**Supplementary Information**

1. **Cost-Benefit Analysis**
	1. **Operations and Development Cost Analysis of Low Carbon Hydrogen**

The cost-benefit analysis of low-carbon hydrogen production first requires operational and development cost analysis, including hardware, services, software, labour, system requirements, infrastructure, and management costs. The industrial plant for low carbon hydrogen production is assumed to be a 1 tonne per day (1TPD) plant, which is hypothesised for the analysis. The operational and development cost of the 1 TPD is shown in **Table S1**.

**Table S1:** Operational and Development Cost Analysis of LCH Production Plant\*.

|  |  |
| --- | --- |
| **Operational and Development Analysis** | **Costs (in $/Year)** |
| **Hardware** | 2,000,000 |
| **Services** | 375,000 |
| **Software** | 500,000 |
| **Labour** | 3,007,500 |
| **System Equipments** | 2,000,000 |
| **Infrastructure** | 5,000,000 |
| **Management** | 750,000 |

*\*It is important to note that the cost analysis is based on estimating, assuming and approximating a 1 TPD plant of low-carbon hydrogen.*

* 1. **Benefits Analysis of Low Carbon Hydrogen**

The benefit analysis usually consists of tangible and intangible benefits, which help in the performance and effectiveness of a plant. Benefit Analysis comprises more effective promotion campaigns, better industry-to-industry or industry-to-consumer retention, enhanced productivity, workflow efficiency, and high-quality and effective equipment. An approximation and estimation analysis of the benefit analysis for industrial low-carbon hydrogen plants is shown in **Table S3**.

**Table S2:** Benefit Analysis of LCH Production Plant\*.

|  |  |
| --- | --- |
| **Benefit Analysis** | **Costs (in $/Year)** |
| **More effective promotion campaigns for public awareness of low-carbon hydrogen** | 100,000 |
| **Better industry-to-industry or industry-to-consumer retention** | 40,000 |
| **Enhanced Productivity** | 70,000 |
| **Workflow Efficiency** | 200,000 |
| **High Quality and Effective Equipments** | 1,000,000 |

*\*It is important to note that the cost analysis is based on estimating, assuming and approximating a 1 TPD plant of low-carbon hydrogen.*

* 1. **Overall Cost-Benefit Analysis of Low-Carbon Hydrogen**

Once the operational, development, and benefit-cost analyses were done based on the approximation and estimation of the low-carbon hydrogen production plant, it is essential to compare the analyses to get the benefit-cost ratio for the final cost-benefit analysis. **Table S3** showcases the overall cost-benefit analysis of low-carbon hydrogen and national government subsidies.

**Table S3:** Overall Cost-Benefit Analysis of Low-Carbon Hydrogen\*.

|  |  |  |  |
| --- | --- | --- | --- |
| **National Government Subsidies** | 25% | 50% | 75% |
| **Total Low Carbon Hydrogen Industrial Plant-Revenue** **(30-year estimation)** | 10.224 (in million $) | 6.81625 (in million $) | 3.408 (in million $) |
| **LCH Benefit** | 1.0575 (in million $) | 0.705 (in million $) | .3525 (in million $) |
| **Increased Productivity Addition** | 9.1665 (in million $) | 6.11125 (in million $) | 3.05 (in million $) |
| **Net-Cost Benefit** | 8.72 | 8.66 | 8.65 |

*\*It is important to note that the cost analysis is based on estimating, assuming and approximating a 1 TPD plant of low-carbon hydrogen.*

**Additional References:**

Bockris, J. O. M. (2013). The hydrogen economy: Its history. *International Journal of Hydrogen Energy,* 38(6), 2579-2588. <https://doi.org/10.1016/j.ijhydene.2012.12.026>

Chew, Y. E., Cheng, X. H., Loy, A. C. M., How, B. S., & Andiappan, V. (2023). Beyond the colours of hydrogen: opportunities for process systems engineering in hydrogen economy. *Process Integration and Optimization for Sustainability*, 7(4), 941-950. <https://doi.org/10.1007/s41660-023-00324-z>

Dillman, K. J., & Heinonen, J. (2022). A ‘just’hydrogen economy: a normative energy justice assessment of the hydrogen economy. *Renewable and Sustainable Energy Reviews,* 167, 112648. <https://doi.org/10.1016/j.rser.2022.112648>

Liu, J., Hu, C., Kimber, A., & Wang, Z. (2020). Uses, cost-benefit analysis, and markets of energy storage systems for electric grid applications. *Journal of Energy Storage,* 32, 101731. <https://doi.org/10.1016/j.est.2020.101731>

Rodrigues, S., Restrepo, C., Kontos, E., Pinto, R. T., & Bauer, P. (2015). Trends of offshore wind projects. *Renewable and Sustainable Energy Reviews*, 49, 1114-1135. <https://doi.org/10.1016/j.rser.2015.04.092>

Sherif, S. A., Barbir, F., & Veziroglu, T. N. (2005). Wind energy and the hydrogen economy—review of the technology. *Solar Energy*, 78(5), 647-660. <https://doi.org/10.1016/j.solener.2005.01.002>

Shih, Y. H., & Tseng, C. H. (2014). Cost-benefit analysis of sustainable energy development using life-cycle co-benefits assessment and the system dynamics approach. *Applied Energy,* 119, 57-66. <https://doi.org/10.1016/j.apenergy.2013.12.031>

Snyder, B., & Kaiser, M. J. (2009). Ecological and economic cost-benefit analysis of offshore wind energy. *Renewable Energy*, 34(6), 1567-1578. <https://doi.org/10.1016/j.renene.2008.11.015>

Tseng, P., Lee, J., & Friley, P. (2005). A hydrogen economy: opportunities and challenges. *Energy*, 30(14), 2703-2720. <https://doi.org/10.1016/j.energy.2004.07.015>

Xiang, Y., Cai, H., Gu, C., & Shen, X. (2020). Cost-benefit analysis of integrated energy system planning considering demand response. *Energy*, 192, 116632. <https://doi.org/10.1016/j.energy.2019.116632>

Kannah, R. Y., Kavitha, S., Karthikeyan, O. P., Kumar, G., Dai-Viet, N. V., & Banu, J. R. (2021). Techno-economic assessment of various hydrogen production methods–A review. *Bioresource Technology*, 319, 124175. <https://doi.org/10.1016/j.biortech.2020.124175>