly coal, oil and natural gas, thus causing the emission of large amounts of CO_2, CH_4 and N_2O, the gases mostly responsible for the GHG effect [1]. The fact that global electricity demand is rapidly increasing, leads to the construction of even more power plants, which in turn causes the emission of more GHG. Chemical waste produced from these plants is usually thrown into the aquifer or soil causing further environmental pollution.

It has been predicted that global warming may lead to economic, as well as environmental disaster [2,3]. Global GDP could be reduced by as much as 25%, while the cost of reducing GHG emissions is about 1% of global GDP [2]. In addition, fossil fuels are getting more expensive, which is mainly because of the fact that they are considered a finite resource and also due to recent economic crisis. Some studies [4,5] indicate that crude oil production will run out within the next 50–100 years, as the time peak of its production (peak oil) is very near or has just passed, although the exact timeframe is still under discussion [6]. According to another study [7], coal peak production is likely to occur between 2010 and 2048. Despite the above speculations, though, new fossil fuel resources are constantly being discovered and the exploitation of former non-exploitable resources is now possible with the aid of new technologies. In contradiction to the previous studies mentioned, other estimations conclude that the lifetime of fossil fuels is almost infinite [8], a fact which could give more lifespan to traditional fossil fuels.

Today it is a fact that most countries choose an energy strategy profile based on domestic priorities and needs and not long term sustainability and GHG reduction [9]. In this light, the main challenge is to effectively pursue Sustainable Development (SD) in the electricity sector, namely providing humanity with adequate energy to cover its needs of producing cheap and secure electricity, while at the same time reducing GHG emissions. This requires the exploitation of energy sources alternatives to the traditional fossil fuels.

Nuclear energy technologies have been present for over half a century providing significant contribution to the electricity

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production domain [10]. Many countries around the world are currently planning to use nuclear energy mainly as a baseline electricity production means or are already using and expanding its use, mostly having taken into consideration the fact that it produces large amounts of electric power and is relatively cheap, thus offering energy security and independence. It also emits almost negligible amounts of GHG, contributing in this way to global and local SD, although waste and health hazards are still present and yet to be solved [3].

Renewable energy technologies, on the other hand, are considered standard options today which contribute to the reduction of high dependence on imported energy and to local development. In addition, they provide environmental benefits with regards to GHG emissions, thus playing an important role in mitigating climate change [11]. Renewable energy is widely spread around the world as a base and peak-load electricity production means and especially nowadays, a quite impressive portfolio of renewable energy technologies is available, although it should be noted that many of them are dependent on weather fluctuations for power output [12].

Nuclear and renewable energy are some, if not the main, options to bring down the carbon intensity of electricity production today. The need to further deploy nuclear and renewable energy has become even more pressing as a result of continuous rising prices in fossil fuels and the Kyoto Protocol requiring countries to effectively reduce their CO_2 emissions in order to mitigate the effects of global warming [13]. The Kyoto Protocol contains market mechanisms, mainly the Joint Implementation (JI) and the Clean Development Mechanism (CDM), which enable developed countries to invest in GHG emission reduction projects on the territory of other developed and developing countries, The majority of these projects (94%) refer to CDM projects, for which the greatest share of is covered by renewable energy projects (63.26%) [14]. Under the umbrella of the CDM, and also independently because of their environmental benefits, renewable energy technologies have known a large deployment and market growth. This has also led to an increase in the R&D for renewable energy, in order to reduce manufacturing costs and enhance current technology efficiency, as well as to make new renewables commercially available and viable [15]. On the other hand, nuclear energy has been excluded from the CDM up to 2012 and has been boosted only by its appealing natural characteristics, that is its energy intensity and low electricity cost. The inclusion of nuclear energy in the CDM has been continuously proposed in discussions in view of the urgent need to tackle global warming, but it has not been accepted on the grounds of a potential increase in Certified Emission Reductions (CERs) supply if many nuclear plants are built, a fact that may lead to the decrease of the value of carbon credits on the market, and secondly due to radioactive waste which still poses a serious threat [1].

A number of studies exist in international literature, which focus mainly on the integration of nuclear and renewable energy in the energy market [16,17] and the relationship between emissions and renewable and nuclear energy consumption [13]. Moreover, Forsberg [12] and Verbruggen [18] explored the future electricity supply by combining nuclear and renewable energy and by providing priority to the sustainable options. However, to the best of the authors' knowledge, there seems to be no paper posing a direct comparison between nuclear and renewable energy in terms of sustainability. In this context, the main scope of this study is to present and compare two emerging nuclear technologies, namely the European Pressurized Reactor (EPR) and the Sodium-cooled Fast Reactor (SFR), with four promising renewable energy technologies, namely Biomass, Solar Photovoltaic (PV), Concentrated Solar Power (CSP) and Offshore Wind in terms of their potential of contributing to SD, and also to examine their differences and future deployment.

Apart from Section 1, the paper is structured along four sections. The methodology is presented in Section 2. Sections 3 and 4 focuses on the presentation of the nuclear and renewable energy technologies respectively, while Section 5 deals with the comparison and discussion of each technology's sustainability factors. Finally, Section 6 presents the conclusions from the main points arisen from this study.

2. Methodology of comparison between nuclear and renewable energy technologies

The proposed methodology adopted for the comparison of the technology options involves the following two steps. Firstly, each technology is presented describing its basic functional characteristics along with its current status and the barriers that prevent its deployment. Secondly, the technology comparison is made with a presentation of specific sustainability factors. These factors are assessed in terms of:

- *Economic dimension*: Net capital cost, electricity production cost.
- *Environmental dimension*: GHG emission, waste produced.
- *Political dimension*: Possible proliferation or misuse.
- *Social dimension*: Public acceptance, visual disturbance, noise.

3. Nuclear energy technologies: European pressurized reactor and sodium-cooled fast reactor

Unlike other low-carbon energy sources, nuclear energy is considered a mature technology that has been in use and further developed for over 50 years [19]. As of December 2011, 30 countries worldwide are operating 435 nuclear reactors for electricity generation and 63 new nuclear plants are under construction in 14 countries [20]. Moreover, electricity from nuclear power plants accounted for 13.5% of the world's electricity production in 2010 [20]. In total, 15 countries relied on nuclear energy to supply at least one-quarter of their total electricity [20]. The countries France, Slovakia and Belgium generated the largest percentage of their electricity in 2010 from nuclear energy [20]. In the following paragraphs the two nuclear technologies are presented.

3.1. European Pressurized Reactor (EPR)

The European Pressurized Reactor (EPR) developed by Framatome, EDF and Siemens is a good representative of Generation III+ reactors. It features an evolutionary design to achieve maximum benefit from the accumulated experience in designing and operating existing PWR units. For the mitigation of severe accidents, the EPR has incorporated most recent technologies from French and German plants [21]. It features an enhanced safety level aimed at limiting the consequences of a postulated severe accident with and without core meltdown. It generates more electricity from a given quantity of fuel, thus conserving uranium resources by 15% and generating 15% less waste [21]. Among other factors, the conversion rate of thermal power into electricity has risen from 34% to 36–37% [21]. This nuclear technology uses moderately enriched (up to 5%) uranium oxide fuel or Mixed Oxide Fuel (MOX). Its net electrical output is in the range of 1600 MWe [22] and has a design maximum core damage frequency of 6.1×10^{-7} per plant per year [23]. Besides the Reactor Pressure Vessel and steam generator, the pressurizer, reactor coolant pumps, accumulators and controlled area are the main components of the EPR.

The EPR is expected to generate about 12,600 GWh/year for a lifespan of 60 years [24]. The construction time is approximately 4.8 years [24]. The first EPR units are currently under construction