Assessing wave energy’s value for decarbonizing the steel industry

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Abstract

In the current energy transition to reach a net zero-carbon scenario, the steel industry is one of the hardest sectors to abate, due to its high energy demand and the use of carbon for its synthesis. It has been proven that through changing the process of production, the carbon can be substituted with hydrogen, allowing a nearly fully eradication of the carbon emissions. However, the hydrogen must come from a renewable source at a constant supply due to the industrial production particularities. Currently, electrolysis is the most advanced technology to produce green hydrogen but is tied to the intermittent electricity supply from renewable sources. Energy storage systems for industrial volumes are with today’s technology an unfeasible option. On the other hand, alternative renewable sources such as wave energy, has demonstrated to bring a predictable, less variable, and complementary production profile to the conventional wind and solar energy. The study has been based on H2GS´s future steel factory in the Iberian Peninsula including a 1GW electrolyser, that must be operational for 8000hours, equivalent to a 90% utilization. The paper suggests that when including wave energy to the supply mix, the total installed capacity can be reduced by a 46%. This leads to a significant cost reduction where the LCOE is decrease by a 26%. Furthermore, the total AEP is reduced which implies less over-capacity sold to the grid, where the technological and geographical similarities entail a low selling price, translating to a project risk reduction.

Keywords*:* Decarbonization; Steel Industry; Green Hydrogen; Electrolyser; Wave Energy

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1. Introduction

Steel is one of the core pillars of the modern industrial ecosystem, present throughout all sectors. The global steel demand is forecasted to grow by nearly 60% by 2050 [1]. The European steel production average 2 tonnes of CO_2 per tonne of steel manufactured, accounting for 5.7% of the total European emissions [2]. To reach the carbon reduction targets set by the Paris Agreement a drastic emission reduction is needed in the steel industry. Through heavy legislation on carbon emissions; as the emission trading scheme and the carbon board adjustment mechanism, the industry has financial reasons to transform it self along with the raise of demand of green steel [3].

1.1. Innovative production routes

The raw material needed for steel production is iron ore, which must be synthesized to direct reduced iron with a reduction agent. The conventional agent used is coal which stands for the vast majority of the carbon emissions [4]. Alternatively, hydrogen could substitute coal, exchanging the infamous by-product of CO_2 for just water. If then an electric arc furnace is used for the final steel production, a 95% of the emissions can be reduced, assuming the hydrogen and the electricity needed are produced from renewable sources [4]. The main challenges ahead consist of the evolution of industrial scale electrolysers and the stable renewable electricity supply due to the industry’s demand [5].

1.2. Ocean energy

The intermittence and uniformity of the conventional wind and solar production profiles are an issue for the more constant demand-side profiles. Alternatively to storage systems, which are challenging for industrial volumes, ocean energy provides a new production profile, diversifying and enabling a higher renewable coverage. Wave energy in particular has been proven to be a less variable, predictable and complementary resource to the conventional renewables [6]. With an untapped global potential of 2TW [7], a maturity in the market would accelerate the transition to 24/7 carbon free electricity and support the decarbonization of the steel industry.

2. Methodology

The steel company H2GS plans to deploy a 1GW electrolyser plant in the north-west of the Iberian Peninsula by 2027. [8] A technical and financial feasibility study is performed to cover the plant's demand when adding wave energy to the electricity mix for a 25-year long project. The plant must to run for 8000h per year, equivalent to a 90% utilization rate, to be financially feasible, according to H2GS. For the wave energy resource, CorPower Ocean's wave energy converter G12, is chosen [9].

2.1. Configuration

As software support, HOMER, an optimizer tool of energy systems, is used [10]. Two models were run through simulations. The first one is composed by a mixed wind-wave offshore farm and an onshore solar plant in parallel with a grid model divided into hourly ratings. In the second model, the floating wind was substituted with an onshore wind farm and the grid model was optimized to match the behaviour of the overall energy system, considering the evolution of the electricity market.

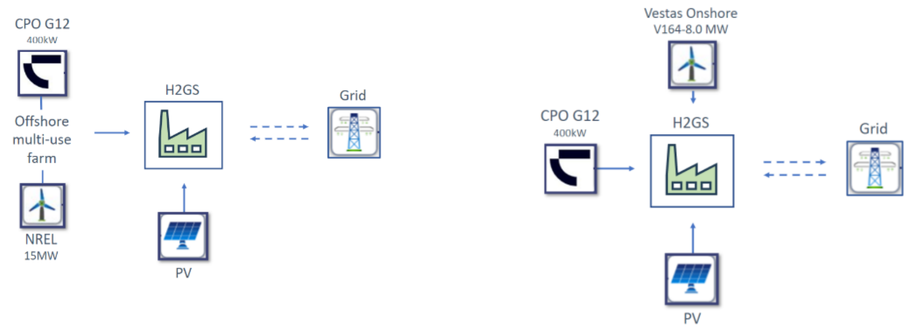

Figure 1. Models set-up

The location of the offshore resource is located 20km from Viana do Castelo in the north of Portugal, where the plant is assumed to be located. Time-series of wave and wind data have been obtained mainly from Copernicus [11]. The costs per technology are obtained through forecast studies for 2030.

The grid model has considered the daily average price for 2027 [12], and the daily price profile for the Iberian electricity market [13], with three grid rate schedules. Due to the similarity in production profiles of the system with the national grid, the purchasing price has been doubled to simulate the high volatile prices in renewable deficit periods. The selling price is considered a tenth of the average price, due to the surplus of renewable supply with similar production profile.

2.2. Main key performance indicators

The renewable penetration, RP (%), is a crucial KPI to measure the consumption of the electrolyser covered by renewable sources. It is also directly linked to the emissions of scope 2 regarding the remaining electricity bought from the grid, entailing an average carbon emission per kWh, 198g CO_2 per kWh in 2020 [14].

$$\mathrm{RP} = \frac{E_{\mathrm{RET}} - E_{\mathrm{su}}}{E_{\mathrm{load}}} \quad (\mathrm{Eq.}\ 1)$$

Where E_{RET} is the energy supplied by the renewable technologies (kWh), E_{su} is the surplus energy sold to the grid (kWh), and E_{load} is the energy consumed by the load.

The main financial KPIs are the Net Present Cost, which is the present value of all the costs of installing and operating the plant, minus the revenues, over its lifetime. Costs include capital costs, O&M, emission penalties and grid purchases. The NPC is the sum of the total discounted cash flows. Secondly, the LCOE represents the cost per unit of energy. It calculates the total annualized cost divided by the energy production.

$$\mathrm{LCOE}_{\mathrm{system}} = \frac{\mathrm{C}_{\mathrm{ann,tot}}}{\mathrm{Production}} \quad (\mathrm{Eq.}\ 2)$$

Where $C_{ann,tot}$ is the total annualized costs of previous NPC, multiplied by a capital recovery factor which consider the real discount rate and lifetime of the project. For the scenarios where the desired demand is covered by renewables and the grid purchases are avoided, and therefore emission penalties, an effective LCOE is calculated.

$$\mathrm{LCOE}_{\mathrm{effective}} = \frac{\mathrm{CAPEX}\ + \mathrm{OPEX} - \mathrm{Grid\ Sales}}{E} \quad (\mathrm{Eq.}\ 3)$$

The effective LCOE is measured by the energy actually consumed by the electrolyser (E), accounting for the over-capacity as benefits from grid sales.

3. Results

A preliminary normalized study was performed to analyse the site-specific properties of the resources and their respective technologies. In Figure 2, the production profiles for the selected technologies are observed for the selected site. The low variability in the wave resource output is visible through the time-series.

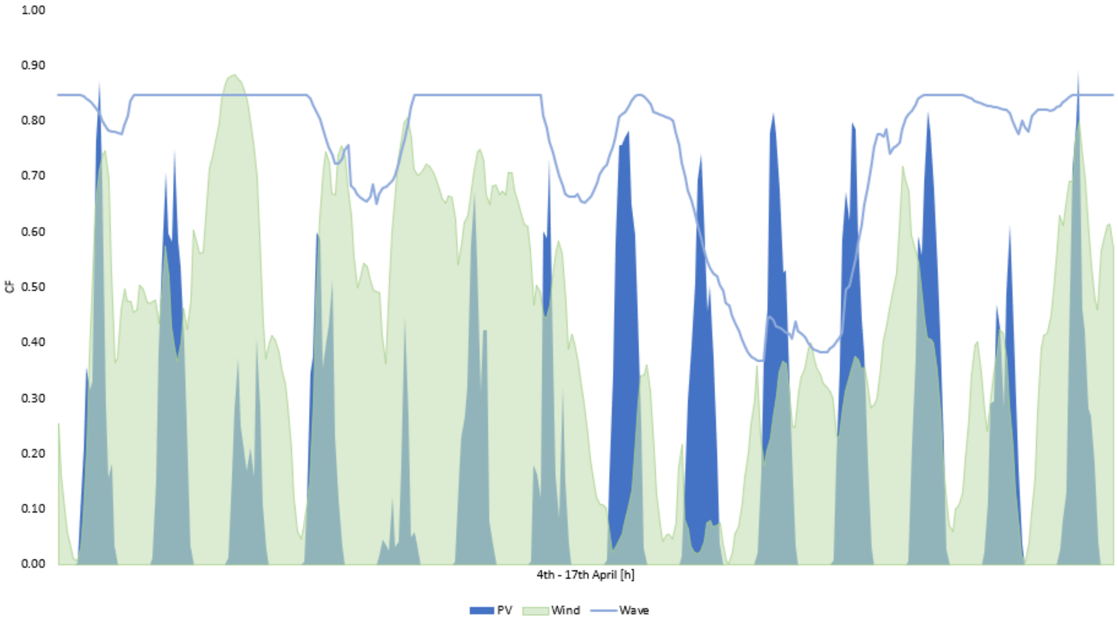

Figure 2. Two-week production profiles

A variability and a complementary test are performed in detail in the full report. It shows that when adding wave to a wind profile, the variability diminishes, and the total average energy output is increased significantly with the given power curves. Additionally, the complementarity effect is studied with a correlation factor of 0.36.

In the project specific study, HOMER ranks the optimal cases by lowest NPC and classified by technology mix. The results of the three best energy mixes for model 1 are represented in Table 1.

Table 1. Model 1

Cases	PV (MW)	Wave (MW)	Wind (MW)	AEP (GWh)	NPC (B€)	LCOE syst (€/MWh)	RP (%)	CO_2 (kt/y)	ETS (M€/y)
1	4405	0	1177	12383	6.52	30	83	301	36
2	4179	15	1179	12114	6.54	30	83	299	36
3	12500	0	0	18251	6.93	19	44	975	117

The results of the three best energy mixes for model 2 are represented in Table 2 with the main KPIs.

Table 2. Model 2

Cases	PV (MW)	Wave (MW)	Wind (MW)	AEP (GWh)	NPC (B€)	LCOE syst (€/MWh)	RP (%)	CO_2 (kt/y)	ETS (M€/y)
1	1173	540	1728	9509	8.36	48	82	315	38
2	1373	0	2480	9358	8.42	47	76	421	50
3	0	762	1832	9249	9.05	52	80	349	42

With the aim of H2GS to reach 8000h of electrolyser utilization, every case simulated for Model 2 were analysed. In this scenario, through a pareto analysis, two cases were chosen with the fixed aim of reaching a renewable penetration of 90%, 8000h per year, and the purpose of not purchasing more electricity from the grid, avoiding thus any second scope emissions.

The cases chosen are the ones with the lowest NPC to achieve a 90% utilization rate. One without wave in the technology mix, and one with wave.

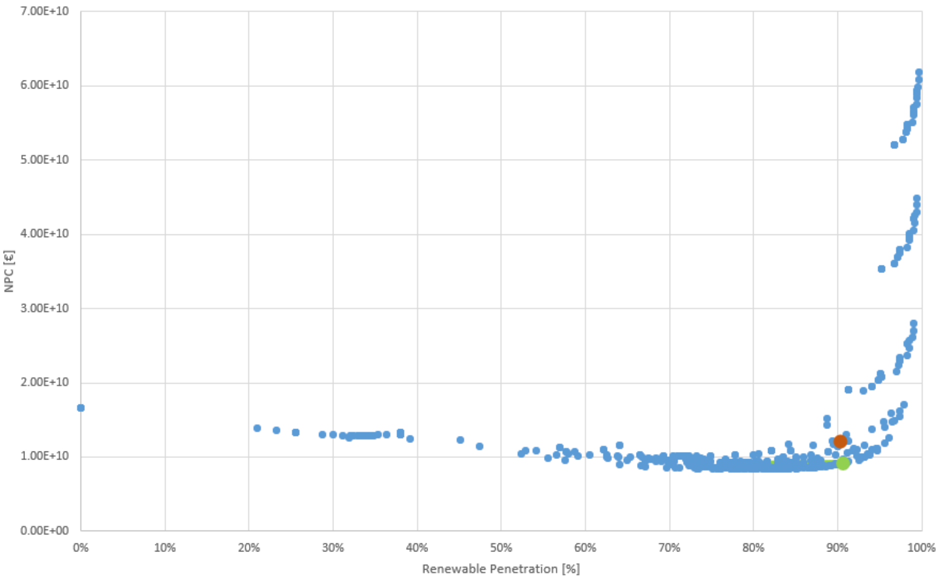

Figure 3. Pareto frontier analysis - Model 2

4. Discussion

The results for model 1 suggest that the high costs of floating wind in relation to its power output profile, leads to an exclusion of its technology for the optimal cases. Some optimal cases were selected due to their good performance and low LCOE, selling electricity back to the grid, which led to a massive deployment of PV. Due to these drivers that modelled the results, the combination of different renewables to cover a base load demand where not represented, leading to different conclusions.

In model 2 for a 90% utilization rate, the findings indicate that the total installed capacity can be reduced by a 46% when including wave into the energy mix, going from 8.4GW needed, to only 4.5GW, Figure 4. Beneficial for land space, supply chain restrictions, etc. This translates directly into a reduction in the total costs. The LCOE of the system for the optimal case, which accounts for the costs of the renewable assets and the sales to the grid, is decreased by a 26%, Figure 5, even if the intrinsic LCOE of wave energy is higher.

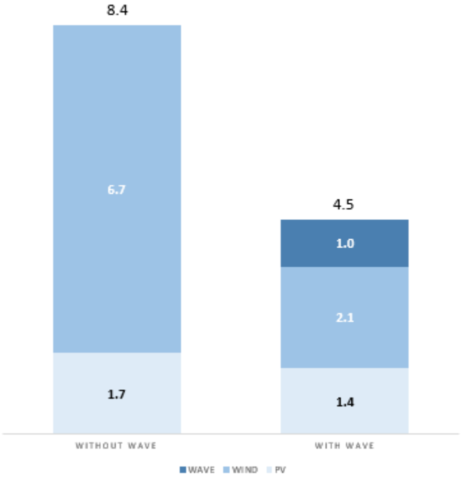

Figure 4. Capacity mix to deliver 90% utilization [GW]

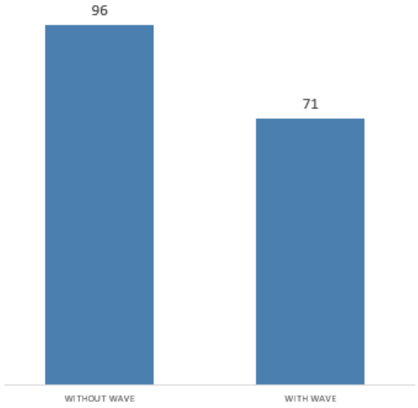

Figure 5. Effective LCOE to deliver 90% utilization [€/MWh]

The reduction in both capacity and AEP, still meeting the plant´s demand, makes the project financials less dependent on sales of over-capacity to the grid, where the technological and geographical similarities of the production profiles of a case with just wind and PV with the overall market, entails a low selling price.

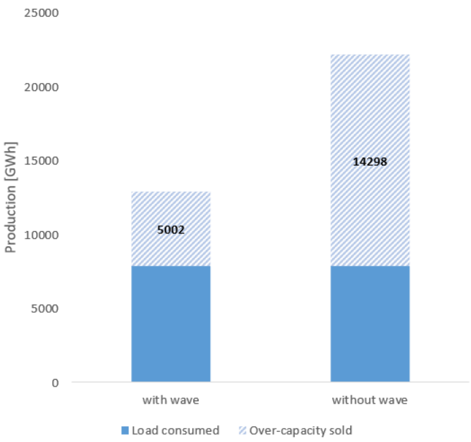

Figure 6. AEP and over-capacity dependent on market prices

By meeting demand with dedicated RE farms to 90% utilization, less electricity is needed to be purchased from the grid, if to be run at 100% utilization, making the H2 projects less dependent on volatile future electricity market price. This translates into an important risk reduction for the project.

5. Conclusions

Wave energy must still prove its maturity and performance but promises a reliable, competitive, and crucial addition to the current renewable sources, covering hours where sun and wind energy are not available. The study suggests that including wave energy to the mix, the over-all electricity price to fulfill a nearly 24/7 renewable demand, is reduced. Additionally, the diversification of resources leads to a reduction in the total installed capacity, which is important for land space limitations and frequent supply chain constraints.

The steel industry is proved to be able to avoid scope 1 emissions through the change of the process and scope 2 emissions through a balanced renewable energy mix supply. This favourable position of fully decarbonizing the steel industry affects positively their business model, not only within the carbon taxes but with the inevitable demand for green steel.

References

[1] «Impact of Hydrogen DRI on EAF Steelmaking», *Midrex Technologies, Inc.*, 2021. https://www.midrex.com/tech-article/impact-of-hydrogen-dri-on-eaf-steelmaking/

[2] «EU climate targets: how to decarbonise the steel industry», 2022. https://joint-research-centre.ec.europa.eu/jrc-news/eu-climate-targets-how-decarbonise-steel-industry-2022-06-15_en

[3] «A European Green Deal | European Commission», 2019. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

[4] «Hydrogen in steel production: what is happening in Europe – part two», *Bellona.org*, 26 de mayo de 2021. https://bellona.org/news/industrial-pollution/2021-05-hydrogen-in-steel-production-what-is-happening-in-europe-part-two

[5] «Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5^0C Climate Goal». 2020. [En línea]. Disponible en: https://irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf

[6] «Enhancing the global renewable energy portfolio», *Bombora*, 2022. https://bomborawave.com/wave-energy/

[7] K. Gunn y C. Stock-Williams, «Quantifying the global wave power resource», *Renewable Energy*, vol. 44, pp. 296-304, ago. 2012, doi: 10.1016/j.renene.2012.01.101.

[8] I. CORPORATIVE, «Iberdrola and H2 Green Steel sign 2.3 billion euros green hydrogen deal», *Iberdrola*, 2021. https://www.iberdrola.com/press-room/news/detail/deal-green-hydrogen-iberdrola-h2-green-steel

[9] «CorPower Ocean - Wave Power. To Power the Planet.», 13 de diciembre de 2021. https://corpowerocean.com/

[10] HOMER Pro, «HOMER Pro - Microgrid Software for Designing Optimized Hybrid Microgrids», 2022. https://www.homerenergy.com/products/pro/index.html

[11] «Data | Copernicus Marine», 2022. https://resources.marine.copernicus.eu/product-detail/IBI_MULTIYEAR_WAV_005_006/INFORMATION

[12] «Market today | OMIP», 2022. https://www.omip.pt/en/plazo-hoy

[13] «OMIE Anual», 2022. https://www.omie.es/es/market-results/interannual/daily-market/daily-prices?scope=interannual

[14] «European Environment Agency», 2020. https://www.eea.europa.eu/data-and-maps/daviz/co2-emission-intensity-9/#tab-googlechartid_googlechartid_googlechartid_chart_1111