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Production and use of electrolytic hydrogen in Ecuador towards a low carbon economy

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ABSTRACT

This paper presents a pre-feasibility study of producing and using electrolytic hydrogen in Ecuador as part of a strategy towards a low carbon economy. Hydrogen could be produced using hydropower either alone or combined with other renewable energy sources. For this study, we analyzed two scenarios of energy availability based on data from the largest hydroelectric power plant in the country. The first scenario assumes that an amount of water equivalent to 30% of that spilled in 2011 could be used to generate additional electricity. Thus, an additional amount of energy equivalent to 5% of the energy produced in 2011 could be available. The second scenario doubles this amount of energy. Economic analysis showed that to obtain low-cost hydrogen (3.00 US$/kg) it is necessary to operate the electrolysis plants 24 h/day, using low-cost electricity (30 US$/MWh). A continuous supply of energy could be possible when new hydroelectric utilities start operating or by integrating hydropower with solar and wind. Three possibilities for using hydrogen are discussed: 1) production of ammonia as a raw material for nitrogenous fertilizers, 2) hydro-treating heavy oils and bio-oils in oil refineries, and 3) as an energy storage medium to offset natural instability and unpredictability of renewables.

1. Introduction

Approximately 53% and 47% of the electricity generated in Ecuador in 2012 relied on hydropower and thermal power (using mostly oil-derived fuels), respectively [1]. Hydropower use is expected to expand in coming years since new hydroelectric utilities, supported by the "Policy to change the matrix of electricity generation" plan, are under construction. This plan, conceived in 2008, establishes the guidelines towards a higher proportion of hydroelectricity, solar, and wind in electricity generation by taking advantage of the country's renewable energy sources potential. The usable potential of hydropower is 21.5 GW [2]; yearly average insolation higher than 4.5 kWh/m^2/day [3] and yearly average wind speeds of 6 m/s at 40 m height [4] have been reported. As a consequence, in 2016, hydropower and wind will constitute approximately 93.5% and 0.6% of the total electricity generation [2]. Two factors that drive Ecuador to new systems for producing electricity are the necessity of reducing the dependence on oil-derived fuels for power generation and the imminent decrease of its oil reserves [2,5]. Using oil and oil-derived fuels (in part imported) is onerous for the country's economy and releases high amounts of pollutants [2]. However, as Ecuador aims to increase the participation of renewables in its energy matrix towards the implementation of a low carbon economy, it is necessary to develop strategies for integrating the operation of renewable energy facilities, better utilization of power plants, and using electricity as an input for processes that currently demand oil sources. Using renewable sources is an important factor for sustainable energy production according to the low carbon economy concept [6].

The operation of the largest hydroelectric utility currently in operation in Ecuador, Hidropaute (Fig. 1), has been influenced by significant seasonal fluctuations of water inflow; thus, part of the water stored in its reservoir dam (useful capacity of 100 million m^3) has frequently been spilled. In the period 1999–2008 an average of

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Fig. 1. Location of Hidropaute and cities mentioned in this assessment.

21% of the water fed to the dam was spilled [7]. This value was 18% in 2011 [8] (Fig. 2). Hidropaute's operational characteristic could change in the future as management of Mazar, a new upstream dam (460 million m^3 capacity), changes. The Mazar dam enables water storage, power generation (170 MW of installed capacity), and regulation of water flow with seasonal rains. But it is expected that water will still be spilled from Hidropaute. In addition, some new hydropower utilities under construction include dams that could potentially have an operational feature similar to that of Hidropaute. Therefore, options for taking advantage of the turbinable spilled water have been sought and production of electrolytic hydrogen is a promising alternative. Electrolysis of water to obtain hydrogen using renewable energy (also known as renewable electrolysis [9]) has been mentioned as a pathway to produce clean energy by means of fuel-cells or combustion engines during peak electricity demand.

Despite studies analyzing the possibility of producing electrolytic hydrogen from hydroelectricity in different countries [10–14], few have evaluated this possibility in Latin America [15–19] and none has been conducted in Ecuador. The objective of this paper is to identify options to produce and use hydrogen in Ecuador and to provide the baseline for further discussion about options for integrating renewables with the concepts of low carbon economy and smart grid systems. Although the paper is based on data of spilled water in the Hidropaute plant, expansion of the energy generation matrix (by including eolic and solar), could open new alternatives for producing hydrogen.

1.1. The Hidropaute power plant

The Hidropaute hydroelectric utility (also known as Paute-Molino) has an installed capacity of 1100 MW. The utility's electricity generation was 6279.5 GWh in 2008 and 5865.3 GWh in 2011, representing approximately 32% of the electricity produced in the country. Factors of utilization were 79.7% in 2008 and 75.7% in 2011, whereas capacity factors were 66.6% in 2008 and 61.6% in 2011 [8]. The average volume of feeding water into the dam from

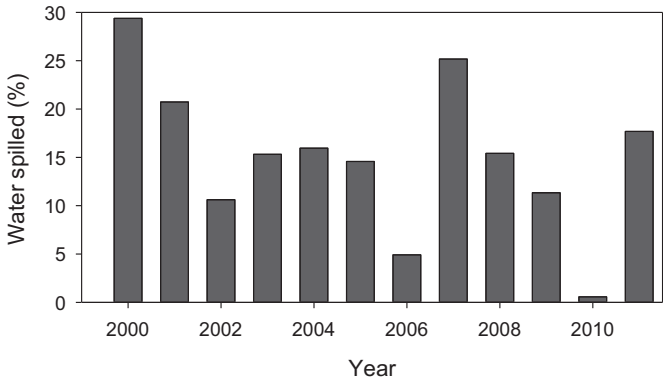

Fig. 2. Percentage of water spilled from the Hidropaute's dam in the period 2000–2011 [7,8]. (Note: The reason for low spilled water in 2010 is because the Mazar dam was filled that year).

1996 to 2008 was approximately 25.10^9 m^3/year, from which a significant part has been released through spillways (Fig. 2). In the Eastern Ecuadorian Andes Mountains, the months from March to July are typically, characterized by abundant rains and, as a result, water flow is high. The months from August to January are drier and characterized by high wind and solar energy potential. However, a large amount of the electricity generated in the country from August to January relies on oil and oil-derived fuels.

Another important operational feature of Hidropaute is the variation of the hourly operation, resulting, in addition to changes of flowing water, from the operation policies given by the CENACE (National Center of Control of Energy), the institution in charge of organizing the operation schedules of generation plants [5]. Integration of hydropower with wind and solar energy for generating electricity could be an alternative to avoid burning fossil fuels for power generation and to incorporate hydrogen in the Ecuadorian energy matrix. For generation of renewable energy intended for hydrogen production, adoption of smart grid management will be necessary besides the integration of renewable sources. The smart grid concept has been recognized as an important tool for the management of the natural intermittency of renewable energy sources [20], which could be critical for an optimum utilization of renewable energy sources in Ecuador.

2. Approach

2.1. Definition of possible uses of hydrogen

To identify possible uses of hydrogen in Ecuador we observed the necessity of substituting oil and oil-derived fuels by renewable sources for producing goods and raw materials, or for generating energy. Since Ecuador does not produce nitrogenous fertilizers (for which ammonia is a basic raw material), there exists an opportunity for using electrolytic hydrogen for ammonia production. Similarly, we have observed that hydrogen is required for oil refining and that currently this hydrogen is obtained from petroleum. This potential availability of domestic consumers of hydrogen was determinant for the selection of alternatives for using electrolytic hydrogen. For the selection of the possible places to produce hydrogen, we took into account the advantage of transporting electricity through the national grid system instead of transporting hydrogen. This is a realistic option in Ecuador because most generation companies, as well as all transmission grids and electricity distribution companies are state owned, avoiding tolls for energy transport through the grids and aiding in decision-making.