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Assessment of the potential for hydrogen production from renewable resources in Argentina

A. Sigal [a], E.P.M. Leiva [b], C.R. Rodríguez [c,*]

[a] Facultad de Matemática, Astronomía y Física, Universidad Nacional de Córdoba, Ciudad Universitaria, 5000 Córdoba, Argentina

[b] INFIQC, Departamento de Matemática y Física, Facultad de Ciencias Químicas, Universidad Nacional de Córdoba, Ciudad Universitaria, 5000 Córdoba, Argentina

[c] Facultad de Ciencias Exactas, Físicas y Naturales, Departamento de Matemática, Universidad Nacional de Córdoba, Ciudad Universitaria, 5000 Córdoba, Argentina

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ABSTRACT

The potential for hydrogen production from three major renewable resources (wind energy, solar energy and biomass) in Argentina is analyzed. This potential for the annual production of wind, solar and biomass hydrogen is represented with maps showing it per unit area in each department. Thus, by using renewable resource databases available in the country, a new Geographic Information System (GIS) of renewable hydrogen is created. In this system, several geographic variables are displayed, in addition to other parameters such as the potential for renewable hydrogen production per department relative to transport fuel consumption of each province or the environmental savings that would imply the production of hydrogen required to add 20% V/V to CNG, with the aim of developing the cleaner alternative CNG + H_2 fuel. In order to take into account areas where energy development would be restricted, land use and environmental exclusions were considered.

Introduction

Hydrogen production from renewable energies is key to marking a gradual transition towards a clean hydrogen economy and a more sustainable and smart energy mix, in the present context of depletion of fossil fuels and their environmental, political and socio-economic impact on our modern societies [1]. The wide availability of wind, solar and biomass resources in Argentina allows envisaging highly favorable future scenarios for the country if the prospects of energy carriers such as hydrogen are properly exploited. Advances in research and in overcoming some obstacles in hydrogen production costs and storage allow that this fuel continues to gain ground in the transportation sector, either in mixtures of 20% by volume with CNG to fuel internal combustion engines adapted for that fuel, or with a purity required by hydrogen fuel cells.

Given the sensitivity of the economic costs of sustainable energy projects to the availability of resources and also given the intermittent and geographically delocalized character of renewable energy resources of the country, data processing and thorough analysis of available information become a critical issue [2].

* *Corresponding author*. Tel.: +54 351 4344982.
E-mail addresses: ramiro246@hotmail.com, ramiro246@gmail.com (C.R. Rodríguez).
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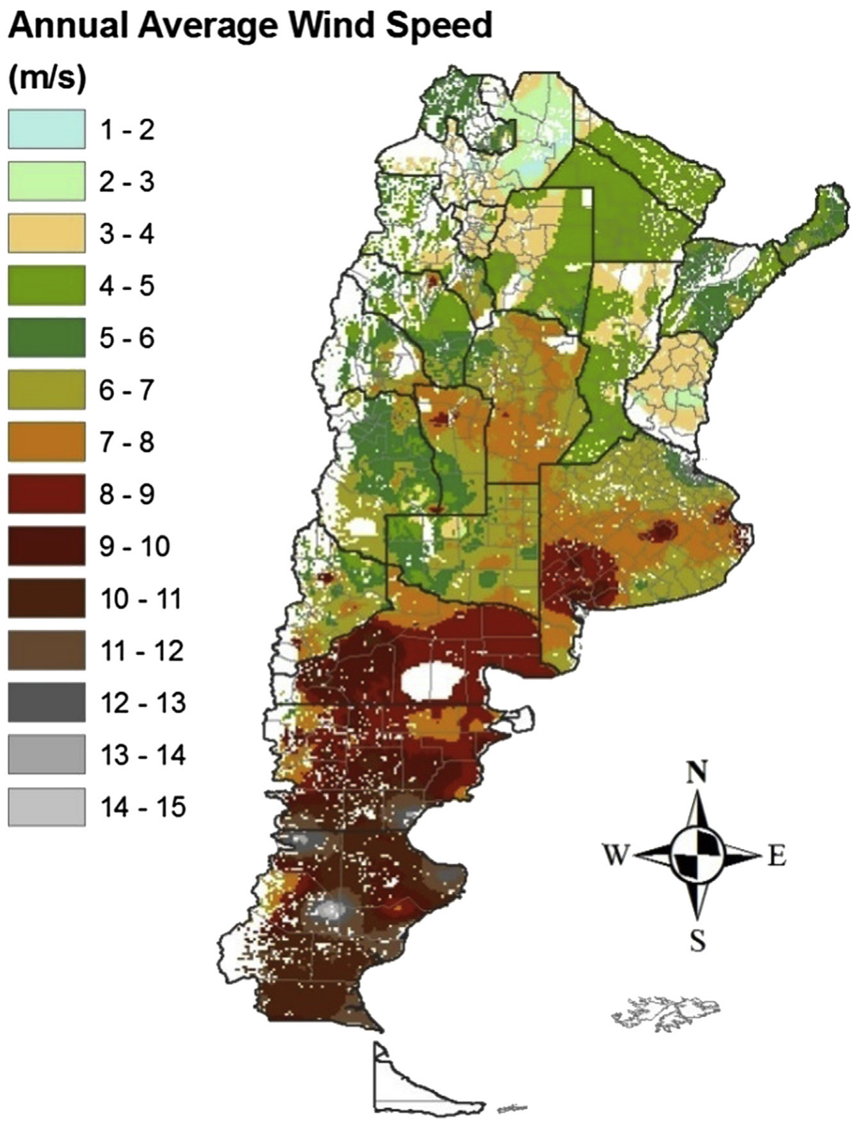

Fig. 1 – Wind speed at 50 m above ground level, at the land suitable for wind sites in Argentina.

In a previous research the potential for producing hydrogen was analyzed from wind resources in the province of Córdoba, Argentina [3]. In this work, the area of analysis is extended to cover the whole country and also to explore two other main renewable energy resources in the country: solar and biomass, in which a geographic information system displaying the most important variables is yielded. A pioneering article on the possibilities of Argentina for developing a hydrogen economy was published by Veziroglu a decade ago [4], and the present work found a strong motivation in that article. We present data of hydrogen production potential from wind, solar and biomass, averaged by department (an administrative local level below a province in terms of importance, or equivalent to a county), in the whole Argentinean map. Maps representing the potential for renewable hydrogen production from wind, solar and biomass are thus drawn. In order to address hydrogen originated from each of these resources, the terms "wind hydrogen", "solar hydrogen" and "biomass hydrogen" respectively, have been coined for this study. However, when these resources are referred to altogether, we use the term "renewable hydrogen" instead. The results for hydrogen generation will then be compared with those of equivalent fossil fuel consumption for transportation in each department. Finally some hypotheses will be put forward to estimate the saving of environmental pollutants in the substitution of fossil fuels by hydrogen. Fuel imports will be considered, as well as the addition of 20% V/V of hydrogen to CNG to develop alternative CNG + H_2 fuel.

Potential for hydrogen production from wind energy

Resource assessment – databases

For the assessment of the wind resource in Argentina, we used the databases of the Eolic Geographic Information System – National Wind Map (SIGE for its acronym in Spanish)

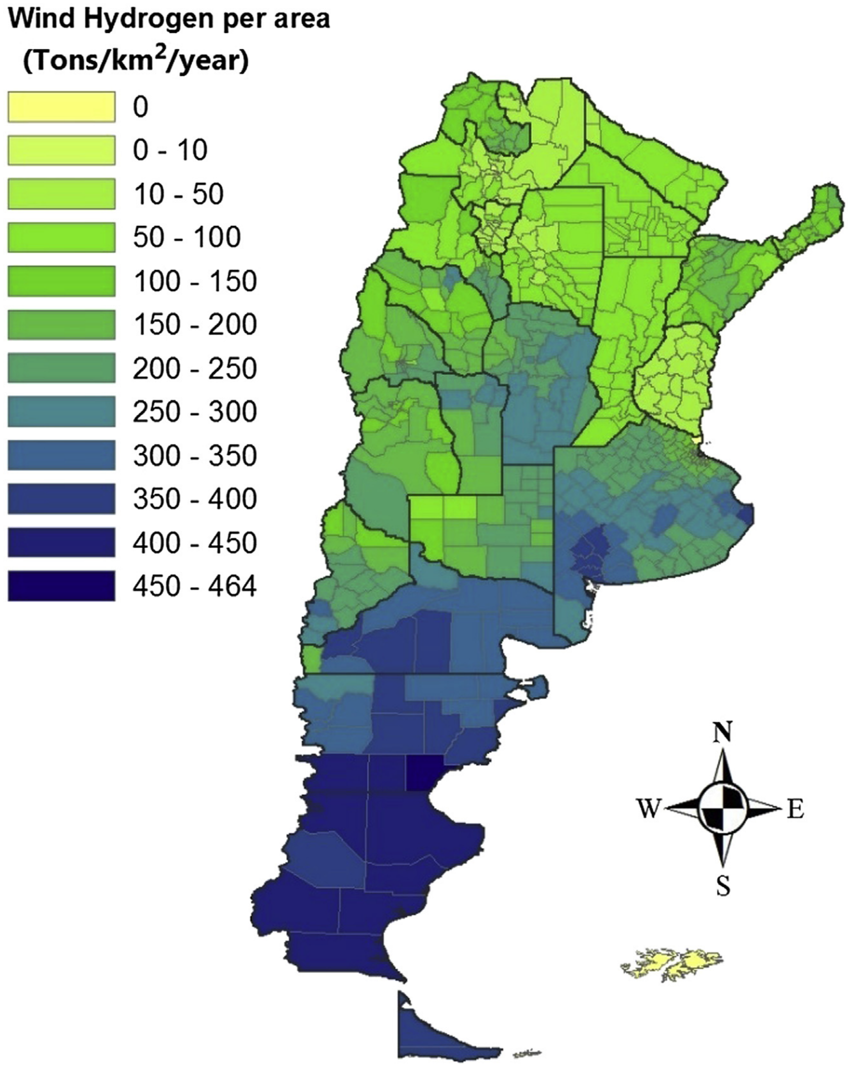

Fig. 2 – Map of the potential for annual production of wind hydrogen, as estimated for each department, in tons/km²/year.

developed by the Ministry of Federal Planning, Investment and Public Services and the Regional Centre for Wind Energy (CREE) of the province of Chubut [5]. This GIS provides information on wind speed, wind roses and power generation potential for different wind turbines anywhere in the country. For its development, data were collected from the Global Digital Terrain Model G-TOPO 30. Roughness calculation analysis was performed by processing images provided by the SAC-Cand Global Land Cover Characterization of the U.S. Geological Survey Satellite. Finally, via a process of reanalyzing data from the last five years on the national meteorological stations, most of which belong to the National Weather Service of Argentina, the wind data shown in Fig. 1 was obtained.

Environmental and land-use exclusions for wind sites included lands with a specific designation such as protected areas, parks, conservation areas, urban areas, water bodies, special landforms and slopes greater than 20%, as calculated on a Digital Elevation Model (DEM) with 90 m resolution. Exclusions are observed in regions without information in Fig. 1.

Methodology to assess hydrogen production from wind

Fig. 2 shows the map of annual potential for hydrogen production from wind, averaged over the area of each department. For the calculations we considered an electrolytic production rate of 52.5 kWh/kg of hydrogen [6]. We have assumed that 5 MW of wind turbines could be installed on each square kilometer. The turbine model considered was from the IMPSA® brand, model IWP-83, of 2.1 MW nominal power (as installed in Wind Park Arauco at Valle de La Puerta, La Rioja). To calculate the wind energy produced by the turbine at a given site, the Weibull distribution corresponding to this site was integrated along with the capacity curve of this wind generator. For all the results that follow, the units of potential for hydrogen production are tons of H_2/km^2/year.

It can be observed that the Patagonian region, the departments of the South Coast, some regions of the center of the province of Buenos Aires and the southern departments of the province of Córdoba have the highest potential for producing hydrogen in the country, with values higher than

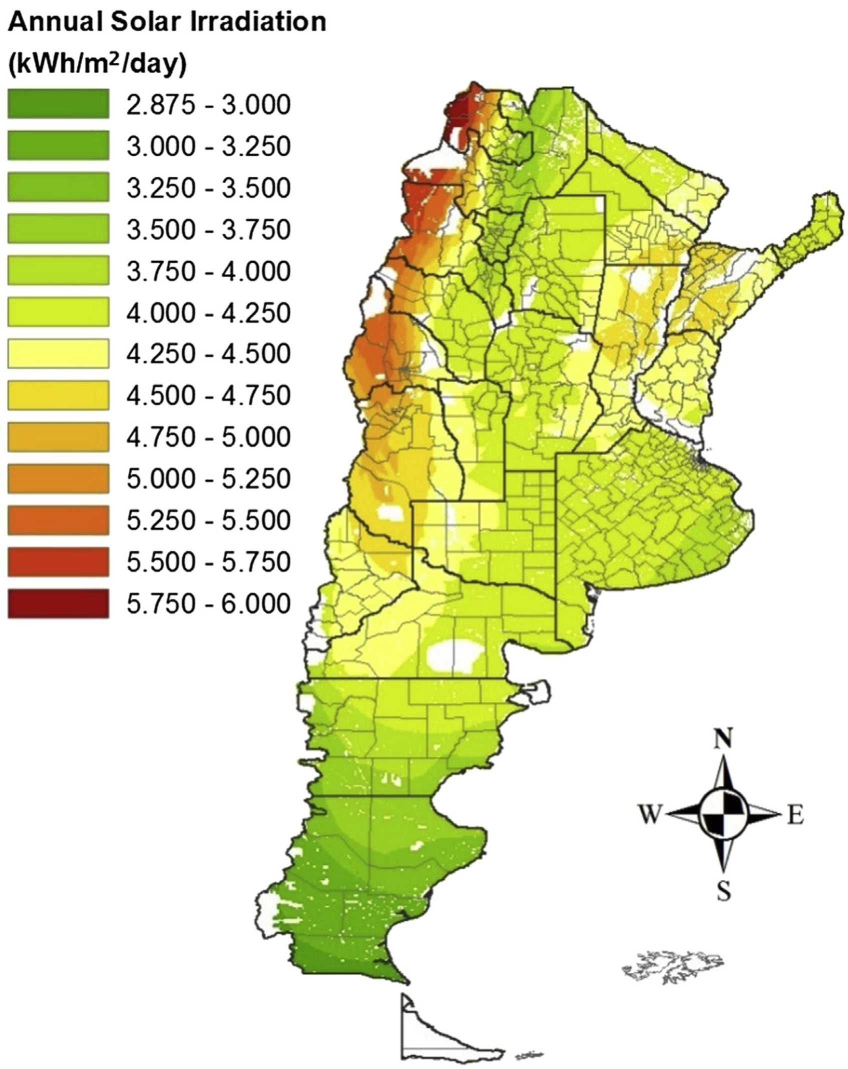

Fig. 3 – Annual average of daily solar radiation expressed in units of kWh/m^2/day.

200 tons/km^2/year. At the south of the province of Chubut, in the department of Escalante, whose provincial capital is Comodoro Rivadavia, we find one of the highest potentials, estimated in 464 tons/km^2/year.

Potential for hydrogen production from solar energy

Resource assessment – databases

In the case of solar databases, we used those given by the Atlas of Solar Energy of Argentina, compiled by Drs. Hugo Grossi Gallegos and Raul Righini at the Department of Basic Sciences, National University of Luján, in 2007 [7]. Databases, structured in heliophany and irradiation layers, contain monthly averages of daily values of global solar radiation on a horizontal plane available in the country up to 1997. This information corresponds to measurements of 28 pyranometric stations and estimations based on local linear correlations of 24 heliographic stations. The *kriging* interpolation model used also employed orographic, phytogeographic and rainfall information provided by satellite approaches. In our work we arranged the annual average of daily solar radiation expressed in kWh/m^2, shown on the map in Fig. 3.

Exclusions for solar projects were applicable to parks and nature reserves, protected areas, water bodies, urban areas and special landforms. The map in Fig. 3 shows solar exclusions observed in empty regions without geographic information.

Methodology to assess the production of solar hydrogen

Fig. 4 shows the map of potential for producing solar hydrogen from electrolysis with the same efficiency as that we considered in the previous wind case, that is, 52.5 kWh/kg of hydrogen. We consider photovoltaic panels of 222 W rated power, with a surface of 1.63 m^2 and an efficiency of 13.6% [8]. We took into account that the effective area occupied by panels was 4.5% of the total land suitable for solar ventures. This value is somewhat larger than the 3% assumed by Mann and

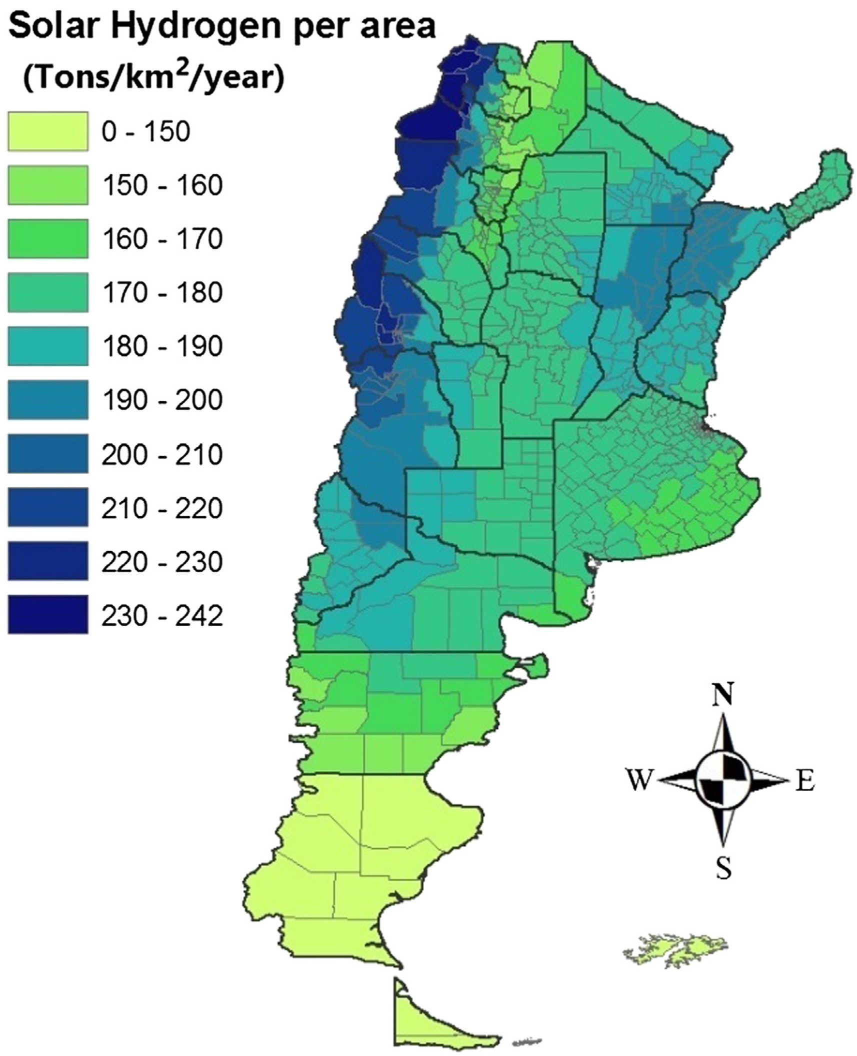

Fig. 4 – Map of the potential for annual production of solar hydrogen, as estimated for each department, in tons/km^2/year.

Milbrandt [2] to make a similar analysis for USA, but considering the lower population density of Argentina (less than half of that of the USA), this appears as a reasonable assumption.

On the left of the map, we can see that all departments of the Andes from the province of Mendoza to the north are highlighted, with a potential production exceeding 180 solar hydrogen tons/km^2/year. On the right side of the map, with a potential between 180 and 200 hydrogen tons/km^2/year, we can find the departments of the Argentine littoral region, north of Entre Rios, center and north of Santa Fe, south of Chaco and whole Corrientes. It should be noted that this high solar potential complements geographically low wind potential in these regions.

Potential for hydrogen production from biomass

Resource assessment – databases

Data used here of available biomass supply for energy production by department were provided by the spatial analysis of biomass production and consumption. The analysis was performed by the FAO (United Nations Food and Agriculture Organization) and an interagency group of professionals in Argentina (Ministry of Energy, Ministry of Environment and Sustainable Development, former Secretary of Agriculture, Livestock, Fisheries and Food, National Institute of Statistics and Census Institute for Climate and Water – INTA). The methodology used is that known as WISDOM (Woodfuel Integrated Supply/Demand Overview Mapping) [9]. To rule out land not allowed for installation of bioenergy plants, we considered the same exclusions as those in the solar projects.

The biomass supply map is shown in Fig. 5.

Methodology to assess hydrogen production from biomass

To calculate the potential for hydrogen production per unit area from the dry biomass supply available in Argentina (BS), a conversion rate of 13 kg BS/kg H_2 was assumed. This value is based on the conversion rate of lignocellulosic plant material to hydrogen via gasification [2]. The results are illustrated in Fig. 6.

Potential for hydrogen production from renewable resources (wind, solar, biomass). Comparison with fuel consumption

Assessment of renewable hydrogen production

In order to illustrate the large capacity of hydrogen production from renewable energy resources in Argentina, we developed the map in Fig. 7, which shows the potential for production of hydrogen from the combination of the three renewable energy resources: wind, solar and biomass. It is known that wind resources are predominant in the country. This fact, combined with the parameters used in the calculation of the previous maps, allows matching areas showing better potential for renewable hydrogen production with those having the highest wind potential. Many departments show a potential of more than 300 tons/km^2/year. This figure indicates that overall the capacity for hydrogen production per unit surface is larger than that reported in the United States [2].

Due to their wind potential, the southern departments with over 500 tons/km^2/year are highlighted. In addition, as already discussed above, Argentina is privileged if we consider the geographical distribution of these three renewable resources, as they geospatially complement each other. Therefore, even the departments with lower potentials at the northern provinces and some of the littoral present an adequate potential for generating over 150 tons/km^2/year.

Fuel consumption for transportation

Fig. 8 shows the consumption of fuels for transportation in the different counties. As there was no availability of consumption data by department, we used the per capita consumption data by province from the Argentine Secretary of Energy [10], together with the population data of each department according to the National Census of Population and Housing 2010 [11]. The transport branches included were: Public Passenger Transport, Freight Transport and Rail Transport. In

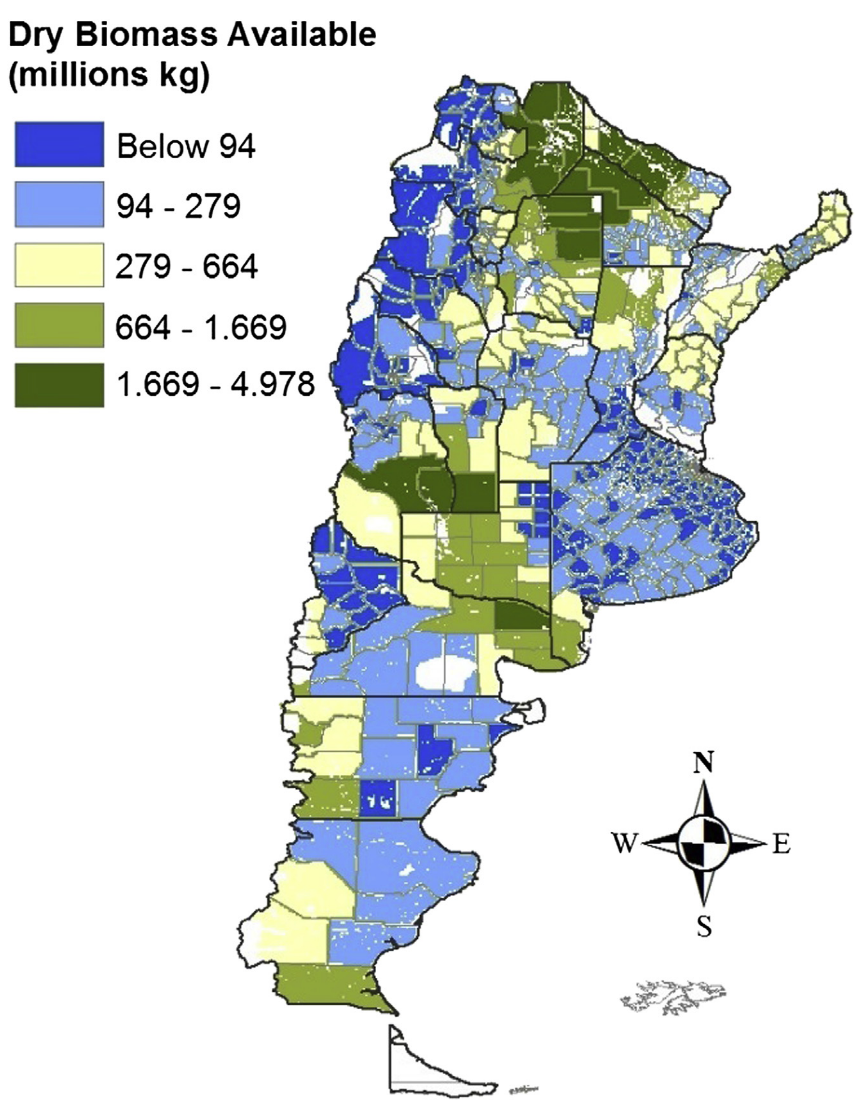

Fig. 5 – Dry biomass available per department in Argentina.

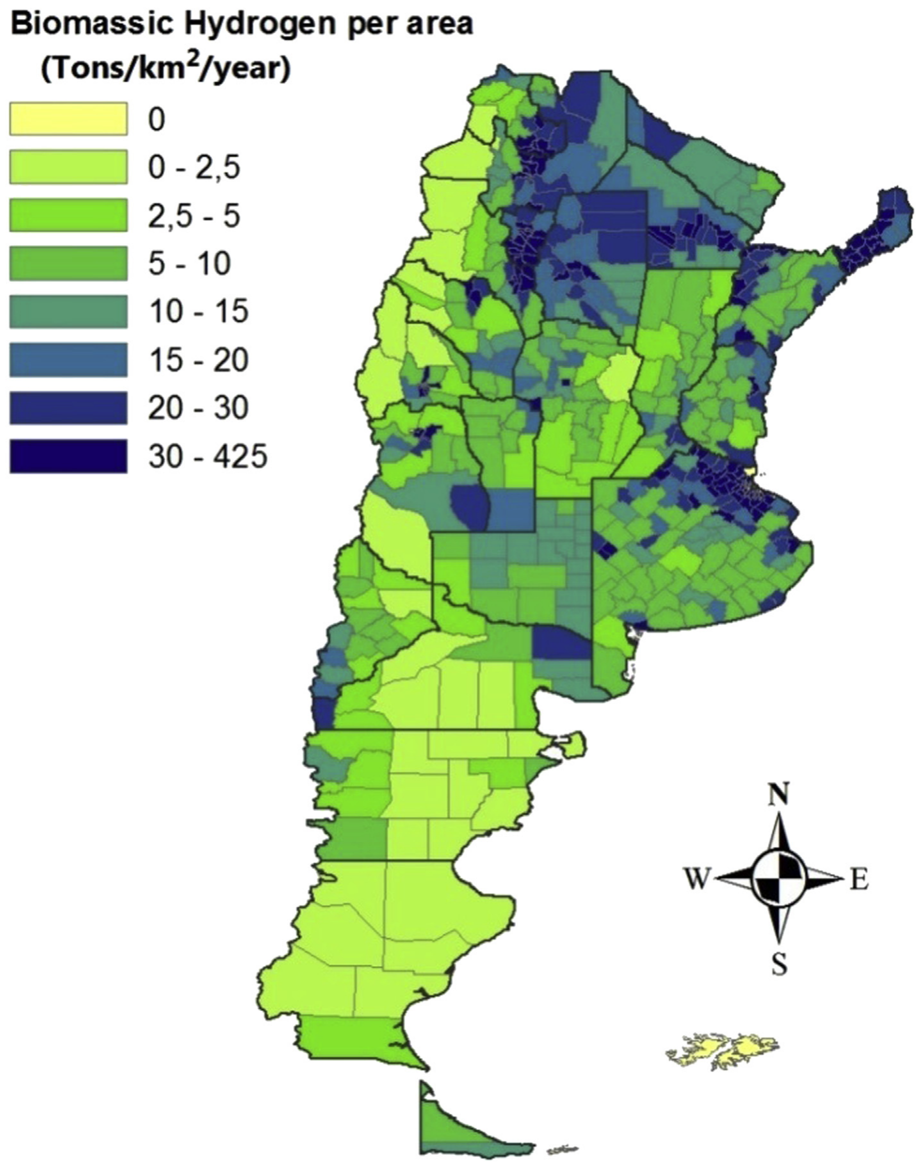

Fig. 6 – Map of the potential for annual production of biomass hydrogen, as estimated for each department, in tons/km^2/year.

addition, we took into account fuels such as Diesel Oil, Fuel Oil, Natural Gas, Diesel Grade 1 (Agrogasoil), Grade 2 (Common) and Grade 3 (Ultra), Natural Gasoline, Naphtha Common, Super and Ultra, Virgin Naphtha and other types of Diesel and Naphtha.

Potential for hydrogen production relative to fuel consumption

In this section we analyze the capacity that each department would have to replace fossil fuel consumption by renewable hydrogen. This was made by dividing the renewable hydrogen production in each department by the total energy consumption of the corresponding province, expressed in hydrogen mass. The results are shown in Fig. 9. As an example, those departments marked in yellow are able to deliver a hydrogen production amounting 11–25 times the hydrogen requirement of the corresponding province for transportation. As expected, given the high population density in the province of Buenos Aires, most departments cannot cover the total consumption of the province with renewable hydrogen. However, even in this case, the southern departments of the province exhibit a capacity of 3–5 times the hydrogen requirements of the province. As a general analysis, it should be noted that each of the provinces has at least one department where the potential for hydrogen production exceeds 10 times its fuel consumption requirement.

Final results and considerations

For purposes of illustration and, to develop a sense of the relevance of the present results of replacing fossil fuels by

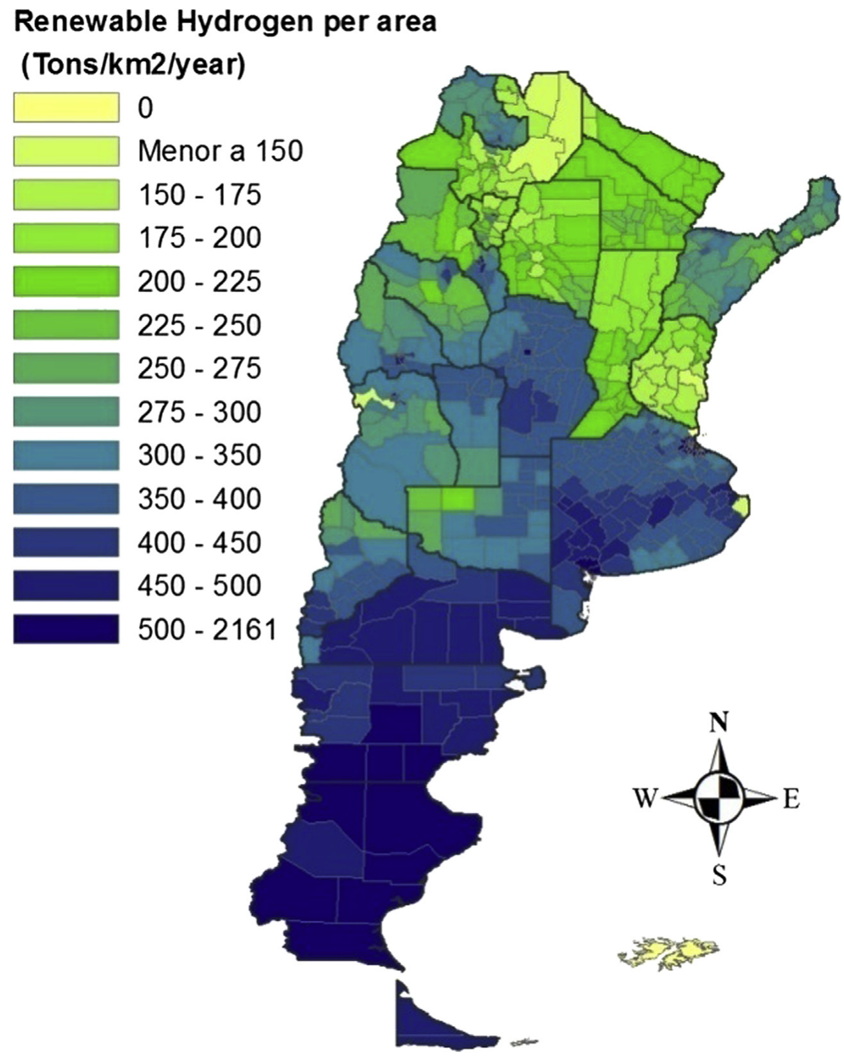

Fig. 7 – Map of potential for annual production of renewable hydrogen, by area department, in tons/km^2/year.

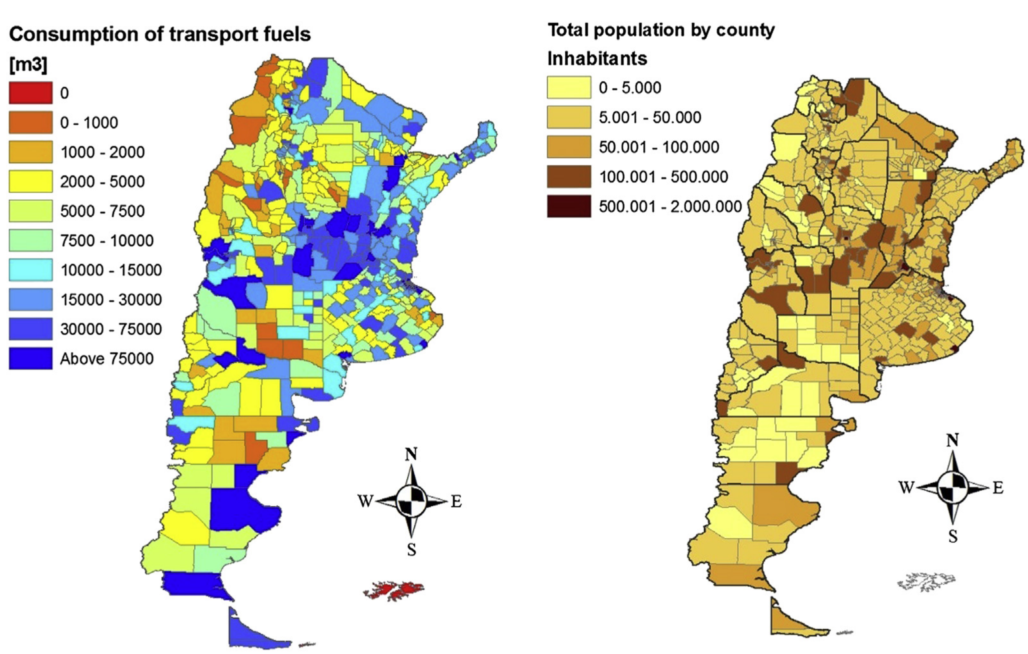

Fig. 8 – (Left) Map of transport fuel consumption by department. (Right) Map of total population by department.

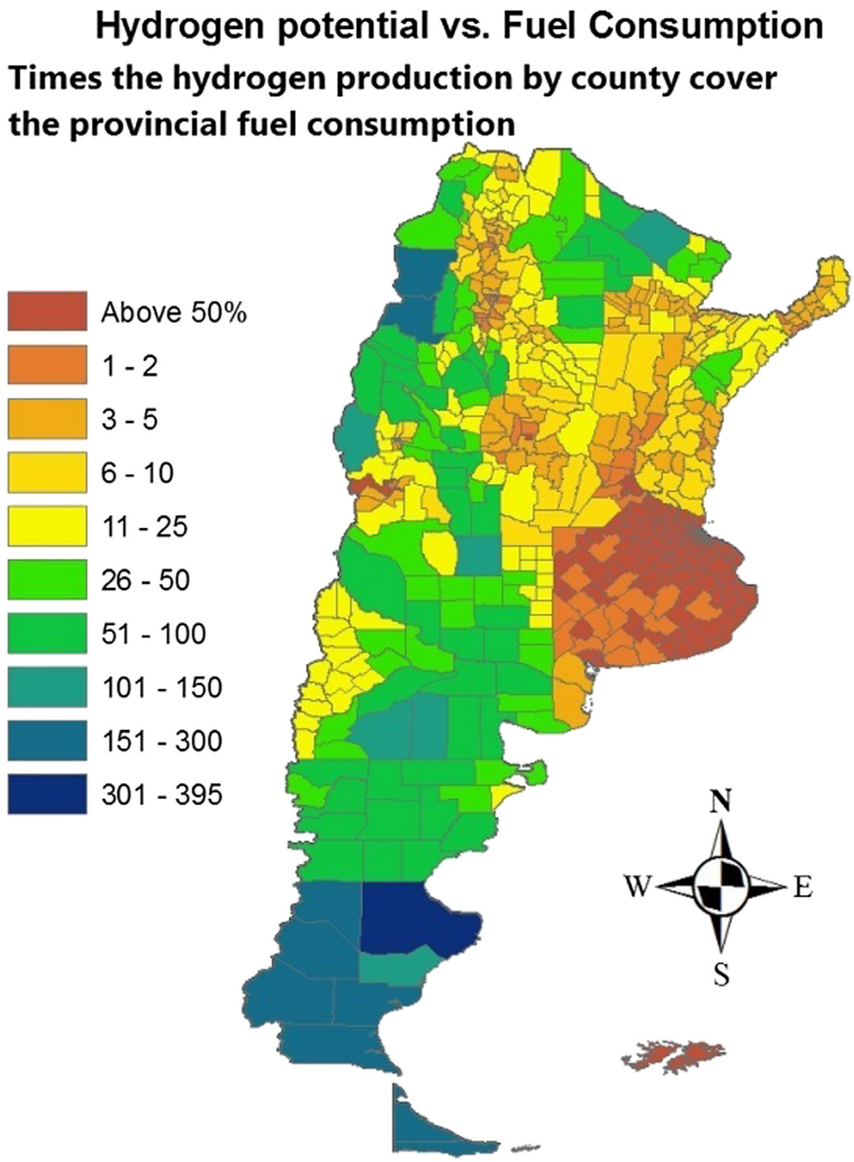

Fig. 9 – Capability of each department to supply hydrogen to fuel transportation to the province its belongs. The colors denote different ratios of hydrogen production by department relative to the total fuel consumption per province. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

renewable hydrogen in Argentina, some sample estimation can be performed.

1) In 2010, 1,645,484 m^3 of fuel for transportation were imported to Argentina, comprising a total of U$S 968 million, of which 1,465,857 m^3 involved different types of gasoil and the remaining consisted of different types of gasoline [10]. Such amount is energetically equivalent to 486,274 tons of H_2. Considering only a 10% occupation of the total land available, it can be concluded that the potential of any of the departments highlighted in Fig. 10 would be enough to replace this fuel importation.
2) Considering a mixture of H_2 + CNG with 20% V/V hydrogen (or CNG plus) to mobilize internal combustion engine vehicles and taking into account that the total consumption of CNG in the country was about 2650 million m^3/year (taking year 2010 as a reference again), the hydrogen requirement to fuel these vehicles with CNG plus would be 595,000 tons/year of H_2. Using about 12% of land suitable for renewable projects, the potential of any of the departments marked in Fig. 10 would be enough to generate this amount. Alternatively, this amount of hydrogen could be delivered using only 2% of the total area of the Deseado department (more highlighted than the rest, Fig. 10).
3) The environmental savings which involve the considerations of the previous item is estimated at 4.5 million tons of CO_2 per year (million tCO_2/year), or analogously, 10.4 million of crude oil barrels not consumed (taking into account that 1 L of petrol produces 2.22 kg of CO_2 after combustion).

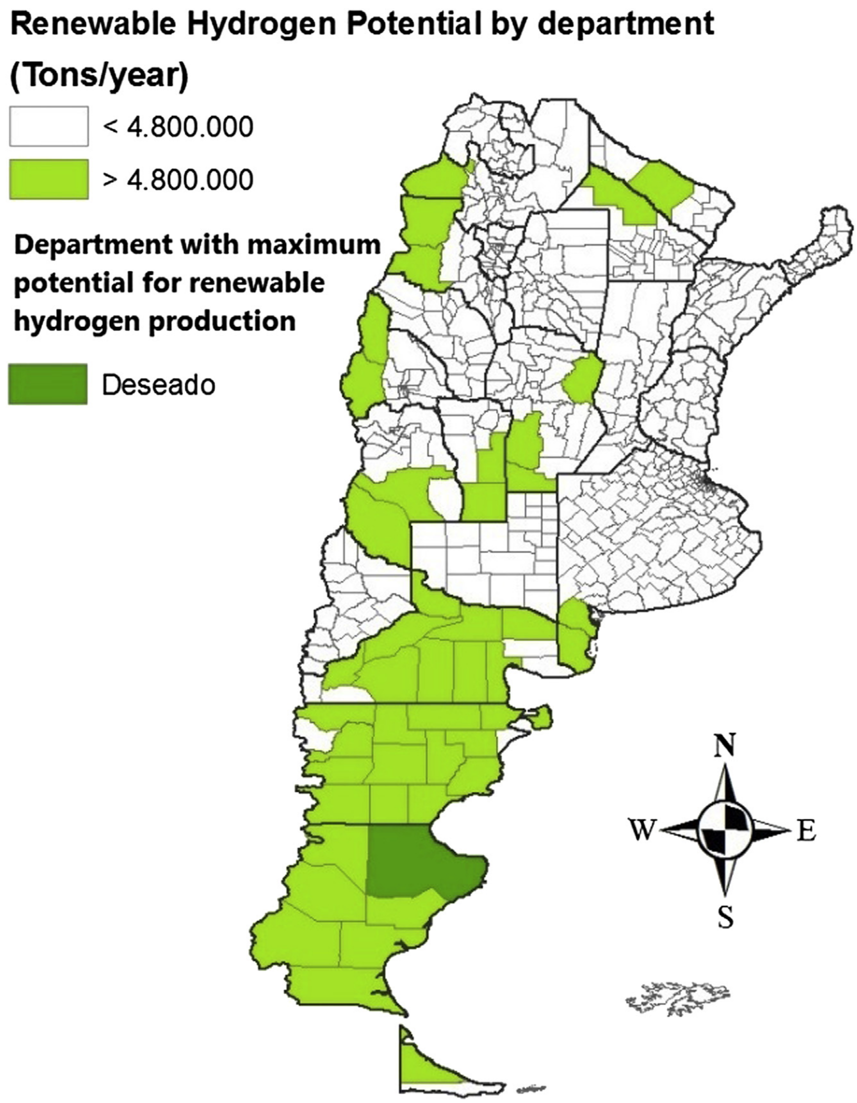

Fig. 10 – Departments with potential for renewable hydrogen production greater than 4,800,000 tons/year. 10% of this potential is energetically equivalent to the total imports of fuel for transportation came into Argentina in 2010.

Conclusions

For the first time, a detailed analysis of the potential for hydrogen production from three main renewable resources (wind energy, solar energy and biomass) in Argentina has been performed in this work.

The research emphasizes the fact that each of the provinces of the country has at least one department where the potential for renewable hydrogen production exceeds 10 times its fuel consumption requirements.

Argentina could produce almost 1 billion metric tons per year of hydrogen from solar, wind and biomass. This is the same potential as that estimated for the United States [2], a country which has a surface 3.5 times bigger than Argentina.

Furthermore, using only ca. 10% of land suitable for renewable projects, the potential of many departments, distributed all over the country, would be enough to replace either the total amount of Argentina's fuel importation for transportation or the hydrogen requirement to generate CNG plus (CNG with 20% V/V of hydrogen), for the total CNG automotive plant in the country.

Argentina has one of the most extensive networks of natural gas pipelines in the world. Therefore, it is interesting to consider the possibility of using them for hydrogen storage and transportation, just as the E.ON Company which has developed this procedure without modifying its infrastructure [12].

The present results envisage an optimal scenario for a future hydrogen economy in Argentina. This will require financial investment from both public and private sectors for the development of sustainable energy projects and the implementation of a suitable infrastructure for using hydrogen as an energy carrier in the transportation sector. As already mentioned, the geospatial distribution of available renewable resources in Argentina also implies a huge opportunity for the advancement of distributed generation in energy policies, meaning greater decentralization, redistribution, self-sufficiency and democratization of the energy system and, as a direct consequence, greater regionalization of production and economy.

For illustrative purposes we can regard the case of the province of Córdoba, which follows the national trend of the CNG industry growth. In this way, in order to give a rough estimation of the infrastructure investment required to transition to hydrogen fuel, this province is representative of the country. Using models of hydrogen delivery scenarios by virtual gas pipelines from central production, the cost estimated of hydrogen production and delivery is about 11.8 U$S/kg H_2.

In a future work we will discuss these issues in details for other delivery scenarios and we will address the analysis of the most cost-effective project for each region, given the availability of primary renewable energy and access to transport capacity.

Acknowledgments

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