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Future prospects for nuclear power in France

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HIGHLIGHTS

- Applies a bottom-up energy system optimization model to define future energy choices.
- Derive scenarios to explore different combination of nuclear policy and emission target up to 2050.
- Underline the resulting challenges in term of power capacity renewal rate and flexibility.

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ABSTRACT

Taking different nuclear policy options from a French perspective, we look at the issues that we were able to pinpoint thanks to the TIMES-FR model. The technico-economic analysis supported by the TIMES-FR model brings robust lessons, whichever technological options are selected:

- The cliff effect puts the French system "up against the wall": sustained investments must be made to renew electricity production facilities coming to the end of their lives.
- This situation opens up opportunities to all industrial channels, with the main challenge being to sustain an ambitious pace of constructing new capacities and answering specific questions for each of them, such as acceptability and reliability.
- In parallel, the current paradigm of increasing electricity consumption is likely to be challenged over the coming decades if environmental issues are still part of public policy.
- These factors make it possible to consider that the question of political options in terms of long-term energy cannot be restricted to a technological choice and must go beyond pro- or anti-nuclear lobbying.

This contribution, which is mainly based on a technical thought process, should fit into the wider framework of a debate on society and behavior choices. The issue of the electricity user will be unavoidable.

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1. Introduction

This paper explores the challenges raised by future alternative nuclear power policy in the unique context of today's French power mix. The French electricity sector relies on the highest share of nuclear energy in the world: in France, 76% of electricity supply comes from nuclear power plants (see chart Fig. 1), which makes the French electricity generation structure unique. Hydropower is the second largest contributor to electricity generation, at 11%. Fossil power plants (half coal, half gas and oil) account for a mere 9% and are mainly used for peak and system operation.

Nuclear power replacement strategy will be a major issue in the future, as we can see by looking at the lifespan of the residual capacities from 2000 to 2050: Fig. 2 provides an aggregate view of the residual capacity evolution used for the model.

As the power sector is characterized by low emission levels, the future electricity generation mix and the share of nuclear energy constitute major issues. This future mix for electricity generation has to be assessed in a context involving numerous environmental constraints reinforced by the Fukushima triple disaster. Indeed, several countries already to envisaged to decrease their share of nuclear (see in Fig. 3 the share of nuclear power output for a set of countries). To understand the specific position of France, it is worthy to review some of these low nuclear transition scenarios.

The most striking case is the nuclear transition under emergency conditions in Japan. Before the Fukushima accident, 29% of

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Nomenclature

ETSAP	Energy Technology Systems Analysis Programme
IEA	International Energy Agency
TIMES	The Integrated MARKAL-EFOM System
TIMES-FR	TIMES France
TSO	Transmission System Operator
RTE	The French TSO
NEEDS	New Energy Externalities Developments for Sustainability, FP6 European project.
RES2020	Monitoring and Evaluating the RES Directives implementation in EU-27 and policy recommendations, Intelligent Energy for Europe program.
WEO	World Energy Outlook

Japan's electricity generation was supplied by nuclear power making the country the third largest nuclear power producer worldwide behind the United States and France. By the end of 2013, all plants had been shut down. The components of this emergency response [2] included conservation measures, reactivating closed thermal plants and massive replacement by natural gas. Portugal-Pereira and Esteban [3] analyzes the implications of four-long term scenarios by 2030 covering different nuclear and renewable strategies and stresses the potentially adverse impacts of a zero nuclear scenario on imported fossil fuel dependency and GHG emissions. Fukushima's reactor meltdown also triggered a strong shift in Germany's nuclear policy, putting a stop to discussions on a possible lifetime extension and reactivating the anticipated phase-out plan decided in 2000. While nuclear accounted for 28% of electricity production in 2010, a complete phase-out is planned for 2022. Bruninx et al. [4] review this process and analyze the 2022 mix. This study focuses in particular on the preferential replacement by coal and lignite and stability issues both in terms of congestion on the German transmission grid and import/export conditions. Schmid et al. [5] analyzes 10 long-term scenarios that combine a nuclear phase-out by 2020 with 2050 mitigation objectives. They highlight a rapid growth in solar and offshore wind plants and discuss the potential shift from net exporter to massive electricity importer in most scenarios.

Belgium has one of the highest shares of nuclear power in the world and is also phasing out nuclear by 2025. The Belgian process has been similar to the German one, with the end of lifetime extension discussions and the reactivation of a 2003 phase-out plan. Kunsch and Friesewinkel [6] propose a 2050 view of alternative scenarios. They find CO_2 emissions increase by +30% to +312%, with only nuclear reactivation or a massive imports leading to a decrease. They consider imports from France with costs similar to domestic nuclear power production based on today's sufficient cross-border transport capacity.

In comparison, the UK is a European exception, with strong government support for nuclear power as a key element of its future energy transition. [7] provides a complete overview of today's actors and an ongoing discussion on creating 15.6 GW of new capacity in the UK. For the long term, [8,9] have evaluated transition pathways for the UK's electricity sector to move towards an almost decarbonized system in 2050. Using existing scenarios [10] and [11] provide an LCA and a water assessment of electricity transition in the UK by 2050. The authors converge in their findings or assumptions of significant nuclear growth, with the exception of one scenario that assumes a 7.5% decrease in electricity demand by 2050 compared to 2009 along with a massive development of CHP and wind.

Finally, we consider the US case, in which the expansion of nuclear power is currently threatened by market-based difficulties associated with the abundance of cheap unconventional gas. Byers [12] describes the decommissioning of existing plants new reactors and a regulatory environment. Sarica et al. [13,14] propose differentiated 2050 electric system scenarios for various mitigation strategies. Their results consistently point to the decisive role of natural gas in shaping the future US electricity mix and creating the stability to reduce contribution of nuclear power.

For France, the long-term environment target, specified in an energy orientation law dated March 2005, is to quarter total GHG emissions by 2050 with respect to 2000 levels. Beyond 2012, the main goal of the European Union's energy package for climate protection has been stated as a firm independent commitment to achieving a reduction of at least 20% in GHG emissions by 2020 compared to their level in 1990.

In this study we propose to assess, at French level, the issues regarding different nuclear policy options pinpointed using the TIMES-FR model which belongs to a category of technological models (bottom-up). Thus, we propose to explore the challenges involved by future alternative nuclear power policy in the unique context of today's French power mix. Section two defines the statements of the TIMES family of models as bottom-up partial equilibrium models and how they may guide energy strategy, namely in the electricity sector and with regard to nuclear power. In section three, we describe the hypothesis adopted for the assessment exercise in order to model the French electricity sector, using a

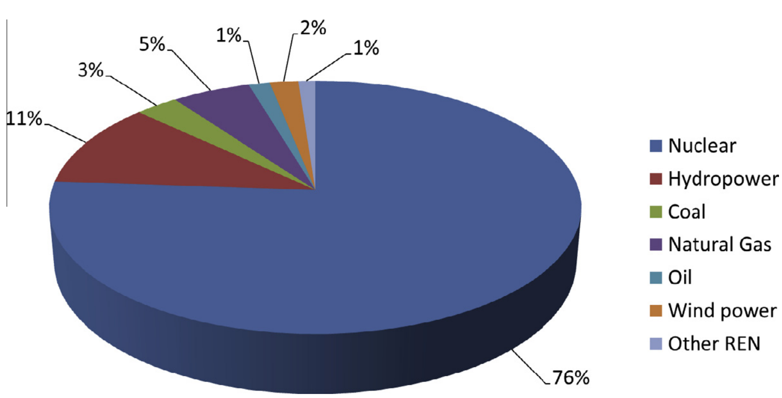

Fig. 1. Breakdown of electricity generation.

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