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Critical technologies for sustainable energy development in Brazil: technological foresight based on scenario modelling

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A B S T R A C T

An important task for energy innovation is to identify opportunities using well-established criteria and methods. This study develops a methodology to identify critical technology groups for a sustainable low-carbon energy system and evaluates innovation opportunities within those technology groups in Brazil. This method integrates a mixed-integer optimization model (MESSAGE) with more than 300 mapped processes with the technological foresight exercise, creating a novel approach to the innovative technology selection criteria. Findings for Brazil show that fossil fuels will still play an important role, but renewables, like wind energy and biomass together, might reach more than 30% of total electric generation. Moreover, carbon dioxide emissions reductions may exceed 50% in high tax scenarios. The most relevant innovation potential for Brazil occurs in the biomass, wind sectors and in carbon capture in ethanol production. The study points that long-term future is uncertain and decision to invest in innovation is risky and should account for the stage of technological and knowledge development in different countries. The strategy for innovation might, thus, include international partnerships that join efforts and a national development strategy focussing on Brazilian particularities.

1. Introduction

Innovation in the energy sector is a key strategy to foster the transition towards a less-fossil-fuel-dependent society (Fouquet and Pearson, 2012). Nonetheless, several barriers challenge this transition. For instance, Narayanamurti et al. (2011) list specific factors that hamper the fast adoption of disruptive technologies in the energy sector, especially in the supply side: high capital costs and slow capital return; competitive advantage; limited development leaps; and reliability.

The vast range of energy technologies currently available implies that there is no single solution to enable the demonstration and commercialization of new technologies (Jänicke, 2012). Nevertheless, the dominant barriers to mainstreaming advanced energy technologies have been widely reviewed in the literature. For instance, Suzuki (2014) suggests that main barriers for diffusion of technological innovation in developing countries are classified as generic barriers and technology-specific barriers. Further Moors et al. (2005) identify the high costs of investment, the high risk involved in committing capital to pilot technologies, and the intertwinement of current production systems as main barriers for innovation, especially in the mining sector. Also Montalvo (2008) classifies the main factors affecting diffusion of low-carbon technologies as governmental policy, economic markets, local communities and social pressure, attitudes and social values, technological opportunities and technological and organizational capabilities. Main barriers are, therefore, summarized as follows:

- Technology risk: possibly the most obvious barrier, leading to the need for development of projects and actions to demonstrate new technologies, in order to confirm predictions of technical performance and operating costs.
- Access to capital for large-scale investment: this barrier is particularly important for technologies such as nuclear, advanced coal and biofuels, but also applicable for manufacturing of solar panels and energy storage devices.

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List of acronyms

ASU	air separation unit
BIG	biomass integrated gasification
bioCCS	biological carbon capture and storage
CCGT	combined cycle gas turbine
CCS	carbon capture and storage
CO_2	carbon dioxide
CSP	concentrated solar power
DNI	direct normal irradiation
FT	Fischer–Tropsch
GCC	global climate change
GHG	greenhouse gas
GTL	gas-to-liquids
HHSS	household and services
ICE	internal combustion engine
NG	natural gas
O&M	operation and maintenance
PP	power plant
PSH	pumped-storage hydroelectricity
PV	photovoltaic
R&D	research and development
TES	thermal energy storage
USW	urban solid waste

- Policy and regulatory uncertainty: many innovative technologies require revision of the legal framework, including the provision of incentives.

Within this context, the first major task for energy innovation is to identify opportunities using well-established criteria and methods (technological foresight). Hence, this paper aims at identifying opportunities for innovation in critical sustainable energy technological blocks for the Brazilian energy sector in order to recommend strategies for promoting a sustainable energy mix through 2050. As of today, Brazil has diverse energy matrix (Fig. 1) with vast renewable resources and, in this sense, it is considered that it can take advantage of this privileged position in order to reach a sustainable economy. To this end, a methodological framework was developed to rank technologies and their critical points based on Jennings and Treco (2013), according to Brazil's energy needs and the country's potential for innovation using a linear programming optimization model.

Market demand pull policy instruments and regulatory push[1] are main drivers for diffusion of low carbon innovations (Horbach et al., 2012). Innovation criteria have been then identified based on these. These criteria emphasize the need for enhancing Brazil's energy security of supply and environmental protection. Thus, this study does not intend to evaluate Brazil's strategic and competitive industrial advantages nor political strategies and instrument mechanisms to foster innovation diffusion, as described by Perc (2012), but rather to identify opportunities for innovation in energy to tackle the explicit needs of the final energy demand of the Brazilian society while also promoting a sustainable future.

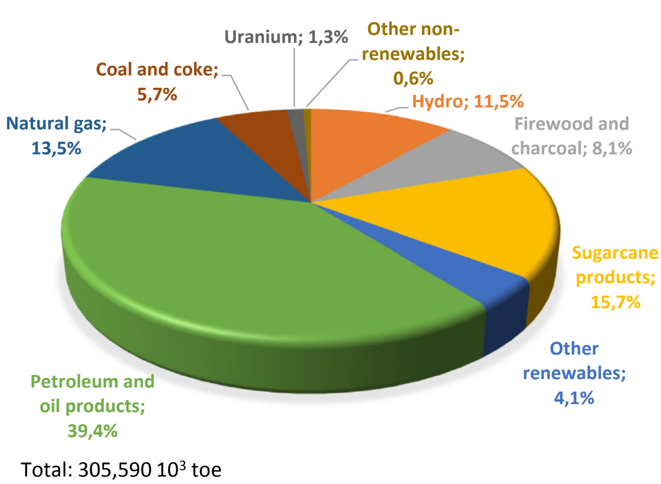

Fig. 1. Brazil's domestic energy supply in 2014 (EPE, 2015).

This paper includes five sections: following the introduction, Section 2 describes the applied method to identify the critical blocks of innovative technologies. Then, in Section 3 Brazil's energy resources potential and the main technologies to be focused in the innovation policy are identified. In Section 4, the critical aspects of each technology and their economic viability are discussed, followed by conclusions.

2. Methods

The methodological procedure developed applied four sequential criteria for identifying critical technologies that would address the challenge of providing energy to the Brazilian society at low private and social costs:

(i) The remaining natural resources potential: technology should benefit from a natural resource endogenous to Brazil.
(ii) Energy security: the technology should be selected as a cost effective option for providing energy, according to different storylines that can restrict the set of options to be selected or increase the cost of some alternatives;
(iii) Environmental sustainability: in the long term, the technology should be part of a strategy to mitigate greenhouse gas emissions in the country.
(iv) Innovation potential: the technology should be developed in Brazil. It has to meet specific features of the country's conditions and/or it must remain in the immature part of the technological innovation and diffusion cycle.

Henceforth, the methodological procedure followed eight steps based on the four criteria presented (Fig. 2): 1. Quantification of the primary energy resources' potential; 2. Updating the linear programming model MESSAGE-Brazil with adequate structures of energy conversion processes and energy flows; 3. Formulation of different storylines to be run in MESSAGE-Brazil; 4 and 5. Simulation of the storylines in MESSAGE-Brazil, version 1.3, in order to find the least-cost supply option mix for each case run; 6.

[1] This is linked to what was previously stated about regulatory uncertainty: regulatory push should, in fact, reduce uncertainty by establishing an adequate regulatory framework to promote innovation.