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EVALUATION OF THE POTENTIAL OF GREEN HYDROGEN FROM WIND ENERGY FOR HEAVY MOBILITY IN REUNION ISLAND

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Abstract

In response to the growth in population, energy demand (particularly in the transport sector), and fossil fuel prices, Reunion's energy transition is based on the massive use of renewable resources. Currently, a large part of the local renewable electricity comes from converting solar and wind resources. However, the intermittency of these resources leads to storage and distribution problems, which can be solved using hydrogen, recognized as a flexible and clean energy carrier. Mainly used in the chemical and refining industries, this energy carrier could contribute to decarbonizing some industrial sectors, producing electricity, or supplying a part of the energy needs for the transport sector. Considering the potential of wind energy in Reunion and the high energy consumption level in the transport sector, producing electrolytic hydrogen powered by wind turbines is a promising alternative for developing green mobility. The present study aims to evaluate the potential of electrolytic hydrogen production, powered by wind resources, for heavy mobility in Reunion Island. The study includes (1) the estimation of the annual requirement of hydrogen to cover the needs of the heavy transport sector and (2) the determination of the wind energy necessary to meet these needs. Based on the hydrogen energy needs for heavy mobility, the results of the study will allow the selection of the most suitable locations for the implementation of wind farms based on the energy potential. This study provides insight into a prospective strategy for energy transition within the transport sector of a geographically isolated island by using hydrogen derived from wind resources. The inherent challenge of intermittency of climate-related renewable resources, such as wind, could be potentially mitigated by employing hydrogen as an intermediary mechanism for storing and distributing intermittent energy.

Keywords

hydrogen production, wind-electrolyzer modelling, heavy mobility, renewable energy, Reunion Island

Highlights

Energy requirement for heavy mobility is estimated for Reunion Island

Offshore wind production sites are investigated

One wind turbine can satisfy hydrogen requirement for heavy mobility

1. Introduction

The transportation sector is one of the largest contributors to anthropogenic greenhouse gas (GHG) emissions [1]. Within this sector, heavy road transport, including freight trucks and buses, plays a crucial role in facilitating global trade and economic growth. However, they are responsible for a significant amount of CO₂ emissions in the transport sector [2]. Urgent efforts are needed to mitigate its carbon footprint. For instance, in Reunion, a French overseas department located in the South West Indian Ocean (SWIO), road transport represents of the major energy consumption of the whole transportation, with a value of 66% (451.95 ktoe) of the energy consumption in 2019 [3].

The high fuel consumption in transport has been an enormous technical challenge because of the huge amount of greenhouse gases released into the atmosphere. This atmosphere pollution has resulted in various environmental problems such as depletion of species, erraticism in climate conditions and global warming. Therefore, decarbonizing the heavy mobility is essential to mitigate the air pollution. Various technologies that use renewable energies are proposed including battery and hydrogen options. Yet, Lithium-ion battery technology presents the drawbacks such as low energy density, and is inconvenient for usage in trucks because of its high specific energy. In Switzerland, for instance, where 12% of the trucks have been electrified with battery technology, the national emission of CO₂ has been reduced by only 2.1% [4]. Therefore, introducing the new energy vector in road transport is a suitable solution to decarbonized transport. Hydrogen has advantages in comparison to battery technology such as high efficiency, high power density, rapid start-up and response to freight changes and longevity [5].

In small islands, the transport sector heavily relies on fossil fuels. Recent studies [6] have examined decarbonization pathways for three islands, including Mauritius in the SWIO, and have found that electric drive trains are the most effective option for reducing carbon emissions in the transport sector. The focus of the study was on the development of infrastructure for battery electric vehicles, which are considered the best low-carbon mobility option for passenger transportation.

However, electrifying heavy-duty vehicles using battery technology presents a significant challenge. As an alternative, the use of green hydrogen has been explored as a substitute for fossil fuels, particularly for hydrogen delivery in the transport sector [6-8]. In the framework of the MAESHA project, the island of Mayotte, has investigated the application of green hydrogen specifically in the freight transport sector [7]. Similarly, the Irish haulage sector has been examined to kickstart a green hydrogen economy [8]. Surveys have been conducted to determine the hydrogen demand, but the production of hydrogen has not been thoroughly investigated. One potential approach is to produce green hydrogen from surplus electricity generated by renewable energy sources [9,10]. Designing an electric mix for islands aiming for self-sufficiency presents a challenge [9]. In this context, a study determined the amount of hydrogen produced under different demand response scenarios for the Gran Canary Island. However, the specific hydrogen demand was not investigated, and only the cost of

hydrogen fuel was determined. In another study [10], the HOMER software was used to utilize excess electricity production from renewable energy sources to produce hydrogen. This hydrogen was then used to fuel four bus routes and 200 cars with moderate use on the island. The demand for hydrogen, particularly for the buses, was relatively low, estimated at 18 kg/day. These studies primarily focused on hydrogen production from the electric grid. However, it may be worth exploring the decoupling of hydrogen production from the grid. This approach could be intriguing as it allows for greater utilization of intermittent renewable energy sources like offshore wind farm, leading to cost-effective production of hydrogen.

This paper analyses the green hydrogen potential for heavy mobility in Reunion. Green hydrogen is suitable for heavy vehicles due to their back-to-base trip, which is suitable to be serviced by centralized hydrogen refueling facilities, the increase of road freight activities [11] and the independence of hydrogen on international price volatility [12]. Hence, hydrogen produced with a wind farm coupled to a Proton Exchange Membrane (PEM) electrolyzer can decarbonize the heavy vehicles complying with road freight activities in the economy. Thus, an estimation of the required green hydrogen required was made from the quantity of fossil fuel consumed by heavy vehicles [13]. In this paper, the energy requirement for heavy mobility is first presented. Then, the methodology to estimate the hydrogen production with offshore wind farms is detailed. Finally, a discussion in Section 4 states the opportunity for a wind-to-hydrogen plant to power heavy mobilities.

2. Heavy mobility: Reunion case study

2.1. Energy requirement

In Reunion, the total amount of energy consumed annually for the transportation is 632.1 ktoe, among which 451.95 ktoe is used for road transport [3]. The estimated energy requirement as a function of the type of transport: 223.37 ktoe/year for private cars, 11.76 ktoe/year for public transport, and 228.58 ktoe/year for other heavy vehicles. These figures have been evaluated from mobility surveys, private vehicles fleet characteristics, and the public transport fuel consumption data.

From this primary energy consumption (E_p), considering the mechanical efficiency (η_m) of a conventional powertrain, the mechanical energy (E_m) needed can be estimated with the following equation:

$$E_m = \eta_m E_p \quad (1)$$

Converting the conventional powertrain to an electrical one, the electrical energy (E_e) requirement to feed the electrical motor is given by Equation 2 considering the electrical efficiency (η_e).

$$E_e = E_m / \eta_e \quad (2)$$

With the parameters given in the Table 1, the electrical energy provided to the electric powertrain is determined to be 776.4 MWh.

2.2. Hydrogen requirement

An electric powertrain can be powered by a battery bank or a fuel cell. In this study, only the second one is considered. Considering the efficiency of a Proton Exchange Membrane Fuel Cell (PEMFC) and the balance of plant of the fuel cell system usually used in transportation applications (η_{fcs}), the chemical energy required (E_{ch}) can be determined. Based on the High Heating Value (HHV) of hydrogen, this energy can be converted to a hydrogen mass (m_{H2}).

$$m_{H2} = \frac{E_e}{\eta_{fcs} \cdot HHV} \quad (3)$$

From Equation 3 and Table 1, 43.8 tons of hydrogen is required annually to power the heavy vehicles in La Reunion.

3. Wind-to-hydrogen sizing methodology

The necessary amount of hydrogen should be generated through water electrolysis, driven by an offshore wind farm. In this section, the wind power modelling based on wind time series data is presented, as well as the electrolyzer model.

3.1. Wind farm modelling

The wind farm production is determined using the windpowerlib python package [14]. In this package, the wind generation is evaluated using Equation 4.

$$P = \frac{1}{8} \cdot \rho_{hub} \cdot d_{rotor}^2 \cdot \pi \cdot v^3 \cdot cp \quad (4)$$

where P is the power output at wind speed v , ρ_{hub} the density at hub height, d_{rotor} the rotor diameter of the wind turbine and cp the power coefficient of the Cp-curve.

Wind speed at the hub height is calculated considering a roughness factor and a linear temperature distribution. The roughness factor is estimated at $6.1e-3$ for surface ocean [15].

3.2. Electrolyzer

Among the various water electrolysis technologies, the Proton Exchange Membrane Electrolyzer (PEME) is the best candidate for coupling with a wind farm [16]. Since the model serves a sizing purpose only, it considers the efficiencies of the electrolyzer (η_{el}), the AC/DC converter (η_{el}) and the compressor (η_{com}) for hydrogen production from a wind farm. In this study, the time interval (Δ) is set to 1 hour, as hourly average wind speed serves as the input data.

$$m_{H2} = \frac{\sum(P \cdot \Delta t) \cdot \eta_{el} \cdot \eta_{com} \cdot \eta_{conv}}{HHV} \quad (5)$$

The compressor efficiency depends on the flow rate. Nevertheless, this study considers an average compressor efficiency for hydrogen compression from 15 bar to 900 bar using a multi-stage compression process. This high hydrogen pressure level is chosen to account for the worst-case scenario, including the possible development of 700-bar hydrogen tanks in heavy-duty vehicles.

Table 1: Efficiency values

Parameters	Value	Reference
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η_m	0.25	this study
η_e	0.9	this study
η_{fcs}	0.45	[17, 18]
η_{el}	0.75	[18]
η_{conv}	0.9	this study
η_{com}	0.87	[19]

4. Results

4.1. Offshore site selection

Wind data

Input data in this study consists of the hourly wind speed at 10 and 100m, temperature at 2 and 10m and surface pressure for the year 2022 derived from ERA5 reanalysis at ~25 km spatial resolution [20]. This data is taken at two ocean pixels within a domain covering Reunion Island and its surroundings. These two pixels which lie at the north and the south of the island are likely to be most suitable for offshore wind project development (Figure 1).

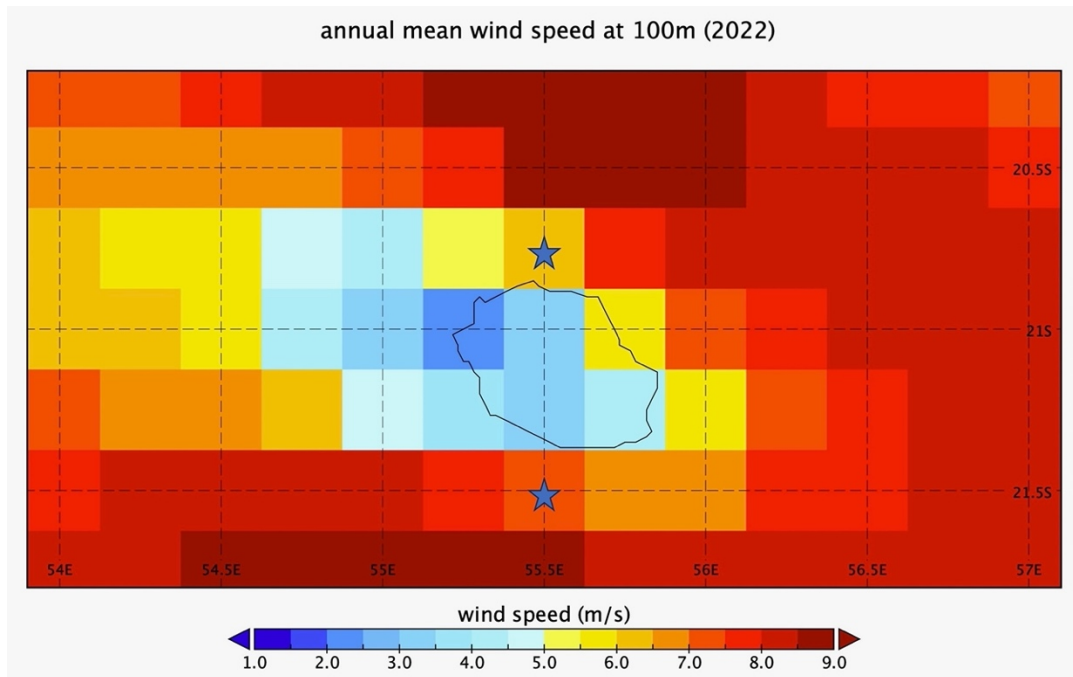


Figure 1: Map of the mean annual wind field at 100m (m/s) for 2022 derived from ERA5 (the stars indicate the location of the ocean pixels selected for the wind-hydrogen modelling).

4.2. Wind farm sizing

This study considers an Enercon wind turbine, whose characteristics are in Table 2. This standard wind turbine has a maximum speed drive of 11.6 m/s. Using the windpowerlib python library, it appears that only 1 turbine is sufficient to produce the required hydrogen (48 t), as 139 t of hydrogen could be

produced annually in the northern site and 198 t in the southern site. The monthly production in the southern site is presented in Figure 2. The production is higher in winter (June-July) than in summer (December-January), consistent with the strengthening of the trade winds during the winter. As an offshore wind-to-hydrogen production is competitive for wind farms above 100 MW according to [21], a wind farm with 25 turbines rated at 105 MW is simulated to evaluate the annual hydrogen production. A production of 3.5 kt H₂ is obtain in the northern site and 4.9 kt H₂ in the southern site. The southern site appears to be the most appropriate to produce hydrogen with offshore wind according to the mean wind speed at 100 m (Figure 1). This production is beyond the actual need of the island and exportation to neighbourhood countries could be investigated.

Table 2: Enercon turbine characteristics [12]

<i>Nominal power</i>	<i>4.2 MW</i>
<i>Rotor diameter</i>	<i>127 m</i>
<i>Rotor area</i>	<i>12,666 m²</i>
<i>Hub height</i>	<i>135 m</i>

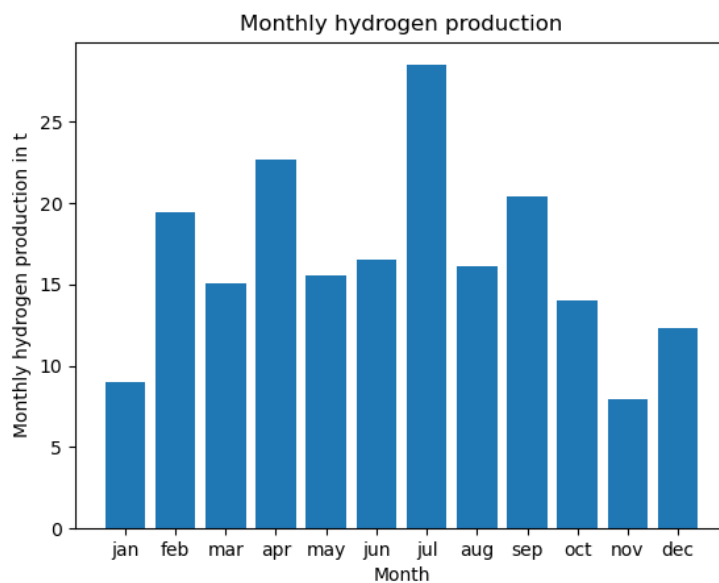


Figure 2: Monthly production of hydrogen in ton with a 4.2 MW turbine at the southern site.

5. Conclusions

To achieve energy autonomy of the Reunion Island, an energy transition is required. A significant effort has already been made to decarbonize the electrical sector. However, a huge effort is necessary to decarbonize the transport sector, particularly the heavy duty vehicles. After estimating the amount of

energy needed to power all the heavy duty vehicles using a fuel cell powertrain, a wind power production estimation is carried out using the wind data from ERA5 and the windpowerlib python library. Two potential sites are investigated. To satisfy the annual hydrogen requirement for feeding all the heavy duty vehicles, one 4.2 MW turbine with a PEM electrolyzer is needed. According to the literature, an offshore wind farm should be at least rated above 100 MW to produce a cost-effective hydrogen. The southern site appears to be the most suitable site according to energy production with an expected 4.9 kt H₂/year. This hydrogen can be exported to other countries, such as those in the South West Indian Ocean. This production should be confirmed with more precise wind data obtained, for instance, from the Météo-France AROME model at 2.5 km spatial resolution and economic interest with a detailed techno-eco analysis.

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