ESSRI Workshops Energy for Sustainable Science at Research Infrastructures

GOBIERNO DE ESPAÑA | MINISTERIO DE CIENCIA E INNOVACIÓN | Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas | ENERGY SYSTEMS ANALYSIS UNIT | Universidad Rey Juan Carlos | EUROfusion

The role of fusion energy in future energy scenarios

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INTRODUCTION

The European Consortium for the Development of Fusion Energy (EUROfusion) has promoted socio-economic studies on fusion to investigate the social acceptability and **the economic competitiveness of fusion power plants in a future energy market,** a work developed by the EUROfusion SES group**.**

A well-assessed model generator, **The Integrated MARKAL-EFOM System (TIMES),** is used to create the worldwide energy system model and look at its possible evolution according to different energy and environmental policies. Using this model, we analyse the contribution of fusion power to a future low-carbon global electricity system. The TIMES model generator was developed as part of the IEA-ETSAP (Energy Technology Systems Analysis Program), an international community which uses long-term energy scenarios to conduct in-depth energy and environmental analyses [1].

TIME's characteristics: technology-rich, bottom-up model generator, uses linear programming to produce a **least-cost energy system**, optimized according to several user constraints, typically for medium to long-term time horizons. Different scenarios can be built following different storylines, modifying uncertainties or driving forces like social dynamics toward transformation, innovation, geopolitical instability, policies or economic factors.

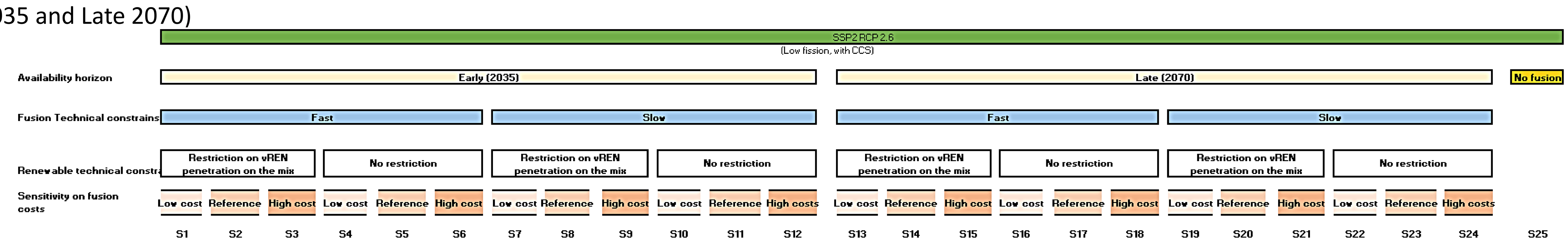
The EUROfusion TIMES Model (ETM) has a global resolution distributed in 17 regions. ETM is a technology-rich model consisting of a large techno-economic database with more than one thousand energy technologies for all the demand (residential, commercial, transport, industry and agriculture) and supply (power and heat generation and upstream) sectors.

Two alternative fusion plants are considered based on the work done in EUROfusion (PPCS and DEMO): basic power plant and advanced power plant**. The costs currently used in ETM are desired targets rather than estimates** [2].

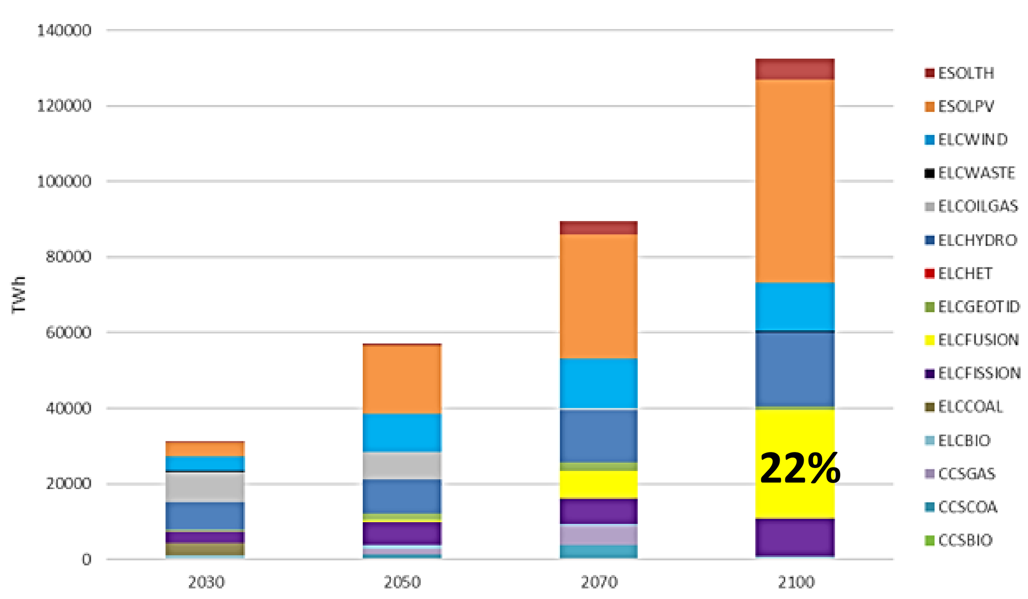
METHODOLOGICAL APPROACH: SCENARIO TREE

The root scenario is aligned with the IPCC SSP2 (middle of the road) climate change scenario. We have selected the 2.6 RCP. Then, we distinguish alternatives for:

- **Fusion availability horizon** (Early 2035 and Late 2070)
- **Fusion deployment rate** (Fast and Slow) based on Tritium availability for start-up
- **Technical restriction on variable renewable electricity deployment** (restriction on vREN penetration and No restriction)
- **Sensitivity on fusion costs** (Low (*0.6), Reference and High (*1.2))



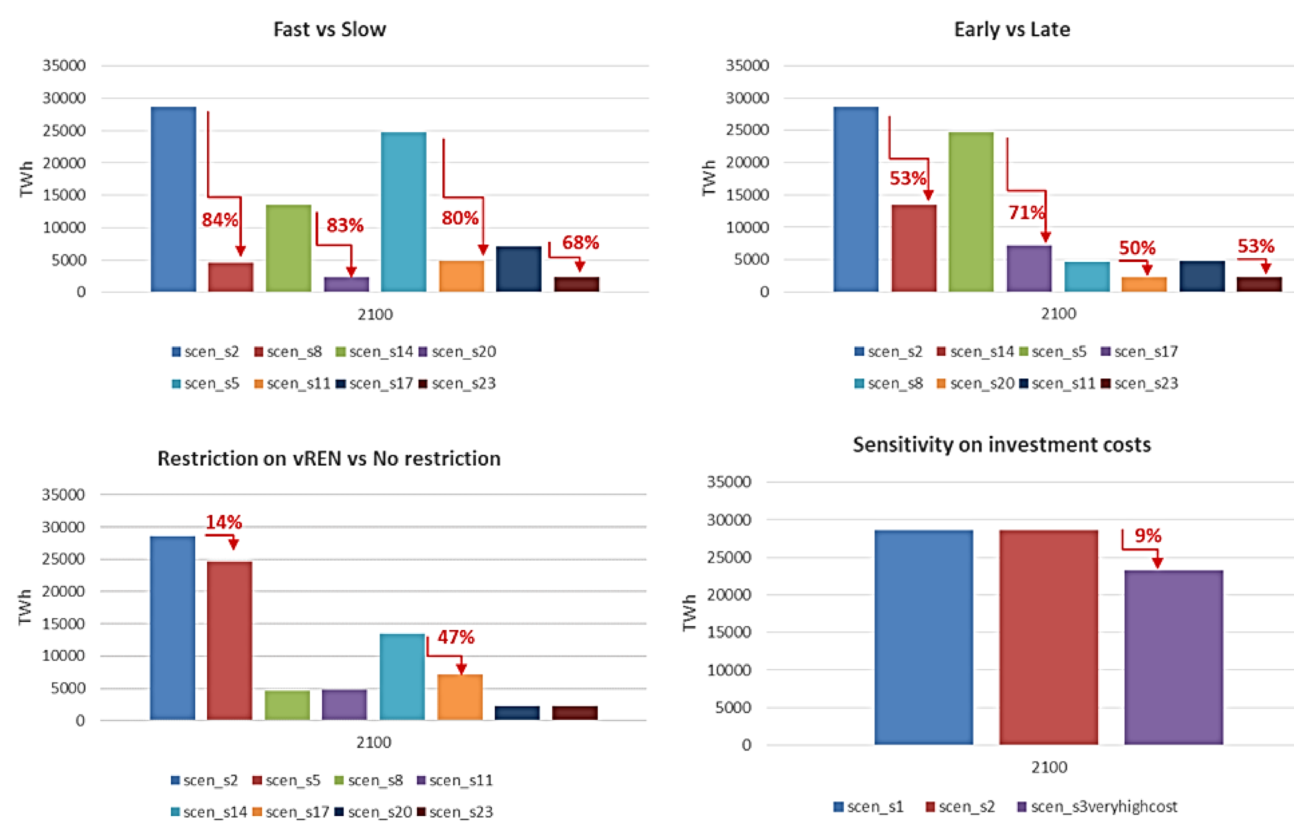
RESULTS: GLOBAL ELECTRICITY MIX (S2)



In all scenarios, the system evolves towards one dominated by renewables, especially solar PV and to a lesser extent wind, and nuclear technologies, including fission and fusion.

The maximum fusion penetration occurs in scenario S02 (early availability and fast diffusion of the fusion technology with restriction on vRES penetration) where it represents 22% of total electricity production in 2100. The minimum deployment of the technology occurs in scenario S23 (late availability and slow diffusion of the fusion technology with no restriction on vRES penetration).

RESULTS: SENSITIVITY ANALYSIS

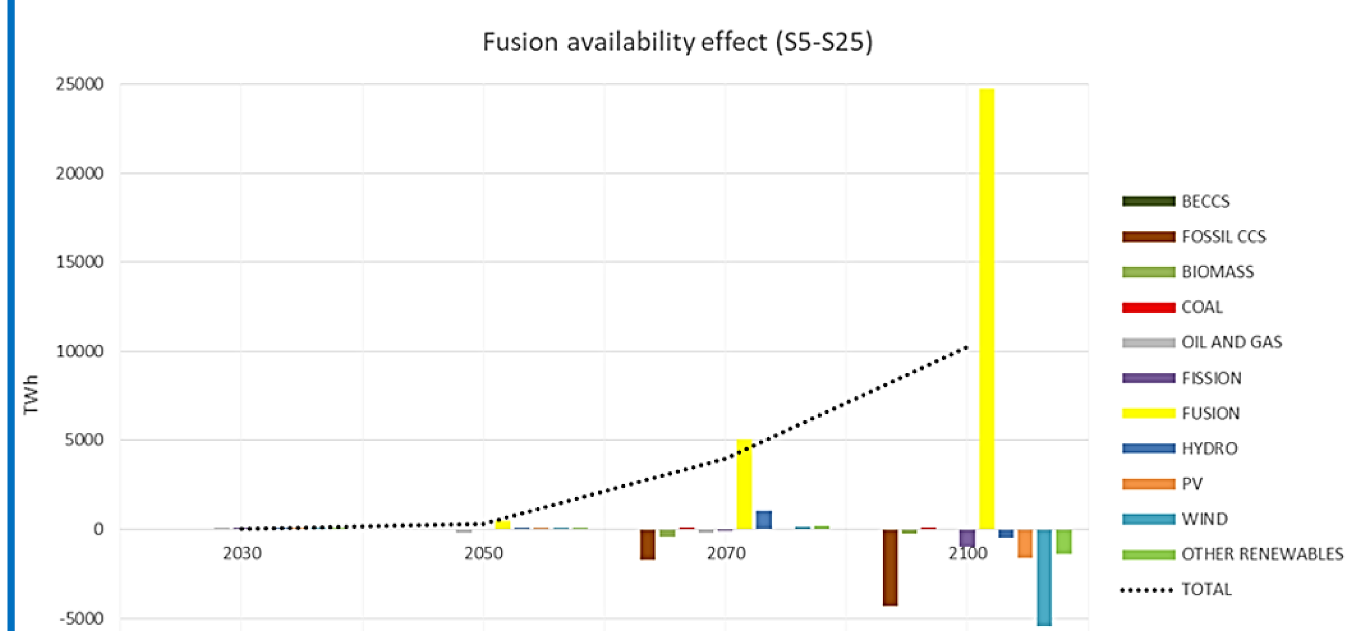


In all scenarios, fusion enters the system shortly after it becomes commercially available. Still, its role is susceptible to the factors analysed, particularly the speed of diffusion (fast or slow) and the time when it is expected to be available (early or late).

Technical constraints on the share of variable renewables (solar PV and wind) seem to play a role only in the scenarios with fast diffusion of fusion technology.

On the contrary, the investment cost of the fusion reactor is not a relevant factor for the expected share of the technology at the end of the century. Only a very strong increase in capital costs (*1.75) will reduce the penetration of fusion by 9%

RESULTS: FUSION AVAILABILITY EFFECT

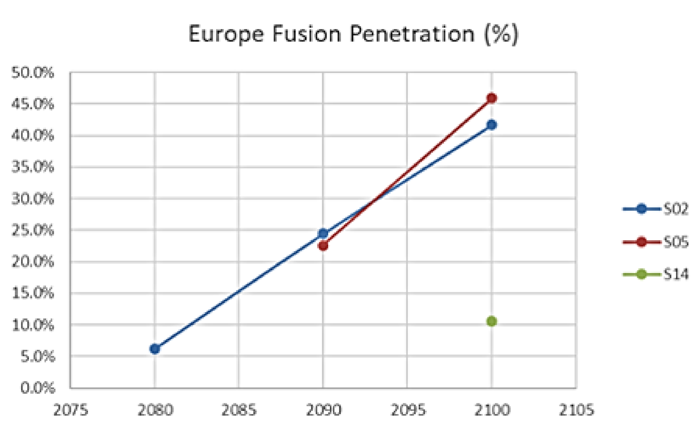


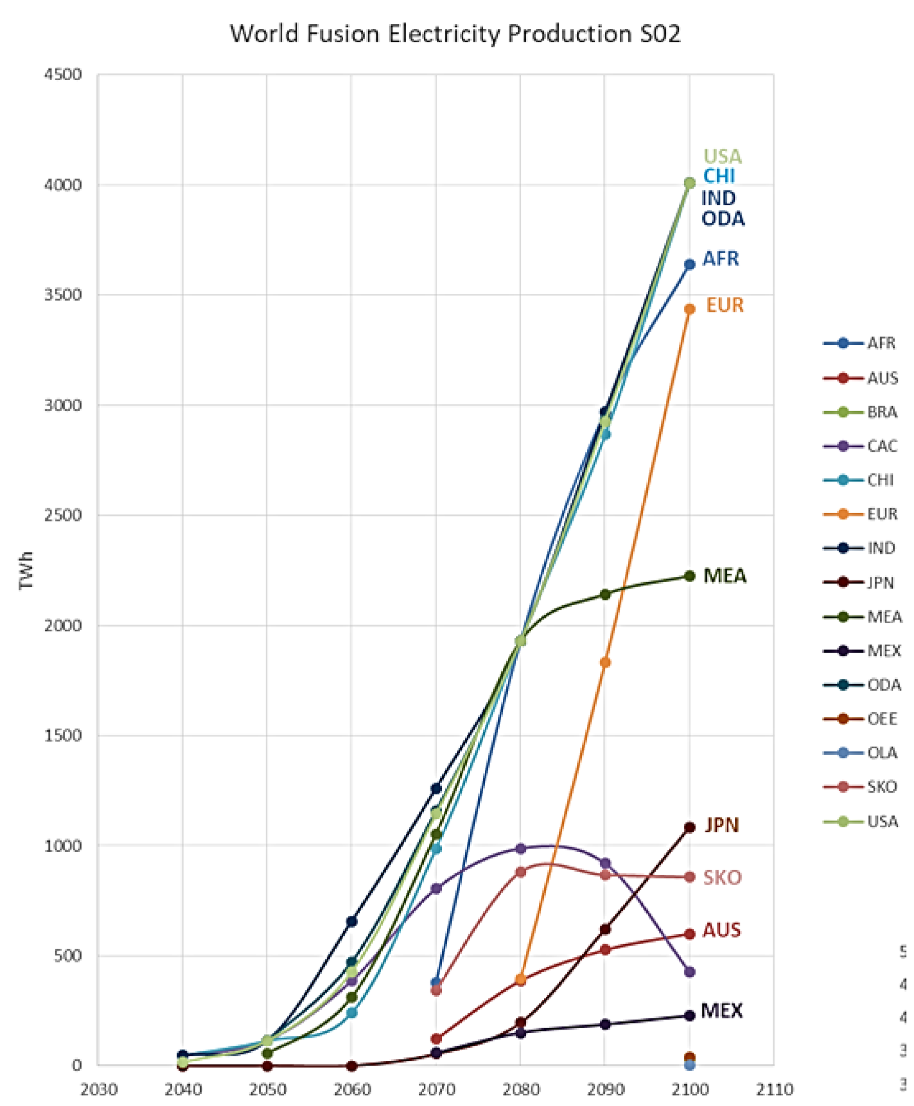
The availability of fusion allows for higher electricity production and thus higher electrification of the energy system. The technologies that are somehow displaced by fusion penetration, according to these results, are first fossil CCS technologies and then some renewables such as wind, solar PV and other renewables.

RESULTS: REGIONAL DEPLOYMENT

Some regions will start using fusion technology as soon as it becomes available. This is the case for China, India and the USA. Other regions start using fusion in 2070, such as Africa, Australia, the Middle East, Mexico, South Korea and other countries in Asia.

Europe starts to use fusion in 2080, waiting for the advanced technology to become available. In S2 and S5 the penetration of fusion is quite significant, reaching 42% and 46% respectively.





CONCLUSIONS AND TAKEAWAY MESSAGES

- **The EUROfusion Times Model (ETM) has been tested against a scenario matrix of 25 scenarios that include variations in parameters that were in principle capable of affecting fusion technology penetration.**
- **In all the tested scenarios, fusion enters the system shortly after it becomes commercially available, but its role is very sensitive to the factors analysed.**
- **The rate of diffusion, linked to the availability of tritium, appears to be the most sensitive factor, followed by the time of availability.**
- **Technical constraints on the share of variable renewables (solar PV and wind) seem to play a role only in the scenarios with fast diffusion of fusion technology.**
- **The investment cost of the fusion reactor is not a relevant factor for the expected share of the technology at the end of the century.**
- **The availability of fusion allows for higher electricity production and thus higher electrification of the energy system.**
- **In the case of Europe, fusion technology penetrates only in scenarios of fast fusion diffusion reaching a share higher than 40% in two of the modelled scenarios. In these scenarios, fusion penetration starts in 2080 and then grows exponentially until the end of the century.**

References: [1] Loulou et al., 2005. Documentation for the TIMES Model - PART I 1–78. [2] Cabal et al., (2017). Fusion power in a future low carbon global electricity system. Energy Strategy Reviews, 15, 1-8