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Clean Hydrogen Production from Onshore and Offshore Wind Turbines Supplemented with Partial Electric Grid Power

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ABSTRACT

In this paper, the overall potential of Newfoundland and Labrador's (NL) electric grid to supplement large-scale wind-powered electrolysis is investigated. Several very large-scale wind to hydrogen developments have been proposed for Newfoundland and Labrador (NL) and are in various stages of pre-development. Also, sixteen inshore bays of NL have been identified for potential offshore wind development. However, the intermittency of wind limits the financial viability of wind to hydrogen production unless integrated with an additional power source. NL's grid is highly hydroelectric, which provides great synergies when integrated with wind-powered electrolysis. The caveat for NL (as well as many other potential locations) is the size of the proposed installations, which is vastly larger than the grid capacity, thus limiting the ability of the electric grid to supplement wind-powered electrolysis. In this paper, various scenarios of installed onshore and offshore wind turbines, as well as the associated hydrogen electrolyzers, are investigated, and the Levelized Cost of Hydrogen (LCOH) is predicted. ArcGIS Pro is used to investigate the potential capacity of the inshore bays for fixed-base offshore wind turbines and their effect on LCOH in the province. For 0.22 MMT to 2.31 MMT annual hydrogen production, the results predict an LCOH ranging from \$6.35/kg to \$4.25/kg. The results of this paper provide new predicted results on LCOH for different quantities of supplemented grid power, which is important for the financial viability of wind-powered hydrogen electrolysis.

KEY WORDS: Wind Power; Clean Hydrogen; Electrolysis; Techno-Economics.

INTRODUCTION

Globally, it is predicted that the LCOH from offshore wind using alkaline electrolysis will range between \$7.66/kg-H_2 and \$3.71/kg-H_2 by 2050 (Giampieri, Ling-Chin and Roskilly, 2024; Hill *et al.*, 2024; Balcı and Erbay, 2025). Several studies suggest that coupling wind power with water electrolysis enhances hydrogen production efficiency (Ikuerowo *et al.*, 2024; Nnabuife *et al.*, 2024), with some research achieving up to 89.7% wind energy utilization (Varela, Mostafa and Zondervan, 2021); however, the major challenge of wind variability requires strategies like standby operation of electrolyzer and energy storage to minimize the fluctuations and improve production efficiency (Fang and Liang, 2019; Varela, Mostafa and Zondervan, 2021; Lu *et al.*, 2023). Innovative research by Angelica et al. (Liponi, Baccioli and

Ferrari, 2023) uses wind electricity for hydrogen production and grid electricity to reduce electrolyzer shutdowns with the option of selling surplus wind power to the grid, resulting in an LCOH of \$7.02/kg-H_2 to \$10.14 /kg-H_2. The increasing demand for clean energy has caused Canada to prioritize renewable-powered electrolytic hydrogen in its hydrogen roadmap (Natural Resources Canada (NRCan), 2020), with the federal and provincial governments working together to develop comprehensive strategies. Newfoundland and Labrador (NL), in particular, has a promising opportunity for hydrogen production from wind energy supported by surplus grid electricity.

NL has excellent potential for clean hydrogen production, especially from hydroelectricity and wind energy. The province's vast onshore (average surface mean speed of 6-8 m/s) (Khan and Iqbal, 2004; Physical Sciences Laboratory) and offshore wind energy potential supported by surplus hydroelectricity make it a strong candidate for integrating wind-powered hydrogen production with partial grid supplementation. The wind data from MSC Wave Atlas show that the south coast's wind speed averages over 7 m/s while the west coast surpasses 8 m/s, exceeding the general requirement for wind speeds before the 100 m hub height adjustment of wind turbines (Environment and Climate Change Canada (ECCC), 2023; Impact Assessment Agency of Canada (IACC), 2025). The feasibility study of hydrogen Production, Storage, Distribution, and Use in the Atlantic provinces of Canada highlights two other primary reasons for NL's strong hydrogen potential, which are: (i) Expected 3.5 TWh/year surplus electricity from Muskrat Falls (Zen and the Art of Clean Energy Solution, 2021) and (ii) Cost-effective hydrogen production potential ranging from approximately \$1.50/kg-H_2 to \$3.25/kg-H_2 (CAD) (Asia Pacific Energy Research Centre (APERC), 2018). Additionally, the study found that hydrogen production costs will be significantly lower for integrated grid electricity and wind power compared with hydrogen production from wind electrolysis alone and grid electricity alone (Government of Canada, Natural Resources Canada, 2020; Zen and the Art of Clean Energy Solution, 2021). Moreover, the introduction of Bill C-49 promises that the sixteen inland bays could be utilized for offshore wind power production in NL (Bill C-49, House of Commons Canada, 2024).

However, the intermittency in wind power is a challenge; therefore, integrating electric grid power with offshore and onshore wind power could strengthen the resiliency of the hydrogen production system in Newfoundland and Labrador. This paper analyzes the clean hydrogen production potential of Newfoundland and Labrador using renewable energy sources, specifically from wind power supplemented with grid electricity.

METHODS

The methodology begins with the data collection of the first four projects selected on August 30, 2023, through the Crown Land Call for Bids for Wind Energy Projects (Call for Bids) issued by the Government of NL (Department of Industry, Energy and Technology, NL, 2023). These projects are: (1) Toqlukuti'k Wind and Hydrogen project (ABO), (2) Burin Peninsula Green Fuels Project (EverWind NL), (3) Project Nujio'qonik (World Energy GH2 Inc), and (4) Exploits Valley Renewable Energy Corporation (EVREC) project. The data collection focuses on wind data, wind turbine plant capacity, and electrolysis information, along with domestic power requirements and NL hydropower generation capacity (C_1). Various literature, along with the International Renewable Energy Agency (IRENA) suggests that the capacity factor of large-scale hydro can range from 35% to 90% (Nasir *et al.*, 2022; Tefera and Kasiviswanathan, 2022; IRENA, 2023), and no specific published data has been found for the capacity factors of NL hydro generation stations. Thus, the base capacity factor of 50% is considered, and the sensitivity analysis is done for varying capacity factors of 50%, 60%, 70% and 80%.

The process is analyzed using three scenarios, varying in the number of plants, grid support, and incorporation of inland bays. The total available power from each scenario is directed to electrolyzers for hydrogen production with an option of backup from grid electricity.

The next step is to supply the electrolyzer with the available power for hydrogen production. The available capacity at any given time is calculated using the formula given below:

$$E = C_1 - \text{Domestic Load} \quad (1)$$

This available power is then sent to the electrolyzer for hydrogen production at the time of intermittency, where P_{req}, is the power required for the electrolyzer when it is running at 100% capacity. If less energy is generated from wind turbines than the P_{req}, then the grid fulfills the difference in the power. If the grid cannot provide the power difference, the electrolyzer will run below 100% capacity.

Considering the initial and final proposed capacity of wind-hydrogen projects, three scenarios are analyzed to calculate the total hydrogen produced and LCOH. Since the proposed projects are multiphase wind-hydrogen projects, the scenarios are analyzed for varied wind farm capacities and grid support to evaluate the trade-offs between system reliability, scalability, and total hydrogen output.

- Scenario 1 involves four H_2 plants having wind farms of 1 GW each with energy supplied from the grid after meeting the domestic load (total wind turbine installed capacity of 4 GW).
- Scenario 2 involves four H_2 plants that are developed fully into wind farms of 22 GW, with energy supplied from the grid after meeting the domestic load (total wind turbine installed capacity of 22 GW).
- Scenario 3 involves four H_2 plants, developed fully into wind farms of 22 GW, with energy supplied from the grid after meeting the domestic load and 16 offshore bays (total wind turbine installed capacity of 33.01 GW).

Identification and Selection of Wind Farms for Hydrogen Production

The locations of four proposed wind-hydrogen project sites are considered for wind farm installation and verified with the wind speed of those locations and found that these projects are strategically located to capture the significant wind resources in the region with a mean speed of 9.9 m/s ('Global Wind Atlas - Newfoundland and Labrador', 2025). For the initial capacity assumption, each wind farm of 1 GW is considered installed at all four sites with an electrolyzer capacity of 550 MW, and a 10% auxiliary plant load of 50 MW is considered, which would be required to operate compressors, pumps, lights, HVAC systems, firefighting systems and standard alkaline electrolyzer rate with 53.1 kWh/kg of power consumption (Kroposki *et al.*, 2006). Similarly, the actual capacity provided by the respective bidder for wind-hydrogen projects at the time of the Call for Bids (August 30, 2023) has been considered for hydrogen production in the final capacity scenario, which are: (1) Toqlukuti'k Wind and Hydrogen project (ABO) – 5GW, (2) Burin Peninsula Green Fuels Project (EverWind NL) – 10 GW, (3) Project Nujio'qonik (World Energy GH2 Inc.) – 4 GW, and (4) Exploits Valley Renewable Energy Corporation (EVREC) project – 3 GW.

Offshore Wind Installation Potential for 16 Bays

Bathymetry data of 16 bays are studied using ArcGIS and global atlas, and the area in each bay where seabed depth is less than 60 m is calculated considering the fixed foundation of offshore wind turbines. The spacing of the turbines determines wake losses, which affects the total energy generation. Thus, a study by the National Renewable Energy Laboratory (NREL) (Mulas Hernando *et al.*, 2023) suggests that there is a wake loss of 12% to 13%, having a wider space of 8 rotor diameters (D) to 12D, and it is 16% to 17% for closer turbine spacing - 8D × 8D. Apart from the wake loss, navigation safety and multiple straight-line options for vessels to pass through the offshore wind farm have to be considered, and the United States Cost Guard and NREL recommend maintaining a 1 nm (equivalent to 1.85 km) distance between the turbines (Mulas Hernando *et al.*, 2023). Since Vestas 4.2 MW is designed for medium to high wind speed, making it ideal for maximizing energy production in diverse wind conditions, a turbine with 117 m rotor diameter and sweep area of 10,751m^2 (*V117-4.2 MW™*, 2025) is considered for estimating the power generation based on the number of turbines that can be installed with a spacing of 1852 m, which will have turbines spacing of 15.8 D, and thus meet the requirements for safe vessel movement and minimize the wake losses. There are two bays, White Bay and Conception Bay, where the seabed depth is more than 60 m; hence, it is not considered for offshore wind turbine installation. Using the details of Table 1, additional power generated from the offshore wind turbines from the bays is predicted. Although the final report on 'Regional Assessment of Offshore Wind Development in Newfoundland and Labrador' published on late January 2025, recommends additional criteria such as consideration of fishing areas and marine protected areas for wind turbine installation, this study was completed beforehand. Thus, future research could integrate these recommendations to optimize the available area for wind turbines.

Table 1: Bathymetry analysis and offshore wind turbine installation capacity for selected bays

Name of Bay	Area (sea depth < 60m) km^2	Number of turbines that can be installed	Size of wind farm (MW)
Bonavista Bay	381	118	494
Pistolet Bay	514	159	666
Bay of Islands	600	185	778
Bonne Bay	631	195	818
Hare Bay	242	75	314
Ingornachoix Bay	477	147	618
White Bay	0	0	0
Notre Dame Bay	1234	381	1600
Trinity Bay	83.2	26	108
Trepassey Bay	533	165	691
St. Mary's Bay	714	220	926
Placentia Bay	684	211	887
Fortune Bay	153	47	198
St. George's Bay	521	161	675
Port au Port Bay	1726	533	2237
Conception Bay	0	0	0

Economic Analysis

The LCOH is calculated using different empirical relations. Assuming that wind turbine CAPEX cost depreciated over 25 years, electrolyzer CAPEX cost depreciated over 10 years, and neglecting the cost for offshore cable, the following calculations are performed. Equation 2 is used to determine the total LCOH.

$$LCOH = \frac{\frac{E_{CAPEX}}{T} + \frac{OPEX}{T} + \frac{WT_{CAPEX}}{T} + C_{grid} - (O_2)_{revenue}}{(H_2)_{out}} \quad (2)$$

Where, E_{CAPEX} is the electrolyzer capital expenditure, OPEX is the operating expenses, WT_{CAPEX} is the wind turbine capital, C_{grid} is the electricity cost of the grid for operating the electrolysis unit, $(O_2)_{revenue}$ is the revenue generated from oxygen sales, T is the economic lifetime, and $(H_2)_{out}$ is the total hydrogen output in kg. The individual parameters are calculated as follows;

Electrolyzer CAPEX:

An economic lifetime of 10 years is assumed, and the installation cost ($I_{CAPEX,\ E}$) of the electrolyzer is set to be $2136.48 per kW (Schmidt *et al.*, 2017).

$$E_{CAPEX} = E_{power} \times I_{CAPEX,\ E} \tag{3}$$

The total installed capacity of the electrolyzer (E_{power}) in MW from Table 2 is used to calculate the Electrolyzer CAPEX. Electrolyzer OPEX is assumed to be 31% of electrolyzer CAPEX over 10 years of economic lifetime (Reksten *et al.*, 2022).

Table 2: Total electrolyzer capacity according to percentage of electrolyzer capacity to turbine

Four sites	Wind Farm (MW)	Ratio of Electrolyzer Capacity to Wind Turbine Capacity									
		0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1
Project Nujio'qonik	4000	2200	2400	2600	2800	3000	3200	3400	3600	3800	4000
EVREC Project	3000	1650	1800	1950	2100	2250	2400	2550	2700	2850	3000
Toqlukuti'k Wind and Hydrogen project	5000	2750	3000	3250	3500	3750	4000	4250	4500	4750	5000
Burin Peninsula Green Fuels Project	10000	5500	6000	6500	7000	7500	8000	8500	9000	9500	10000
Total capacity of the electrolyzer (MW)		12100	13200	14300	15400	16500	17600	18700	19800	20900	22000

Wind Turbine CAPEX:

The total wind turbine installed capacity (WT_{power}) from Table 2 for each case is used in the following equation to calculate total wind turbine CAPEX. The installation rate of wind turbines ($I_{CAPEX,\ WT}$) is set to be $1572.56 per kW for onshore and $6538.22 per kW for offshore, respectively (IRENA, 2023).

$$WT_{CAPEX} = WT_{power} \times I_{CAPEX,\ WT} \tag{4}$$

Wind turbine OPEX:

The wind turbine OPEX (WT_{OPEX}) is calculated based on the total wind turbine installed capacity (WT_{power}) for each case given above in GW. Here, the operational and maintenance cost ($OM_{turbine}$) for the turbine is kept at $55.95 per kW for onshore and $155.25 per kW for offshore, respectively (IRENA, 2023).

$$WT_{OPEX} = WT_{power} \times (OM)_{turbine} \tag{5}$$

Grid Fees:

The selling rate (SP_{grid}) for the general services by NL Power is $0.22869 per kWh or $1.58 per MWh (NL Power, 2024). Using Equation 6, the grid fees are calculated.

$$C_{grid} = P_{excess} \times (SP)_{grid} \tag{6}$$

Where, P_{excess} is the excess power generated from NL Hydro.

Oxygen Revenue:

Initially, the total amount of oxygen produced from the dissociation reaction of water is calculated by using the reaction equation of electrolysis, which is as follows:

$$2H_2O(l) \rightarrow 2H_2(g) + O_2(g) \tag{7}$$

The mole ratio of hydrogen to oxygen gas is 2:1. This means that two moles of hydrogen are produced for every mole of oxygen. However, the molecular weight of hydrogen is 2 g/mol, and the oxygen is 32 g/mol, so from the electrolysis of water, around 8 kg of oxygen is produced for each kg of hydrogen (Maggio, Nicita and Squadrito, 2019). This total oxygen (kg) is a function in the equation of oxygen revenue, which has the per kg cost of oxygen, which is \$ 3.3 per kg ($(SP)_{O_2}$) (Squadrito, Nicita and Maggio, 2021). With these input values, Equation 9 is used to predict the total oxygen revenue.

$$(O_2)_{total} = (H_2)_{out} \times 8 \tag{8}$$

$$(O_2)_{revenue} = (O_2)_{total} \times (SP)_{O_2} \tag{9}$$

RESULTS AND DISCUSSIONS

Using the initial and final capacities of four proposed wind-hydrogen projects and the calculated capacity of 16 inland bays, as explained above in the methodology section, the energy generation for individual scenarios is calculated. The energy produced from onshore wind turbines is primarily used to run the electrolyzer, whereas the grid electricity will supplement the electrolyzer if the wind power plants cannot meet the energy demand during periods of low wind or electrolyzer shutdown. Assuming a 50% capacity utilization factor for hydropower generating stations in NL, the energy available for running the electrolyzer is calculated. As illustrated in Figure 1, the excess energy available after meeting the island load is minimal in winter (from December to April), remaining below 2 GW, while in summer (from May to October), the available excess energy ranges from approximately 95 GW to 189 GW. This excess capacity from the grid supplements the energy for electrolyzers in all three scenarios.

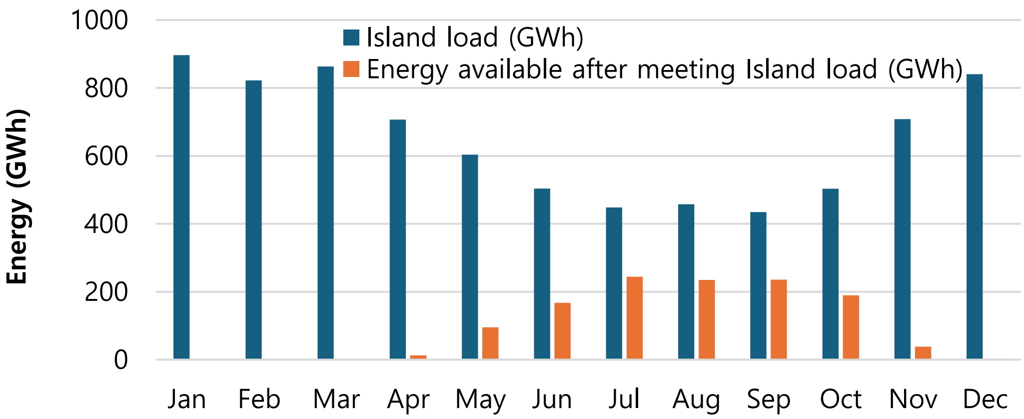
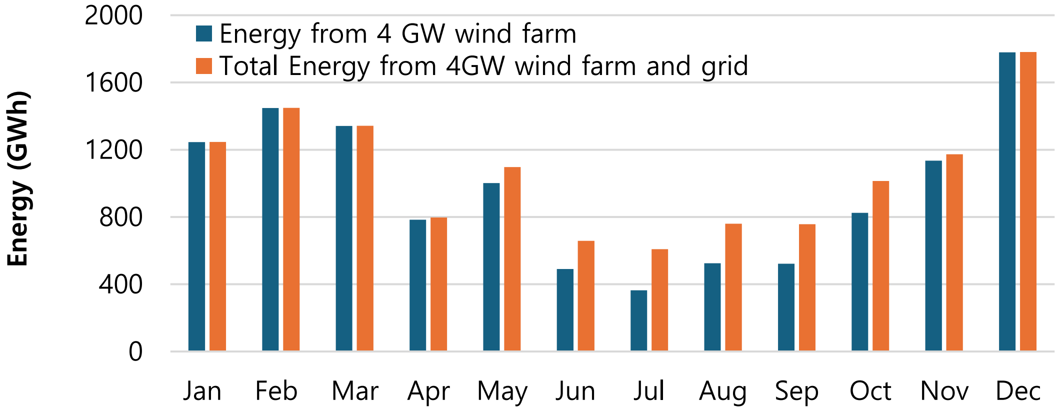
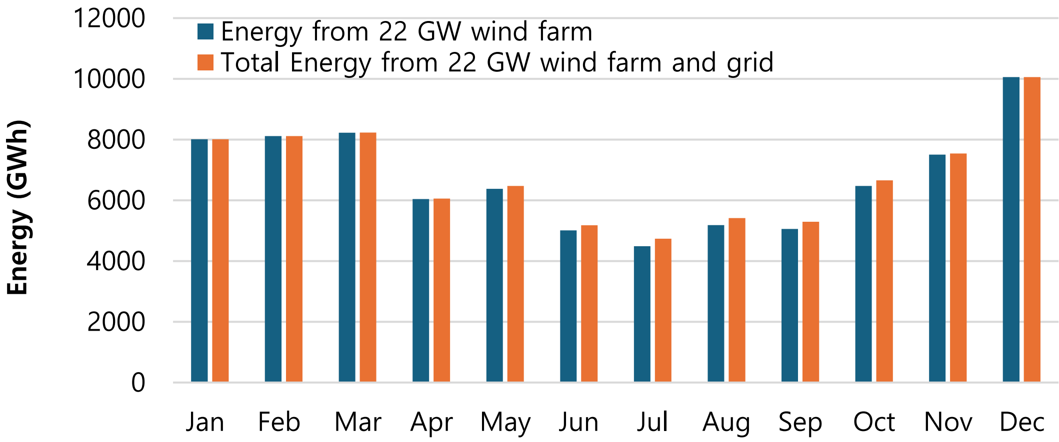


Figure 1: Island load and excess energy available from the grid for the year 2023

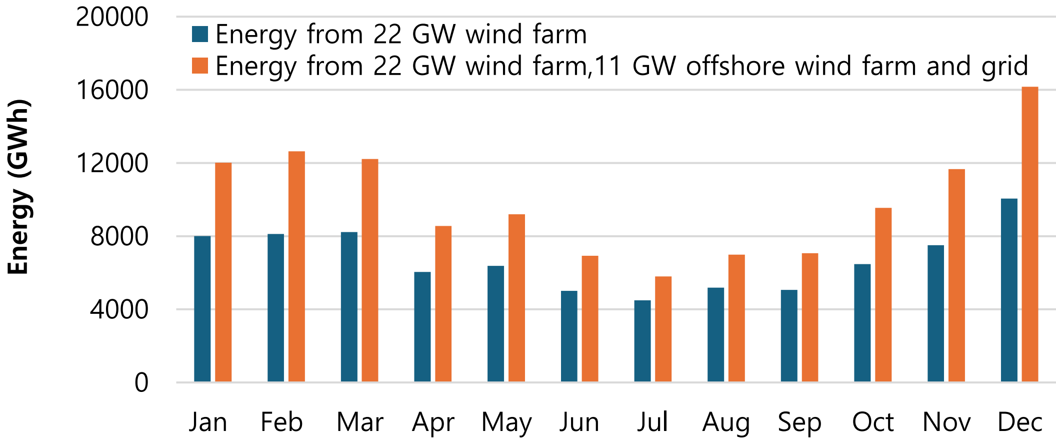
Figure 2 presents three different scenarios for energy produced from wind turbines installed at four proposed sites, varied with the addition of grid electricity and inland bay capacity. Figure 2(a) represents the 4 GW scenario where wind farms of 1 GW each are installed at four sites, and excess energy is available from the grid after meeting the domestic load to supplement the hydrogen electrolyzer. Figure 2(b) shows a 22 GW scenario where the four potential sites are developed to their full potential, and the excess energy is available from the grid after meeting the domestic load. Figure 2(c) represents the 33.01 GW scenario, where the four sites are developed to their full potential and the addition of an offshore wind farm from 16 bays developed to full capacity, supplemented with grid.



(a) Scenario 1: Energy available for 4GW wind farm



(b) Scenario 2: Energy available for 22 GW wind farm



(c) Scenario 3: Energy available for 33 GW wind farm

Figure 2: Energy available for electrolyzer for different scenarios for the year 2023

As illustrated in Figures 2(a) and 2(b), the addition of grid electricity does not significantly vary the total energy available for hydrogen production in both the initial and final capacity scenarios of wind-hydrogen projects, except during the summer season. However, the onshore wind farm, when supplemented with offshore wind and grid electricity, significantly enhances the energy available to run the hydrogen electrolyzer, as shown in Figure 2(c). In contrast to Scenario 1 and Scenario 2, the energy generation during the winter season spikes, with peak generation ranging from approximately 16.16 TWh in December to 12.21 TWh in March. This increase is due to prevailing high-speed winds in the winter, which further boosts the offshore wind power production capacity. The summer months also show higher energy when excess grid electricity and offshore wind farms are utilized compared to the case without grid electricity.

Based upon the annual energy required to run the hydrogen electrolyzer and available excess energy, the total hydrogen production is calculated at varying capacity utilization of hydropower. This calculated hydrogen output is used to predict the LCOH using Equation 2 for all three installed capacities: 4 GW (onshore), 22 GW (onshore) and 33.01 GW (onshore and offshore). Table 3 presents the comparative analysis of the hydrogen production in MMT and LCOH in $/kg varying under different capacity utilization scenarios of hydropower (50% to 80%), wind and electrolyzer capacity ratio (55% to 80%) and grid connectivity (with and without grid).

Table 3: LCOH under varying grid capacity utilization and electrolyzer-to-wind turbine capacity scenarios

Scenarios		**Capacity Utilization of Hydropower**	**H_2 (MMT) at 60%**	**H_2 (MMT) at 65%**	**LCOH ($/kg) Electrolyzer Capacity to Wind Turbine Capacity Ratio**					
					55%	**60%**	**65%**	**70%**	**75%**	**80%**
4 GW (Each Onshore Site of 1 GW)	**Without Grid**	-	0.22	0.22	5.05	5.31	5.57	5.83	6.09	6.35
	With Grid	50%	0.24	0.24	4.58	4.81	5.05	5.28	5.52	5.75
		60%	0.26	0.26	4.22	4.44	4.66	4.87	5.09	5.30
		70%	0.29	0.29	3.84	4.03	4.23	4.43	4.62	4.82
		80%	0.31	0.31	3.47	3.65	3.83	4.01	4.19	4.36
22 GW (All Onshore Sites of Full Capacity)	**Without Grid**	-	1.52	1.52	3.96	4.16	4.36	4.57	4.77	4.97
	With Grid	50%	1.54	1.54	3.90	4.10	4.30	4.50	4.70	4.90
		60%	1.56	1.56	3.85	4.05	4.24	4.44	4.64	4.84
		70%	1.59	1.59	3.79	3.98	4.17	4.37	4.56	4.76
		80%	1.62	1.62	3.72	3.91	4.10	4.29	4.48	4.67
33.01 GW (Onshore + Offshore)	**Without Grid**	-	2.18	2.21	6.18	4.39	4.46	4.60	4.73	4.87
	With Grid	50%	2.18	2.24	6.16	4.37	4.39	4.53	4.67	4.80
		60%	2.18	2.26	6.16	4.37	4.36	4.49	4.63	4.76
		70%	2.18	2.28	6.16	4.37	4.31	4.44	4.57	4.71
		80%	2.18	2.31	6.16	4.37	4.25	4.38	4.51	4.65

Hydrogen production ranges from 0.22 MMT to 0.31 MMT in the base scenario (initial capacity) and from 2.18 MMT to 2.31 MMT in the 33.01 GW scenario (full-phased capacity with offshore) at electrolyzer-to-wind turbine capacity ratios of 60% and 65%, respectively. In the previous two scenarios, hydrogen production increases gradually when supplemented with grid electricity. However, in the third scenario of 33.01 GW, hydrogen production for up to 60% electrolyzer capacity to wind turbine capacity ratio is constant even with the addition of grid electricity. This is because the energy available from the 33.01 GW wind farm exceeds the energy required for the electrolyzer. However, as the electrolyzer-to-wind turbine capacity ratio increases to 65%, hydrogen production increases with an increase in the energy supplied from the grid. In this situation, the energy required by the electrolyzers is more than the energy available from the grid; and thus, hydrogen production increases until the excess energy available from the grid matches the electrolyzer's energy demand.

The LCOH for 4 GW scenario ranges from \$6.35/kg to \$3.47/kg with the varying capacity utilization of hydropower and electrolyzer capacity to wind turbine capacity ratio. When analyzed under a fixed electrolyzer capacity to wind turbine capacity ratio, the LOCH tends to decrease with the increased utilization of grid support. Similarly, when analyzed under a fixed capacity utilization of hydropower, the LCOH decreases with the increasing electrolyzer capacity to wind turbine capacity ratio.

The LCOH for 22 GW scenario ranges from \$4.97/kg to \$3.72/kg with the varying capacity utilization of hydropower and electrolyzer capacity to wind turbine capacity ratio. A similar trend is observed for this scenario, where the LCOH decreases with increased utilization of grid support at a fixed electrolyzer to wind turbine capacity ratio. Additionally, for a fixed hydropower capacity utilization, the LCOH decreases as the electrolyzer-to-wind turbine capacity ratio increases. In both scenarios, although increasing these parameters lowers the LCOH, higher capacities may not always be feasible.

The LCOH for 33.01 GW scenario ranges from \$6.18/kg to \$4.25/kg with the varying capacity utilization of hydropower and electrolyzer capacity to wind turbine capacity ratio. Since hydrogen production remains constant at 55% and 60% electrolyzer to wind turbine capacity ratio across all grid capacities, the LCOH also remains constant for all grid capacities. However, the addition of grid results in a decrease of \$0.02/kg in LCOH as compared with the scenario without grid integration. Across all grid capacities utilization, the LCOH decreases by approximately 30% from \$6.16/kg to \$4.37/kg when the electrolyzer to wind turbine capacity ratio increases from 55% to 60% and further increment to 65%, results in the LCOH dropping to \$4.36/kg, \$4.31/kg, \$4.25/kg for 60%, 70% and 80% grid capacity utilization respectively. After this point, the LCOH begins to increase from \$4.37/kg by approximately 3% for each 5% increment in electrolyzer capacity to wind turbine capacity ratio across all grid capacity utilization scenarios ranging from 50% to 80%.

Figure 3 below shows the sensitivity analysis of the LCOH for varying electrolyzer to wind turbine capacity ratios ranging from 55% to 80% and grid capacity utilization scenarios ranging from 50% to 80%.

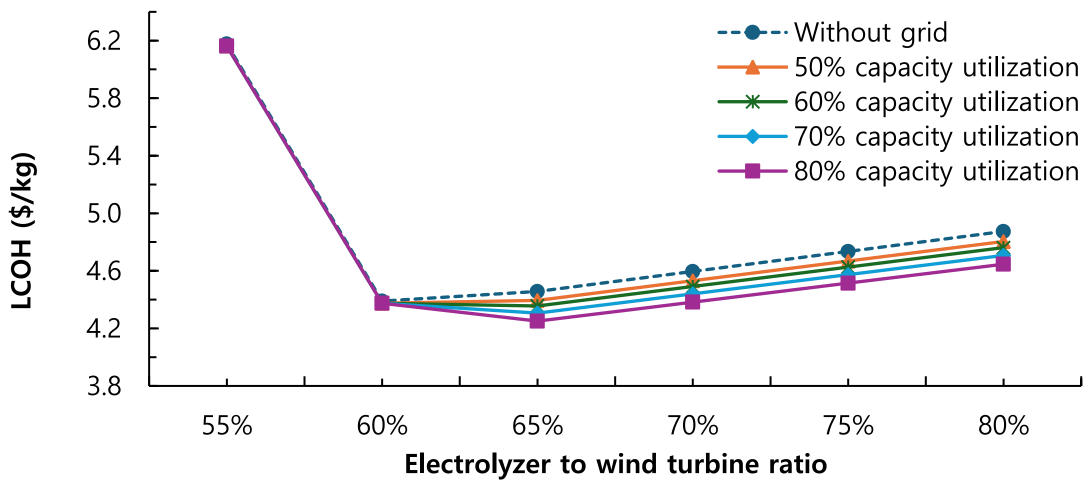


Figure 3: Sensitivity analysis of LCOH for varying electrolyzer to wind turbine capacity ratios and grid capacity utilization

As explained above and seen in Figure 3, the local minima of the LCOH ($4.37/kg) occur at 60% electrolyzer to wind turbine capacity ratios for all grid capacities. Moreover, this value further drops down to $4.25/kg at 65% electrolyzer to wind turbine capacity ratios as the capacity of grid utilization increases to 80%. Beyond this point the LCOH graph shows a gradual increase with increasing electrolyzer to wind turbine capacity ratios across all grid capacities.

Although few studies indicate that most of the oxygen produced as a by-product from water electrolysis could be reutilized effectively (Kato *et al.*, 2005; Arsad *et al.*, 2023; Hönig *et al.*, 2023); however, the oxygen-selling market is not fully developed yet in NL as the projects are still in pre-mature stage. Thus, the LCOH is further predicted for 33.01 GW scenario by considering 25% and 50% of oxygen revenue, as shown in Table 4. It is predicted that the LCOH could be further reduced to a range of $3.73/kg to $3.59/kg for 25% oxygen revenue and to a range of $3.07/kg to $2.93/kg for 50% oxygen revenue across grid capacity utilization of 50% and 80%, respectively.

Table 4: Comparison of LCOH for 33.01 GW scenario with and without oxygen revenue

Scenarios		**Capacity Utilization of Hydropower**	**LCOH at 60% Electrolyzer to Wind Turbine Ratio ($/kg)**			**LCOH at 65% Electrolyzer to Wind Turbine Ratio ($/kg)**		
			No Oxygen Sale	**25% Oxygen Sale**	**50% Oxygen Sale**	**No Oxygen Sale**	**25% Oxygen Sale**	**50% Oxygen Sale**
33.01 GW (Onshore + Offshore)	**Without Grid**	-	4.39	3.73	3.07	4.46	3.80	3.14
	With Grid	50%	4.37	3.71	3.05	4.39	3.73	3.07
		60%	4.37	3.71	3.05	4.36	3.70	3.04
		70%	4.37	3.71	3.05	4.31	3.65	2.99
		80%	4.37	3.71	3.05	4.25	3.59	2.93

CONCLUSIONS

This study conducted the techno-economic analysis of hydrogen production from wind energy integrated with grid electricity. This study considers the four potential sites for wind farms for clean hydrogen projects in NL and 16 offshore inland bays. Three different scenarios were studied to estimate the hydrogen production potential and LCOH, and it is found that the base case with initial capacities of 4 sites (4 GW) produces 0.22MMT to 0.31 MMT hydrogen at $6.35/kg to $3.47/kg LCOH; full-phased capacity of four sites developed to 22 GW produces 1.52 MMT to 1.62 MMT at $4.97/kg to $3.72/kg and 33 GW scenario with a full-phased capacity of four sites and addition of bays yields 2.18 MMT to 2.31 MMT at $6.18/kg to $4.25/kg. The local minima of LCOH yields at 65% electrolyzer to wind turbine capacity ratio ranging from $4.39/kg to $4.25/kg for 50% to 80% grid capacity utilization. Increasing the grid capacity utilization lowers the LCOH, while increasing the electrolyzer to wind turbine capacity ratio results in the lowest LCOH at 65%. The LCOH could be further reduced when the revenue generated from oxygen is considered. Thus, the integration of offshore and onshore wind energy along with the existing capacity of the grid electricity is highly promising for hydrogen production at a competitive price in Newfoundland and Labrador.

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