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Total number of authors:
12

Publication date:
2010

[Link back to DTU Orbit](#)

Citation (APA):

Cabal, H., Lechón, Y., Hamacher, T., Muehlich, P., Eherer, C., Ciorba, U., Gracceva, F., Ward, D., Han, W., Biberacher, M., Grohnheit, P. E., & Pina, A. (2010). *The possible role of fusion power in a future sustainable global energy system using the EFDA TIMES global energy model*. Abstract from Joint IEW-ETSAP Workshop, Stockholm, Sweden.

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The possible role of fusion power in a future sustainable global energy system using the EFDA Times global energy model.

JEL classification code: Q42

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Long Abstract:

Energy is one of the main drivers in the economic development of a country or region. Access to the energy services is essential to improve the social wealth and to reach societal prosperity.

Nowadays, the global economy is changing fast. While developed countries and regions, such as the EU or the USA, are experiencing a stationary economic growth, developing countries, such as China, are getting a place among the outstanding economies. Such a changeable panorama makes very difficult to sketch the global energy system in a long term. Global environmental concerns are aggravating and energy demand is increasing so new more efficient technologies and with abundance of resources are needed to guarantee the energy supply in a sustainable global economy.

Renewable technologies turn to be a good option in terms of sustainability and security. From the end of the last century till now, renewable technologies have experienced great advances in terms of capacity, efficiency and costs but the intermittent nature of some of them make this option difficult to take on the whole responsibility of the energy supply. In this context, nuclear fusion, a new technology with no greenhouse gases (GEI) emission, few hazardous residues and no risk of accident, shows up in the power technologies portfolio.

Fusion is the process that heats the Sun and all other stars, where atomic nuclei collide together releasing a great amount of energy. In a fusion reactor there are no carbon emissions. Fusion fuels, deuterium and tritium, are abundant. The former may be extracted from sea water, the last from lithium from the earth's crust. Fusion process is highly efficient, energy produced with small quantities of fuel is huge. The only radioactive wastes are plant components that have to be disposed at the end of the lifetime of the plant and whose average half life is less than 100 years. Regarding the probability of large scale nuclear accidents, it is insignificant because the amount of fuel is very small and chain reactions are not possible. Finally fusion power plants are

capable of providing large amount of electricity which makes them suitable for working in a base load way. On the other hand, fusion power is not free of generating other environmental impacts such as those derived from C-14 emissions during the plant operation as it was studied under the first SERF (Socio-Economic Research on Fusion) projects that dealt with externalities of fusion.

But fusion technology is still at a pre-demonstration stage. Although big efforts have been done in terms of research and development supports, there is still a long way to go until the first fusion power reactor starts working.

In November 1985, the ITER project was born as a result of the collaboration of the former Soviet Union, the USA, the European Union (via Euratom) and Japan. The People's Republic of China and the Republic of Korea joined the project in 2003 and India in 2005. The aim of the project is to demonstrate that it is possible to produce commercial energy from fusion. The ITER machine is designed for a 500 MW installed capacity. During its operational lifetime, ITER will test key technologies necessary for the next step: the demonstration fusion power plant (DEMO project) that will capture fusion energy for commercial use. ITER construction is expected to end by 2017 and the achievement of the first plasma by 2018. ITER's operational phase is expected to last for 20 years. After that, a conceptual fusion reactor design could be completed and DEMO will lead fusion into its industrial era, beginning operations in the early 2030s, and putting fusion power into the grid as early as 2040. That means that being an incipient technology in the 2050s, we will need a prospective analysis in a long term to assess what the role of fusion power will be in the global future energy system. Such analysis can be undertaken with a tool able to provide the optimum energy system composition in terms of social wealth and sustainability.

The cost of fusion power stations remains uncertain, of course, as the systems are still under development. However earlier studies of the cost of fusion devices revealed that the costs depend most strongly on a few key items, particularly the site and buildings, the superconducting magnets and the balance of plant (such as turbines). This means that the costs of a future fusion plant are not very sensitive to design details – more important is the production of power in a reliable way; which must be demonstrated by the fusion research programme.

There have been a wide range of studies of costs, varying primarily in the assumed materials and technology as well as assumptions about the fusion performance in scientific terms. Whilst a wide range of plants have been studied, the overnight capital costs vary from typical values of $4\$/W_e$ for early generation plants to around $2\$/W_e$ for mature, advanced fusion plants. This range is implemented in the EFDA Times Model (ETM) with the early generation plants assumed to be available in 2050, evolving to an advanced, mature plant over the following 30 years.

The ETM is a multi-regional, global and long-term energy model of economic equilibrium, responsive to energy technology innovations, domestic and international trade energy policies, climate change mitigation and environment objectives. It has been developed within the European Fusion Development Agreement (EFDA) framework starting in 2004 and forms part of the Times

family of energy models. In ETM the world is divided into 15 regions linked by energy and emissions permit trading variables. Time horizon will be 2100. The reference energy system includes five energy consumption sectors (residential, commercial, agriculture, industrial and transportation) and two energy supply sectors (electricity production and upstream/downstream). Technologies, in the ETM, are divided into technologies working at the base year and the future potential technologies entering the energy system during the whole period of study. All of them are very well characterized by a number of technical, environmental and economic parameters. Energy demand drivers (annual growth rates of population, GDP, number of households ...) are provided exogenously, then driver projections are performed using the GEM-E3 (general equilibrium model for Europe and the World) model and finally, demands for energy services are linked to the drivers' projections. That means that ETM has the capability of estimate the response of the demands to changes introduced in the model. In ETM, the different regions are connected by inter-regional exchange process (trade of commodities). Trade in ETM can be bi-lateral between two regions and multi-lateral between several supply and demand regions. In a bi-lateral trade, there is one inter-regional exchange process between the two regions, thus, there is a balance between both regions. A multi-lateral trade however, is based on a common marketplace for a commodity which has several producing and consuming regions. A new region for the marketplace is created and each region has an only inter-regional exchange process between itself and the marketplace region.

From 2004 till now, ETM has been constantly updated and improved within successive SERF projects with the collaboration of different Euratom associations. Last version has been developed in December 2009 and preliminary results for different environmental scenarios are presented in this work.

Two framework scenarios are defined as follows:

- Base case scenario (SC1): there is no limit to CO₂ emissions
- 450ppm scenario (SC2): a limit of 450ppm in CO_{2-eq} concentrations is set by 2050

For these framework scenarios, conservative assumptions on fusion costs, energy demand and Uranium resources have been taken. Key parameters that will determine the penetration of fusion power are identified and used for sensitivity analysis focusing on the penetration of fusion power.

These results have to be taken as very preliminary. The main aim of the work is testing the ETM model, the only energy model which includes the future fusion technology in the global long-term energy portfolio. Results show that in a base case scenario, with no measures for CO₂ emission reductions, coal technologies play a dominant role in the global power production in 2100. Fission technologies supply also an important amount of the global electricity by 2100 experiencing a big increase from 2040. Wind and hydro are the only renewable technologies, having a very small share in the global power generation. In this scenario, fusion does not enter the energy system.

When CO₂ emission restrictions are imposed, the global energy system composition changes completely. In a 450ppm scenario (SC2), coal technologies disappear in 2035 being mainly replaced by nuclear fission technologies which experience a great increase until 2070. Afterwards, this share starts decreasing to end in a small share in 2100 due to uranium resources exhaustion. Fission technologies are then replaced by the fusion power plants that starting in 2070 are responsible of almost half of the global electricity production in 2100. Also wind and hydro play an important role in 2100.

Fusion technology, in the beginning, is going to be expensive when comparing with other mature technologies. Consequently, it will not be a competitive alternative, but may have the opportunity to enter the global energy system, more specifically, the global power generation system, when environmental restrictions are imposed. In a scenario with no CO₂ emission limits, fusion technology does not participate being the cost is the main parameter in the optimization process.

However, the panorama changes completely when CO₂ emission restrictions are introduced. Then fusion enters the system replacing nuclear fission and fossil fuel technologies.

To conclude the work, a sensitivity analysis will be presented on the key parameters that affect the possible role of fusion in the future global energy system.