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Can green hydrogen exports contribute to regional economic development? Exploring scenarios from the Dutch-Brazilian green hydrogen corridor for the state of Ceará

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Abstract

To meet climate change mitigation targets, an exponential increase in global green hydrogen trade is expected. Countries rich in renewable energy resources would be in a favourable position to become exporters, potentially bringing opportunities for socio-economic development. The Brazilian state of Ceará is developing a large-scale green hydrogen hub, which is expected to provide one-fifth of European Union (EU) imports by 2030 via the green corridor between Ceará and The Netherlands. Located in what has historically been the least-developed Brazilian region, the green hydrogen hub could bring unique opportunities for regional development in Ceará. However, while empirical studies on economic impacts from other renewable energy projects in developing economies show limited localised benefits, the potential economic co-benefits from export-oriented green hydrogen projects remains uncertain. This study combines semi-structured interviews and input-output modelling to estimate impacts on value-added, income and jobs (by gender) in Ceará according to four local content share scenarios and three renewable energy technologies (onshore wind, offshore wind and solar photovoltaics). By doing so, this study is the first to estimate the potential for economic co-benefits from export-oriented green hydrogen projects in a developing economy context, in a sub-national level, while accounting for technology- and project-specificity as well as impacts on gender inequality. Results suggest that highly internationalized scenarios, that is, with low local content shares and dominated by multinational companies, would not only present local benefits that are often an order of magnitude lower, but could, through distributional implications of employment types, also exacerbate existing income and gender inequalities.

Key words: Economic Co-benefits; Green Hydrogen; Gender; Input-Output Analysis; Regional development; Brazil

JEL codes: O14, O19, Q56, R58

1. Introduction

Reaching net-zero greenhouse gas emission targets would require a massive expansion of cross-border trade of green hydrogen (IEA, 2022; IRENA, 2022b). As an energy carrier, green hydrogen allows the transport of stored renewable energy from places with abundant low-cost renewable sources to places with low availability of renewables but high demand (IRENA, 2022d). While the world's first-ever international shipment of hydrogen took place as recently as February 2022, estimates are that 12 Mt/yr would be exported by 2030 (IEA, 2022). The ascent of such an international hydrogen market is expected to impact global value chains and create new opportunities for exports and green industrialization (Eicke & De Blasio, 2022; Pflugmann & De Blasio, 2020; Van de Graaf et al., 2020).

Some argue that the rise of a global green hydrogen market could present a unique opportunity for developing and emerging economies to develop in line with more sustainable pathways, given their renewable energy potential (IRENA, 2022d). Aiming to leverage on green hydrogen exports to promote regional development, the Brazilian State of Ceará has created a green hydrogen hub in February 2021, the "HUB H2V". The state of Ceará is located in the North-East region of Brazil, which is both the region with the lowest Human Development Index (HDI) and income per-capita and the region with the highest potential for renewable energy (Vasconcellos & Caiado Couto, 2021), which would allow green hydrogen production at more competitive prices (IRENA, 2022b). Moreover, the Port of Pecém has a direct connection to import corridors in Europe since the Port of Rotterdam (Netherlands) is one of its shareholders. As a result from this favourable position, the HUB H2V is expected to provide around a fifth of European green hydrogen imports by 2030 via the "green corridor" between the Port of Pecém and the Port of Rotterdam (Port of Rotterdam, 2022, 2023). This has led to great expectations that the green hydrogen hub could bring unique economic opportunities for Ceará (Secretariat for Economic Development and Employment, 2022).

However, emerging research identifies some challenges. The technology capabilities (considering equipment manufacturing and patents) for a green hydrogen economy are concentrated in advanced economies (Wappler et al., 2022). This means developing regions may be unable to compete in value-added sectors and hence have economic gains from green hydrogen limited to exports (Eicke & De Blasio, 2022). The literature of foreign direct investments in developing economies suggests that export-based industries dominated by foreign capital often present very few linkages (and benefits) to the rest of the economy (Gallagher & Zarsky, 2007). Indeed, evidence for investments in other renewable energy technologies such as hydropower, wind, and solar, indicate that economic co-benefits from renewable energy projects are limited in contexts of scarce pre-existing capabilities (Lema et al., 2021; Vasconcellos & Caiado Couto, 2021).

Nevertheless, the potential economic co-benefits from export-oriented green hydrogen projects in developing country contexts have not yet been assessed. Studies on green hydrogen have focused on techno-economic feasibility, overlooking socio-economic aspects (Hanusch & Schad, 2021; Kalt & Tunn, 2022; Müller et al., 2022). This study contributes to filling this gap by providing a first estimate of potential impacts on value-added, income, and employment (disaggregated by gender) via a technology-specific input-output (I-O) model. Input-output analysis (IOA) is a commonly used approach for estimating ex-ante economic impacts

(International Labor Organization, 2017; Miller & Blair, 2021) and has been used to assess the impact of renewable energy investment projects including onshore wind, solar photovoltaics and hydropower (Jenniches, 2018; Milani et al., 2020; Vasconcellos & Caiado Couto, 2021). As I-O models can be used to estimate the direct, indirect, and induced effects of a change in one industry on the rest of the economy by describing how industries are interconnected (Miller & Blair, 2021), they provide additional insights when compared to employment factor and inventory approaches (International Labor Organization, 2017; Jenniches, 2018). Moreover, IOA has lower data requirements than general equilibrium models, which can be an advantage especially in the context of new economic activities like green hydrogen production where data is often unavailable (International Labor Organization, 2017; Jenniches, 2018).

Some shortcomings of previous IOA studies addressed in this study are that, firstly, many IO models, including some of those used in assessing impacts of development finance (e.g., JIM, 2021) estimate impacts from “any” one dollar of investment in the energy sector, not differentiating between one dollar invested in fossil fuels and one dollar invested in a wind park, for instance (International Labor Organization, 2017; Pai et al., 2021). This differentiation is nevertheless crucial in the context of climate change. Models like the JEDI and EIM-ES have started to overcome this limitation by incorporating technology-specific input structures (Fearnehough & Skribbe, 2022; NREL, 2022). However, they did not include green hydrogen technologies at the time of this study. Secondly, relying exclusively on macroeconomic data from statistics office imposes limitations when assessing impacts of emerging technologies (International Labor Organization, 2017; Miller & Blair, 2021) given uncertainties concerning e.g., project design and technology characteristics. Thirdly, the assessment of impacts on gender equality is understudied in the literature (Jenniches, 2018), despite its key role in achieving sustainable development.

Finally, previous studies on impacts from renewable energy overwhelmingly focused on national level impacts in OECD countries like United States, Germany and Spain (Jenniches, 2018), even though substantial differences could be expected across the economic structures of regions and countries (Miller & Blair, 2021). These shortcomings can be problematic since past evidence suggests that technology-specificity, project design aspects, and local socio-economic context are all determinants for economic co-benefits of renewable energy projects (Lema et al., 2021; Milani et al., 2020; Vasconcellos & Caiado Couto, 2021). Technologies have different levels of labour intensity, while investment projects may be designed in a full-package fashion with little space for the involvement of local firms and actors. The inexistence of local supply chains requires that technologies are imported and limited local capabilities may lead to structural dependencies on foreign knowledge and providers (Lema et al., 2021; Milani et al., 2020; Vasconcellos & Caiado Couto, 2021).

This study incorporates the technology, project, and context specificities highlighted above via the formulation of scenarios for development of export-oriented green hydrogen projects in the Green Hydrogen Hub (HUB H2V) at the Port of Pecém in the state of Ceará. For instance, the share of project expenditures carried out locally is used to limit the impact analysis to the state of Ceará, while the changes in final demand are specified to account for green hydrogen-specific production and operation structures, and the local context capabilities are reflected on the sub-national coefficients describing the structure of the economy of Ceará. To overcome uncertainties related to an emerging technology, this study combines IOA with qualitative semi-structured interviews with stakeholders involved in the development of the HUB H2V and a field visit to Pecém.

Therefore, this study contributes to the literature by estimating economic impacts for green hydrogen investments in a developing economy, in a sub-national level and accounting for technology-specificity as well as gender (in)equality. As such, it provides a first estimate for green hydrogen technologies, while contributing to expand the literature on non-OECD countries and on the impacts of the energy transition on gender. By using a mixed-methods approach that combines semi-structured interviews with macroeconomic and investment cost data, it is better able to overcome data limitations and uncertainties related to an emerging technology and project design. In addition, by modelling scenarios that allow for comparison between different technology, project, and country characteristics, it contributes to bridge the gap between qualitative case study based evidence with quantitative economic modelling techniques.

The rest of this paper is organized as following. Section 2 provides an overview of the materials and methods. Section 3 summarizes the key assumptions and scenarios. Section 4 presents the results from the input-output analysis. Section 6 discusses the main results and implications for policy making, identifying areas for further research, while Section 7 provides the key conclusions from this study.

2. Materials and Methods

This study combines qualitative semi-structured interviews and quantitative input-output modelling to estimate impacts on value-added, income and jobs (by gender) in Ceará according to different scenarios. This mixed-method approach is commonly used to translate qualitative narratives about the future into inputs for quantitative scenario modelling (Mallampalli et al., 2016), including for I-O analysis of renewable energy projects (Simas & Pacca, 2014).

Stakeholder expectations for green hydrogen production in the state of Ceará are identified via 21 semi-structured expert interviews (conducted between May and November 2022), a field visit to Port of Pecém (in May 2022), as well as official documents and communications. Sample selection criteria for the interviews was based on the direct involvement of the stakeholder in the development of a green hydrogen economy in the state of Ceará, while ensuring for representativeness across stakeholder types (e.g., local government, local university, industry association, project developers and foreign governments/international actors). A snow-balling approach was followed to expand on the initial selection and sample size was defined based on saturation, that is, when no new information or (unrepresented) stakeholder was identified. The list of interviews can be found in Table 1. Interviews and documents were coded using Nvivo 20.

Table 1 - List of interviews

	Date	Stakeholder type	Origin
1	18/05/2022	Industry Association	Local
2	18/05/2022	Industry Association	Local
3	19/05/2022	Government	Local

4	20/05/2022	Project Developer	Local
5	20/05/2022	University	Local
6	26/05/2022	Government	National
7	26/05/2022	Government	National
8	26/05/2022	Technical Education	Local
9	31/05/2022	University	Local
10	01/06/2022	Project Developer	Multinational
11	09/06/2022	Government	Local
12	18/08/2022	Consultant	International
13	20/09/2022	Technology provider (Electrolysis systems)	National
14	20/09/2022	Port	Local
15	21/09/2022	Industry Association	National
16	22/09/2022	Steel Maker (User)	Multinational
17	22/09/2022	Steel Maker (User)	Local
18	18/10/2022	Technology provider (Electrolysis systems)	Multinational
19	21/10/2022	Port	Local
20	24/10/2022	Government	European
21	18/11/2022	Port	European

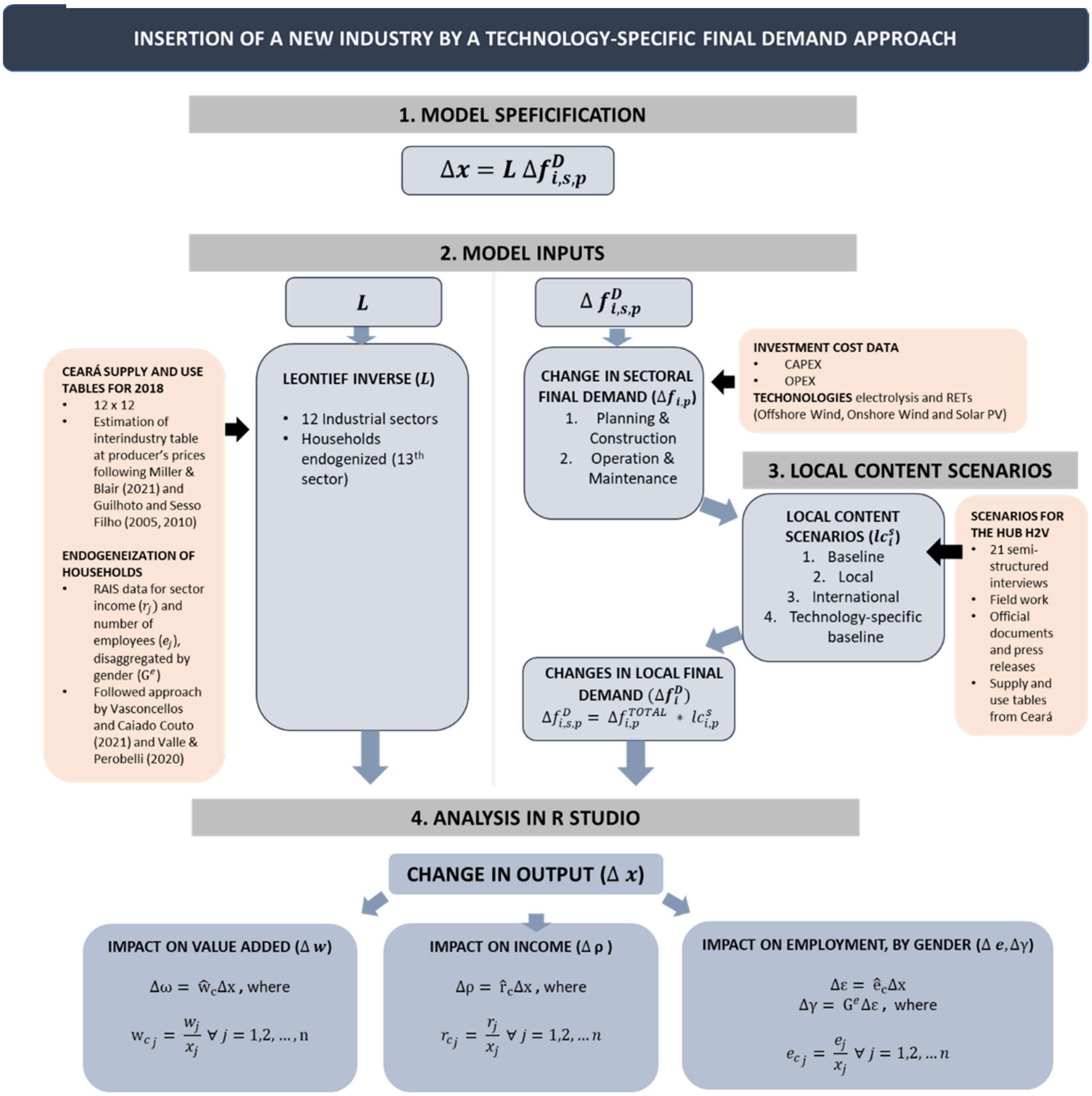
Regarding the input-output analysis, this study uses a semi-closed static Leontief model to estimate impacts on output, value added, employment and household income from salaries. Employment is measured in full-time equivalent (FTEs) and disaggregated by gender. The following paragraphs briefly summarize the methodology followed in this study (see also Figure 1). A more detailed explanation can be found in the supplementary material.

To determine the Leontief inverse, this study uses the Supply and Use tables for state of Ceará in the year of 2018 provided by the Brazilian Institute of Geography and Statistics (IBGE), the most recent economic data available at the sub-national level. These tables are organized in a 12x12 commodity-by-industry matrix (Instituto Brasileiro de Geografia e Estatística - IBGE, 2022b). Data for employment and income, disaggregated by gender and sector, is taken from the RAIS database from the Brazilian Ministry of Employment (Ministry of Employment, 2022).

Since there was no green hydrogen production in the state of Ceará in the year of 2018, green hydrogen had to be included as a new industry. For this, a final demand approach is followed, as explained by Miller and Blair (2021). To ensure that the change in final demand incorporates technology-specificity, investment cost data for green hydrogen is disaggregated into component parts. These components are then allocated to specific economic sectors. Investment cost data is grouped into Capital Expenditures (CAPEX) and Operational Expenditures (OPEX) to estimate effects during two phases: 1) Planning and Construction; and 2) Operation and Maintenance. This is a similar approach as followed by other studies and models (Fearnehough & Skribbe, 2022; International Labor Organization, 2017; Milani et al., 2020; NREL, 2022; Vasconcellos & Caiado Couto, 2021). Impacts for the construction phase are estimated for the entire construction period, and are not recurrent. Impacts for the operation phase are estimated by year of operation.

In order to capture only the effects on the local economy, the shares of each investment component that is spent in Ceará is estimated via local content scenarios. The formulation of such scenarios is explained in the next section, and, in detail, in the supplementary material. Table 2 provides an overview of the data and sources used in this study.

Figure 1 - Methodological approach



#	Data	Source(s)
1	Ceará's Use and Supply tables disaggregated in 12 sectors for the year of 2018.	Brazilian Institute for Geography and Statistics (IBGE), 2022: System of regional accounts. Available at: https://www.ibge.gov.br/estatisticas/economicas/contas-nacionais/9054-contas-regionais-do-brasil.html?=&t=resultados Accessed on Feb 2023.
2	Employment (FTE) and average income per industry for the state of Ceará in the year 2018, disaggregated by gender	Ministry of Employment (MTE), 2022: RAIS data. Available at http://pdet.mte.gov.br/rais
3	Green hydrogen input structure	Reports like IRENA (2020), ISPT(2020), Danish Energy Agency (2022), LAZARD (2021) .

		Peer reviewed techno-economic feasibility studies for Brazil (Macedo & Peyerl, 2022; Nadaleti et al., 2020). NREL(2018) H2A : Hydrogen production analysis model. Double-checked in interviews
4	Local content scenarios	21 Semi-structured interviews between May and November 2022 Sectoral shares of domestic supply from the Ceará Supply-Use Tables Mapping of local assembly companies during field work
5	Renewables input structure (onshore wind, offshore wind and solar photovoltaic)	Cameron & van der Zwaan (2015); Glasson et al. (2022); Kattumuri & Kruse, (2019); Meyer & Sommer (2016); Nasirov et al (2021); Sooriyaarachchi et al (2015); Tegen et al. (2015) IRENA (2022c)
6	Exchange rate	Official exchange rate of the day 31/12/2018 for fiscal purposes.

Table 2 - Summary of data and sources

2.1 Assumptions and scenario formulation

As explained, economic co-benefits of renewable energy projects will depend on technology, project, and context-related factors. These will be explained below.

2.1.1 Technology assumptions

Assumptions regarding technology factors include cost structure (i.e. how the investment components will be reflected in demand for certain industry sectors) and employment intensity, measured by, for instance, the number of full-time equivalent (FTEs) employed by mega-watt (MW) of installed capacity. Table 4 provides a summary of cost assumptions in USD/kW of installed capacity disaggregated by technology, sector and project phase. The employment factor for the operation of an electrolysis plant phase is assumed to be 0.07 FTE/MW for green hydrogen. Assumptions are based on a combination of interviews and a literature review of renewable investment projects available on the supplementary material. Large-scale electrolysis projects are expected to lead to fewer jobs per MW of installed capacity since employment factors do not increase linearly with scale (Interviews 4,10,13). Operating an electrolysis plant is not job-intensive (operating a 20MW-100MW electrolysis plant requires between 5-10 FTE)(Interviews1,3,4,10,13,15). No direct employment in the new green hydrogen sector is assumed in the construction phase, as preliminary planning activities would be conducted by other existing companies (Interviews 1,3,4,10,13,15).

For green hydrogen projects, the source of electricity is an important factor. Green hydrogen is produced via electrolysis (AEC) using renewable electricity – usually from solar and wind – to separate water into oxygen and hydrogen (IEA, 2022; Macedo & Peyerl, 2022). Whether this electricity will be sourced from existing wind and solar farms (and hence probably displacing other consumers) or include the investment on an entirely new wind and solar farm is an important determinant. For green hydrogen exports to qualify for green certificates required for imports in the European Union, renewable electricity generation has be to "additional" to what is already connected to the grid (Interviews4,10,12,20)(European Commission, 2023). This means that project developers will likely have dedicated generation or at least some form of power purchase agreement (PPA) to ensure electricity for electrolysis comes from new solar or wind based power generation (Interviews4,10,18).

We hence assume that every investment in a new electrolysis plant would be expected to lead to investments on a new renewable energy generation unit to meet the electricity requirements for green hydrogen production, but we also report results for electrolysis plant alone to provide a comparison with how truly additional green hydrogen production would be in comparison to an expansion of the renewable energy capacity for other end-uses (e.g., grid decarbonization, electrification of transport and industry processes, etc). We assume this renewable energy generation unit can be a solar-photovoltaics, onshore wind, or offshore wind farm. The capacity factors of these electricity generation technologies are assumed to be equal to the average of the state of Ceará, implying that each 1MW of electrolysis capacity would require 1.58 MW of offshore wind, 2.22 MW of onshore wind, and 4.06 MW of solar-photovoltaics installed (see supplementary material).

Costs for renewable energy technologies are also available in Table 4. Employment factors are assumed to be 0.64 FTE/MW, 1.1 FTE/MW, and 1.3 FTE/MW for onshore wind, solar photovoltaics, and offshore wind, respectively. Costs and employment factors are based on the literature review (see Supplementary Material).

Sector	**CAPEX (USD/kW)**				**OPEX (USD/kW)**			
	Green H2	OnWind	OffWind	SolarPV	Green H2	OnWind	OffWind	SolarPV
S01: Agriculture	0	0	0	0	0	0	0	0
S02: Extractive Industries	0	0	0	0	0	0	0	0
S03: Transformation industries	713	912	2,136	534	22	18	42	12
S04: Electricity, gas, water, and other utillities	0	0	0	0	0	12	19	10
S05: Construction	22	189	286	155	0	0	0	0
S06: Commerce	0	0	0	0	0	0	0	0
S07: Transport storage and post services	0	49	0	0	0	0	0	0
S08: Information and communication	0	0	0	0	0	0	0	0
S09: Financial activities, insurances, and related fees	120	49	290	97	11	0	0	0
S10: Real state activities	0	0	0	3	0	2	0	0
S11: Other activities and services	168	38	145	60	0	0	0	0
S12: Public administration, defense, healthcare, education, and social security (PADHESS)	0	0	0	0	0	0	0	0
Green Hydrogen	0	0	0	0	0	0	0	0
Households	0	0	0	0	2	23	46	39
Total	**1023**	**1237**	**2857**	**849**	**35**	**55**	**107**	**60**

Table 3 - Cost assumptions in USD/kW of technology installed capacity

2.1.2 Project-related assumptions

The Green Hydrogen Hub at the Port of Pecém (HUB H2V) was officially established in February 2021 via the signature of a Memorandum of Understanding (MoU) between the Government of Ceará (GoC), the Industry Association of the State of Ceará (FIEC), the Complex of Pecém (CIPP), and the Federal University of Ceará (UFC). The CIPP is currently a joint-venture between the GoC and the Port of Rotterdam (PoR) from the Netherlands, established in 2018 (Interviews1,2,3,11,14,15,19,21). Until November 2022, 20 MoUs had been signed between the GoC and potential investors (see Table 4).

	Company name	**Company sector**	**Company Origin**
1	Enegix Energ	Energy	Australia
2	White Martins/Linde	Industrial gases	Brazil/United States

3	Qair	Energy	France
4	Fortscu	Iron ore	Australia
5	Energias de Portugal (EDP)	Energy	Portugal
6	Neoenergia/Ibérdola	Energy	Brazil/Spain
7	H2Hellium	Energy	Brazil (Rio de Janeiro)
8	Eneva	Energy	Brazil (Rio de Janeiro)
9	Hytron	Electrolyser provider	Brazil (São Paulo)
10	Diferencial Energia	Energy	Brazil (São Paulo)
11	Engie	Energy	France
12	Total Eren	Energy	France
13	Transhydrogen Alliance	Hydrogen Association	European
14	AES Brasil	Energy	Brazil (São Paulo)
15	Cactus Energia verde	Energy	Brazil (Rio de Janeiro)
16	Casa dos Ventos	Energy	Brazil (Ceará)
17	H2 Green power	Green Hydrogen	United Kingdom
18	Energy Vault SA	Storage technology	Switzerland
19	Nexway	Energy	Brazil (São Paulo)
20	Mitsui	Multi-sector	Japan
21	ABB	Technology supplier	Switzerland
22	CaetanoBus	Automobile	Portugal

Table 4 - List of MOUs signed with the Government of Ceará up to November 2022

Given the announcements from companies that have signed a memorandum of understanding with the HUB H2V, projects can be divided into two phases: in the short-term (up to 2025), most announcements are for plants on the range of 20-500MW, with a median size around 100MW. These announcements add to 2 giga-watts of installed capacity. Hence, we assume 2 GW of electrolysis capacity by 2025 under 20 plants of 100 MW. Announcements for the long term are mostly on the giga-watt scale (Interviews1,3,15). We do not take these into account given uncertainties regarding both the technology progress and the structure of the economy by then.

Whether project developers are local or foreign firms and how much these firms are going to buy from local firms or import are key determinants for assessing the impacts of a project. The majority of prospective investors that signed initial MoUs with the GoC are multinational companies or Brazilian companies located in other states (Table 4) (Interviews1,3,4,11,14,15,19). MoUs often include clauses establishing that investors would undertake efforts to source goods and services locally, even though not legally binding (Interviews4,11,14,19). Nevertheless, projects will likely be based on high shares of imports. Project developers estimate that at least two-thirds of total systems costs would be spent on imports from other countries due to (perceived) better cost-efficiency, faster development of foreign technologies, and existing companies supply chains (Interviews 4,10,18).

2.1.3 Context characteristics

Not only the decision of the developers counts, but also the local economic structure: for developers to be able to buy from the local economy there must be local firms that are able to supply the products and services and labour can only be hired locally if there are enough skilled people available to work. The policy and regulatory environment may require investors to buy a minimum share of products and services from the local economy.

The Port of Pecém is surrounded by an industrial complex with companies that could play a role across the green hydrogen value chain. For instance, in the upstream, there is the Brazilian wind blade manufacturer Aeris Energy, the biggest wind blade manufacturer in Latin America and supplier for turbine manufacturers such as Vestas, Nordex, Siemens Gamesa and WEG (Aeris, 2023). Moreover, Vestas has a factory in the state of Ceará (Vestas, 2023).

Regarding the local labour market, 420 thousand people were unemployed in Ceará in 2018, while 1.3 million people were underemployed (Instituto Brasileiro de Geografia e Estatística - IBGE, 2022a). Based on the expectation of employment creation, the GoC together with the local industry association and the GIZ are conducting trainings on green hydrogen aiming to build the skills required for a future workforce (Interviews1,8,12,15). Hence, most stakeholders do not expect constraints in the local labour market (Interviews1,8,12,15).

2.1.4 Local content scenarios

Four local content share scenarios (s) are estimated. The "*International Project*" scenario assumes that technologies are imported, project development activities are undertaken in multinational headquarters and insurances and fees are also taken abroad. Only construction and plant operation expenditures are assumed to be local, where the baseline value is taken instead. The *International Project* scenario seems to be the most realistic based on the field work and interviews and given the companies that have already signed an MOU, but is the one that assumes the lowest local content share. In contrast, the "*Local Technology*" scenario is based on the assumption that 100% of goods and services required in the investment would be sourced locally in Ceará, which is not realistic given that no local industries to supply some products and services. This scenario provides an idea of what could have been the maximum benefits in such a project. The "*Economy Baseline*" scenario takes the share of domestic supply in the total supply for each sector i from the supply-use tables of Ceará. However, since sectors are highly aggregated, these may not be representative of specific technologies. The "*Technology-specific baseline*" hence adapts the baseline scenario where necessary to incorporate the specific local capabilities for each technology (electrolysis, onshore wind, offshore wind and solar photovoltaics) (see Supplementary Material). Tables 5 and 6 summarize the local content shares used in this study for the construction and operation phase, respectively.

Not all scenarios are equally realistic, but differences in impacts between scenarios could be an indicator of how economic benefits from international renewable energy investments would depend on country, technology and project characteristics. For instance, by comparing the Baseline and Technology Baseline, it is possible to assess whether investments in a green hydrogen production plant would generate higher or lower impacts than what would have been expected on average. Moreover, by comparing the International and Technology-specific and Baseline scenarios, it is possible to see how different project decisions regarding imports of technologies can affect local outcomes. Finally, the difference between the Baseline and Local scenarios could provide an first idea (from a static point of view) on to which extend increasing local capabilities could impact economic benefits.

The technology-specific scenario and the international scenario could be realistic for the current projects being developed and are based on the interviews. For the technology-specific baseline, local content shares in sector S03: Transformation Industries would change from the baseline, since Ceará has a well-established local wind turbine assembly industry (Aeris and Vestas have factories in the area) but no solar or electrolysis manufacturing/assembly industry (Interviews). For offshore wind, it is assumed that for some parts the onshore industry could relatively easily adapt to offshore in the short-medium term, while for others (e.g., installation of sub-structures offshore) this would be more difficult. The *Baseline* and *Local* scenarios do are not intended to be realistic, but rather to support comparison.

	Local Technology	**Economy Baseline**	**International Project**	**Technology Baseline H2**	**Technology Baseline ONW**	**Technology Baseline OFW**	**Technology Baseline PV**
S01: Agriculture	1	0.587	0.000	0.587	0.587	0.587	0.587
S02: Extractive Industries	1	0.648	0.000	0.648	0.648	0.648	0.648
S03: Transformation industries	1	0.635	0.000	0.000	1.000	0.700	0.000
S04: Electricity, gas, water, and other utilities	1	0.775	0.000	0.775	0.775	0.775	0.775
S05: Construction	1	0.595	0.595	0.595	0.595	0.595	0.595
S06: Commerce	1	0.809	0.000	0.809	0.809	0.809	0.809
S07: Transport storage and post services	1	0.729	0.000	0.729	0.729	0.729	0.729
S08: Information and communication	1	0.868	0.000	0.868	0.868	0.868	0.868
S09: Financial activities, insurances, and related fees	1	0.703	0.000	0.703	0.703	0.703	0.703
S10: Real state activities	1	0.608	0.000	0.608	0.608	0.608	0.608
S11: Other activities and services	1	0.748	0.000	0.500	0.500	0.500	0.500
S12: Public administration, defense, healthcare, education, and social security (PADHESS)	1	0.791	0.000	0.791	0.791	0.791	0.791
Green Hydrogen	1	0.000	0.000	0.000	0.000	0.000	0.000
Households	1	0.699	0.000	0.699	0.699	0.699	0.699

Table 5 - Local content shares during the construction phase

	Local Technology	**Economy Baseline**	**International Project**	**Technology Baseline H2**	**Technology Baseline ONW**	**Technology Baseline OFW**	**Technology Baseline PV**
S01: Agriculture	1	0.587	0.0	0.587	0.587	0.587	0.587
S02: Extractive Industries	1	0.648	0.0	0.649	0.649	0.649	0.649
S03: Transformation industries	1	0.635	0.0	0.000	1.000	0.377	0.000
S04: Electricity, gas, water, and other utilities	1	0.775	1.0	1.000	1.000	1.000	1.000
S05: Construction	1	0.595	0.0	0.596	0.596	0.596	0.596
S06: Commerce	1	0.809	0.0	0.809	0.809	0.809	0.809
S07: Transport storage and post services	1	0.729	0.0	0.730	0.730	0.730	0.730
S08: Information and communication	1	0.868	0.0	0.869	0.869	0.869	0.869
S09: Financial activities, insurances, and related fees	1	0.703	0.0	0.500	0.500	0.500	0.500
S10: Real state activities	1	0.608	0.0	0.609	0.609	0.609	0.609
S11: Other activities and services	1	0.748	0.0	0.500	0.500	0.500	0.500
S12: Public administration, defense, healthcare, education, and social security (PADHESS)	1	0.791	0.0	0.792	0.792	0.792	0.792
Green Hydrogen	1	0.000	0.0	0.000	0.000	0.000	0.000
Households	1	0.699	0.5	0.699	0.699	0.699	0.699

Table 6 - Local content shares during operation phase

2.2 Sensitivity analysis

Since input-output analysis is a linear model, changes in absolute values for the total final demand would lead to an equivalent change in total impacts. Hence, it is instead more insightful to look at the different sectoral allocations of the change in final demand since sectors have different multipliers and impacts could hence change depending on the sectoral allocation. Therefore, regarding the uncertainties concerning the CAPEX for green hydrogen electrolysis, we estimate results with a different sectoral allocation, where project development is allocated directly to households reflecting the possibility of direct employment instead of outsourcing, and the indirect costs are disaggregated into owner management and supervision, land costs, permitting costs, insurance, and grid fees. These costs are estimated based on the previous literature review on investment costs (see Supplementary Material).

Cost.Item	Sector	Value.kW
Electrolyzer (Stack)	3	321
Balance of plants (Gas separation, compression and gas treatment)	3	110
Civil, Structural & Achitectural (Construction)	5	22
Utilities and Process Automation (Water, piping, ICT)	3	86
Power supply and electronics (Electrical installations)	3	196
Owner project management and supervision	13	48
Engineering, project management, construction supervision and management	13	46
Land costs	10	0.008
Permitting costs	11	2
Insurance	9	69
Grid fees and electricity consumption	4	38
Total		**938**

Table 7 - Disaggregated costs for sensitivity analysis

Moreover, another area of uncertainty concerned the employment factors, given the wide ranges reported on the literature. We hence re-estimate impacts by varying employment factors into a "low impacts" and a "high impacts" scenario. Similarly, we look at the sensitivity of our results for the capacity factors since higher capacity factors leads to lower installed capacity for renewable energy per electrolysis capacity and hence overall lower expenditures. Table 8 summarizes the configuration of the sensitivity analysis.

Finally, we estimate one scenario combining all aforementioned variations that increase economic impacts when compared to the default configuration ("AllMax") and one scenario combining the values that negatively affect economic impacts when compared to the default configuration ("AllMin"). All of these scenarios are estimated in combination with the local content scenarios (LocalTechnology, EconomyBaseline, TechnologyBaseline, and InternationalProject).

Dimension	Scenario	Scenario name	Project phase	Baseline	Lower impacts	Higher impacts

Project	Project development in-house during construction phase (Households)	ProjDev13	Construction	Costs aggregated and allocated to "Other activities and sectors"		
Technology	Different employment factors	EmpMax and EmpMin	Operation	0.7 0.64 1.1 1.3	0.05 0.1 0.1 0.7	0.1 2.2 4.0 1.7
Local context	Capacity factors	CFHigh and CFLow	Construction and Operation	24% 44% 62%	27% 48% 68%	20% 40% 56%

Table 8 – Summary of sensitivity analysis

3. Results

Firstly, we will discuss the main results from our analysis, by type of impact: value-added, income, and employment. Secondly, we will discuss the robustness of these results by contrasting them with the results from a sensitivity analysis.

3.1 Value-added

For the construction of an electrolysis plant alone adding to two giga-watt of electrolysis capacity, total impacts on value added are estimated to be around 25 USD million and 380 USD million for the *International project* and *Technology baseline* scenarios, respectively. This means the construction of 2 gigawatt electrolysis capacity could lead to between 0.02%-0.28% growth in value added when compared to 2018 for these two scenarios. This is between 56-4 times lower than the 1.12% increase if the average coefficients for Ceará would be taken into account. Total value added impacts would amount to 1.5 USD billion in the *Economy baseline* and 2.3 USD billion in the *Local technology* scenarios.

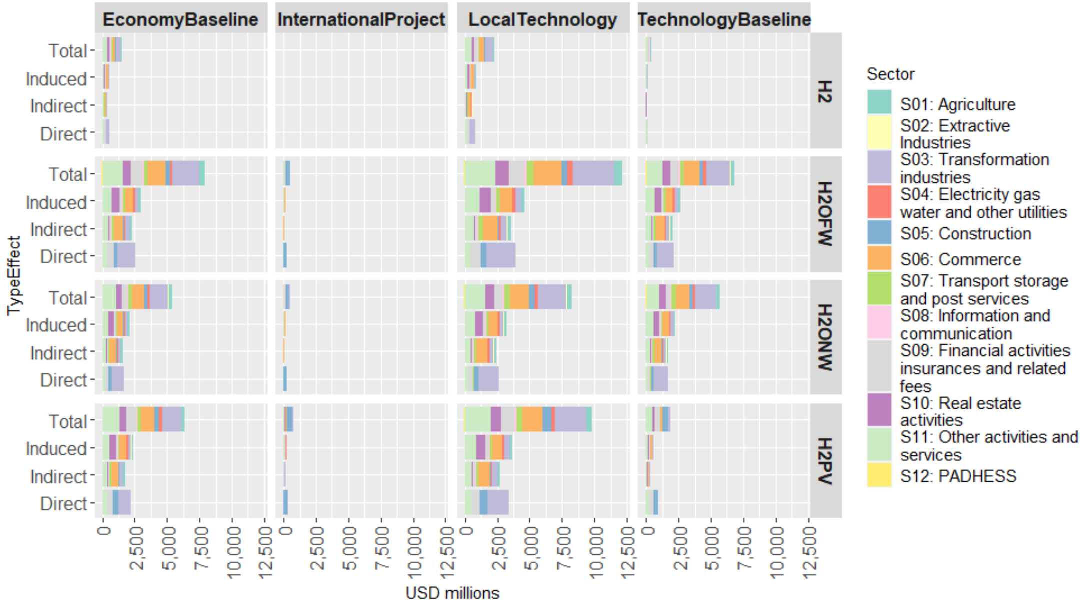


Figure 2 - Impacts on value added from the construction of 2GW of electrolysis capacity

When considering electrolysis together with the construction of new renewable energy generation units, impacts on value added increase to between 514 USD million to 6.8 USD billion for the *International Project* and *Technology Baseline* scenarios, depending on the renewable energy technology and local content scenario. This would represent an increase of 0.37- 4.99% compared to 2018. For all technologies, impacts on from these two scenarios are at least one order of magnitude lower than for the *Economy Baseline* (5.3-7.8 USD billion or 3.92-5.75%) and *Local Technology* (8.2-12 USD billion, or 6.04-8.86%).

In the operation phase, the differences between scenarios are smaller than in the construction phase. This is mainly due to the fact that spendings for the operation of the plants is a major cost component and considered to happen locally in all scenarios. Interesting to note is that in the *International Project* scenario, the operation of an electrolysis plant would lead to mainly induced effects for value added in the productive sectors, since material costs for operation are assumed to be replacement parts, and hence imported, leaving only direct labour as a local expenditure. Estimated impacts in the operation phase are between 11 and 25 USD million for electrolysis alone for the *International Project* and *Technology Baseline* scenarios, and between 155-515 USD million when including renewable energy generation in these two scenarios, depending on the renewable energy technology.

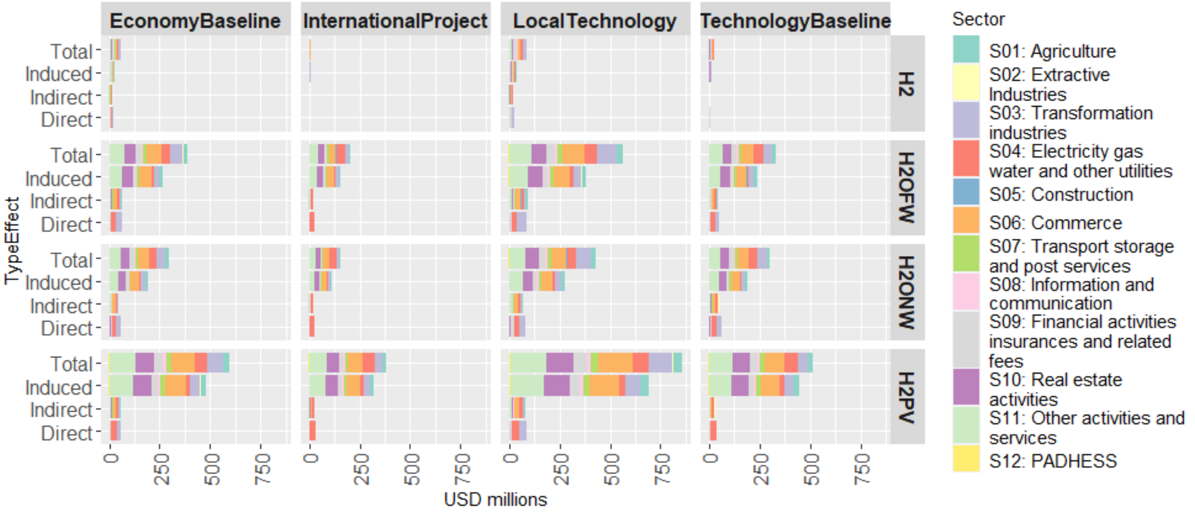


Figure 3 - Impacts on value added from the operation of 2GW of electrolysis capacity

3.2 Income

Similarly to value added, the largest share of impacts would come from the operation of the renewable energy unit and impacts are higher for the construction than operation phase. In the construction phase, impacts are orders of magnitude lower for *International Project* scenarios when compared to *Economy Baseline* scenarios: total income effects are 6 USD million for electrolysis alone and 140-206 USD million when adding renewable energy technologies for *International Project* scenario versus 450 USD million and 1.6-2.3 USD billion for *Economy Baseline.* Technology-specific scenarios are somewhere in between for all four technologies: 94 USD million for electrolysis alone and 475 USD million to 2 USD billion for electrolysis with renewable energy. Impacts are higher for solar photovoltaics in scenarios that do not take technology-specific capabilities into account and lower in scenarios that do (Figure 4).

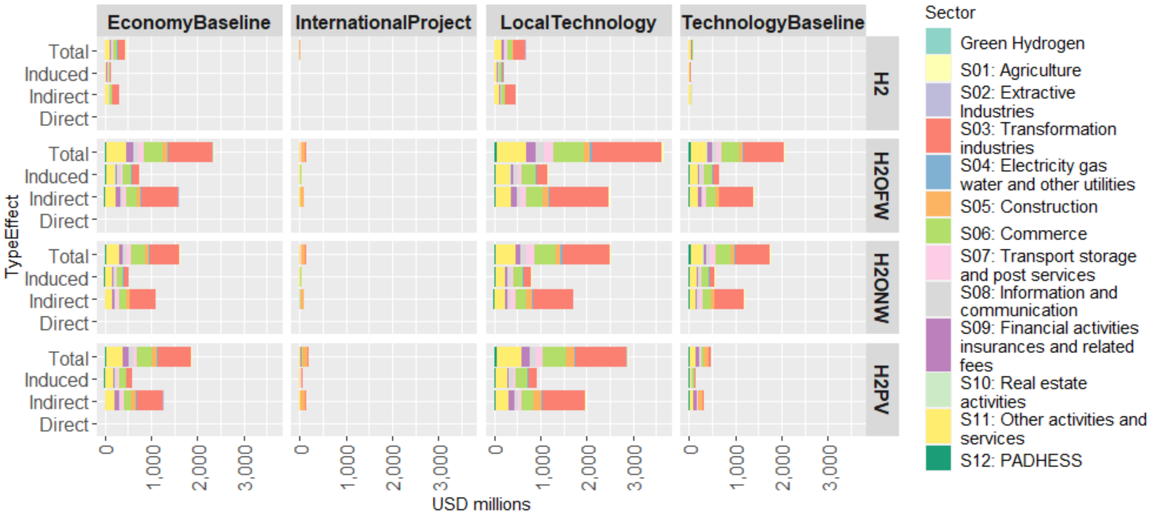


Figure 4 - Impacts on income from the construction of 2GW of electrolysis capacity

In the operation phase, impacts of *Technology Baseline* scenarios are always higher than *International Project* scenarios. For electrolysis alone, impacts are 5 and 9 USD million, respectively. When adding renewable energy generation, total income effects are 150-350 USD million for *Technology Baseline* and 90-250 USD million for *International Project* scenarios. Total impacts for scenarios with Solar PV are higher than those for wind technologies for both international and technology-specific scenarios. This is due to much higher employment factors, that lead to higher direct and induced effects despite lower indirect effects given inexistence of local value chain.

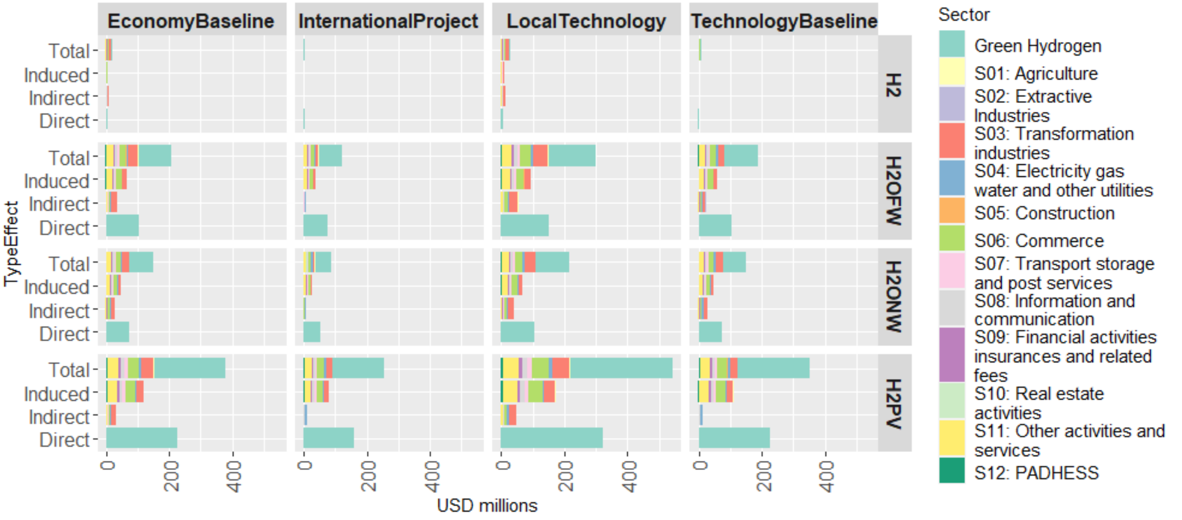


Figure 5- Impacts on income from the operation of 2GW of electrolysis capacity

3.3 Employment

For employment, there are similar findings than for value added and income. In the construction phase, impacts on total number of jobs in the international scenario would be 5 times lower than impacts on the technology-specific scenario for electrolysis and solar photovoltaics (1.9 % versus 4.2% increase compared to 2018 levels). In contrast, this difference goes to over ten times lower for wind technologies. Moreover, impacts in technology specific scenarios are 13-15 times higher than international ones for wind technologies. Figure 6 shows employment effects during the construction phase in full-time equivalent jobs.

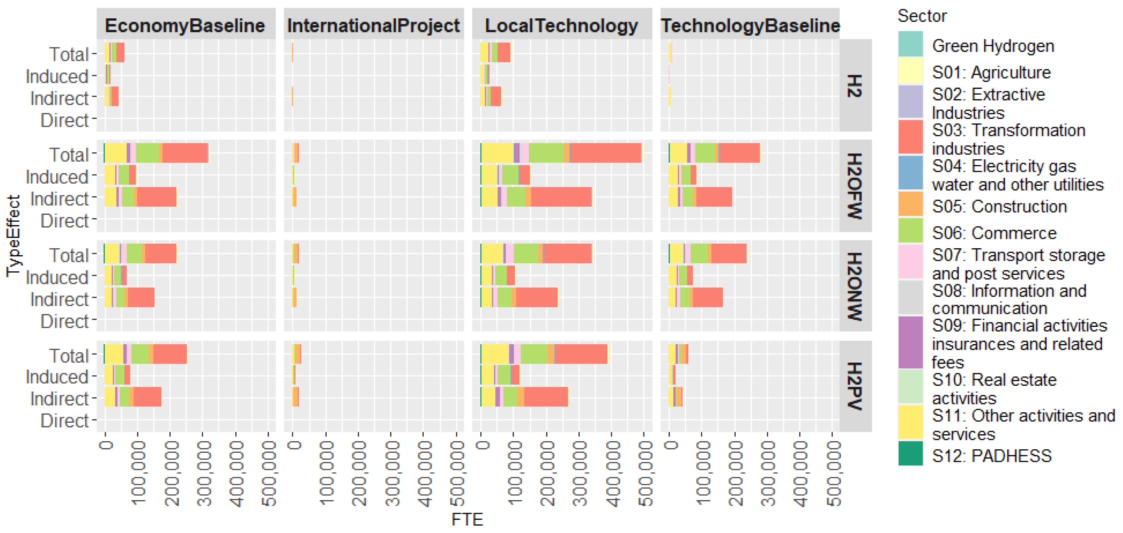


Figure 6 - Impacts on employment from the construction of 2GW of electrolysis capacity

Also important to note is that technologies have different construction periods: electrolysis and solar photovoltaics take less than one year to be built, whereas onshore and offshore wind takes more than one year to be built (see Supplementary Material). Hence, the number of full-time equivalent jobs is different from the number of jobs. For instance, saying it takes two full-time equivalent jobs to perform a task in one year could imply either that it takes two workers to perform the task in one year or one worker to perform the task in two years. Table 9 shows the results also in number of jobs, normalized by years of construction.

	Impacts on employment										
	Construction						Operation				
	Direct	Indirect	Induced	Total FTE	Total Jobs	% 2018	Direct	Indirect	Induced	Total	% 2018
Electrolysis plant (2GW)											
InternationalProject	0	631	296	927	927	0.1%	70	82	212	364	0.0%
TechnologyBaseline	0	8,236	4,023	12,259	12,259	0.8%	98	257	388	743	0.1%
EconomyBaseline	0	42,698	19,236	61,934	61,934	4.2%	98	1.251	832	2.182	0.1%
LocalTechnology	0	64,809	29,148	93,957	93,957	6.4%	140	1.913	1.242	3.295	0.2%
Electrolysis plant (2GW) + Offshore wind farm (3.16 GW)											
InternationalProject	0	13,529	6,349	19,878	7,951	0.5%	2.114	800	5.237	8.151	0.6%
TechnologyBaseline	0	196,177	88,084	284,261	113,705	7.7%	2.955	2.667	7.953	13.575	0.9%
EconomyBaseline	0	222,730	100,481	323,211	129,285	8.8%	2.955	4.664	8.794	16.413	1.1%
LocalTechnology	0	345,100	155,391	500,491	200,196	13.6%	4.227	7.125	12.754	24.106	1.6%

Electrolysis plant (2GW) + Onshore wind farm (4.44 GW)										
InternationalProject	0	12,642	5,933	18,574	12,383	0.8%	1.488	721	3.796	6.005	0.4%
TechnologyBaseline	0	167,873	74,932	242,805	161,870	11.0%	2.080	3.627	6.415	12.122	0.8%
EconomyBaseline	0	154,344	69,338	223,682	149,121	10.1%	2.080	3.488	6.327	11.895	0.8%
LocalTechnology	0	239,219	107,306	346,524	231,016	15.7%	2.975	5.294	9.163	17.432	1.2%
Electrolysis plant (2GW) + Solar PV farm (8.12 GW)										
InternationalProject	0	18,689	8,771	27,460	27,460	1.9%	4,537	1.009	10.748	16.294	1.1%
TechnologyBaseline	0	40,892	20,226	61,117	61,117	4.2%	6,344	1.184	14.861	22.389	1.5%
EconomyBaseline	0	175,864	79,880	255,743	255,743	17.4%	6,344	3.990	16.043	26.377	1.8%
LocalTechnology	0	271,931	123,290	395,222	395,222	26.9%	9,074	6.019	23.054	38.147	2.6%

Table 9 - Impacts on employment

Impacts on employment during the operation phase are highest for solar photovoltaics given a combination of higher employment factors and larger renewable energy installed capacity. Comparing to Figure 5, we see that the share of direct employment in the green hydrogen sector in total employment is lower than the share of green hydrogen in total income. This is because green hydrogen is assumed to take the average salary of the existing energy sector, which is about five times higher than the average in the state. This leads to a higher share of income than of number of jobs.

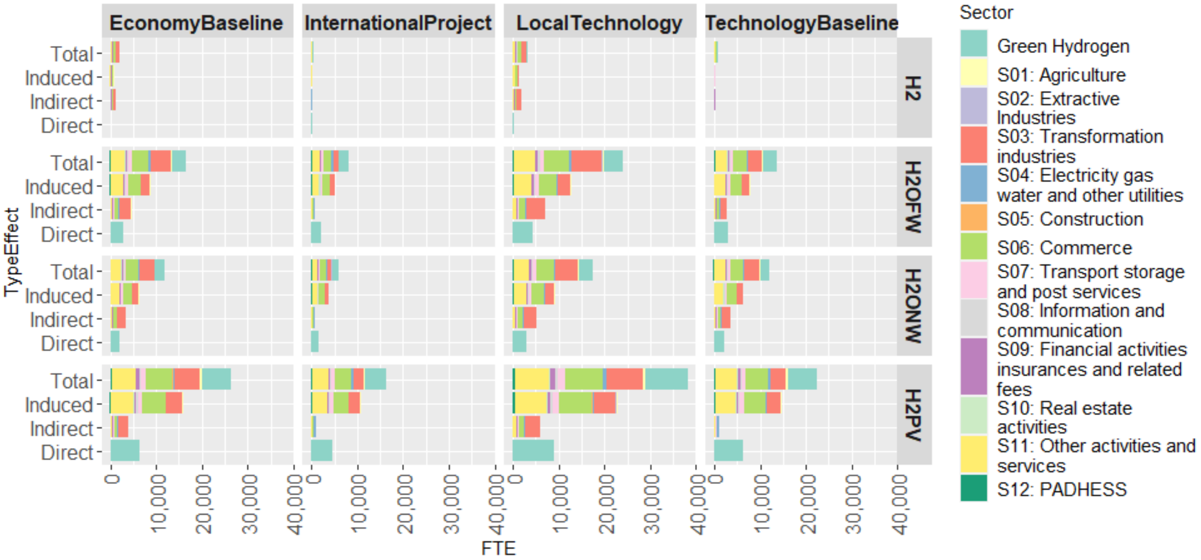


Figure 7 - Impacts on employment from the operation of 2GW of electrolysis capacity

3.4 Employment by gender

Figure 8 shows the estimates of employment disaggregated by gender. In all scenarios, jobs are expected to be created primarily for men. This is due to the current gender shares in the most impacted scenarios in each of these phases: construction (with 91% jobs for men) and utilities (with 83% jobs for men).

In the operation phase, it can be seen that especially direct employment would be gender unequal (around 80% of jobs created for men), while indirect and induced effects are closer to the state average of 62 %. This implies that sectors with lower local content shares present higher potential for reinforcing gender inequalities as impacts spread less to sectors where women employment is higher.

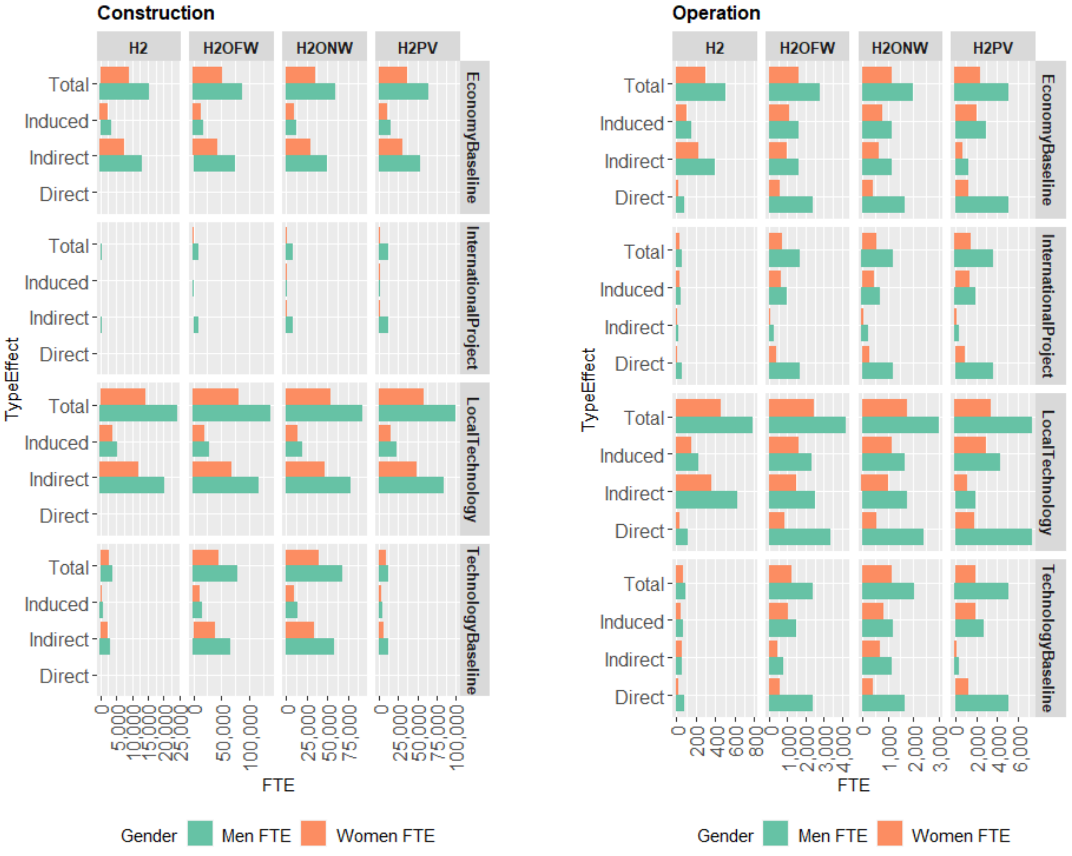


Figure 8 - Employment creation by gender

4. Sensitivity analysis

Figures 9-11 summarizes the highest, lowest, and default values from the sensitivity analysis for the construction phase. Impacts remained at the same order of magnitude and the ranking between technologies and local content scenarios remained unchanged. Hence, while different sectoral allocations and capacity factor assumptions would impact results, this is not substantial to alter the main findings in this study.

However, for the operation phase, changes were more substantial. Results are summarized in Figures 12-14. The pattern for value added does not change much, except for a higher increase in Solar PV due to employment factors in operation phase. Nevertheless, there are substantial differences for income and employment in the operation phase. Hence, employment factors in operation phase is the most sensitive assumption in this study, but at the same time the one with the highest level from uncertainty in the reviewed literature (see Supplementary Material).

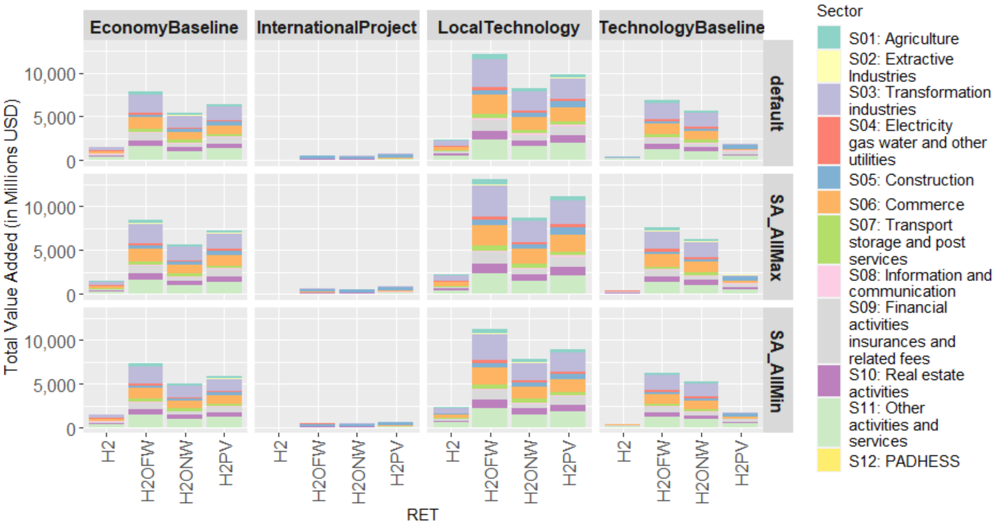


Figure 9 - Summary from sensitivity analysis for value added in the construction phase

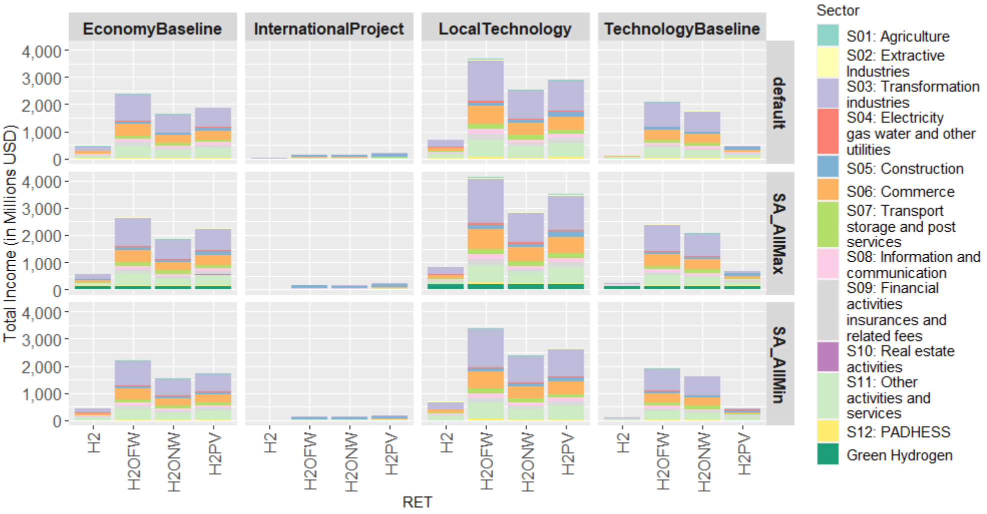


Figure 10 - Summary from sensitivity analysis for income in the construction phase

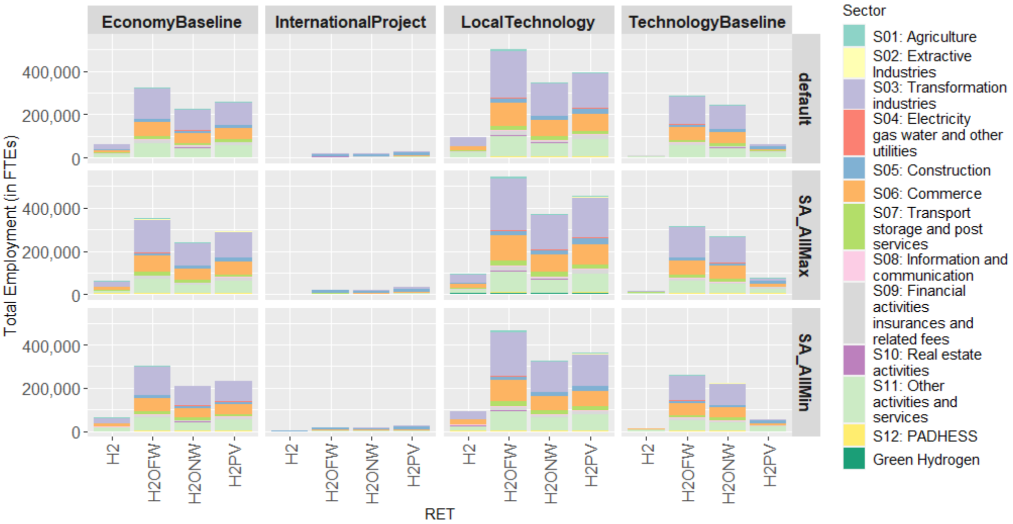


Figure 11 - Summary from sensitivity analysis for employment in the construction phase

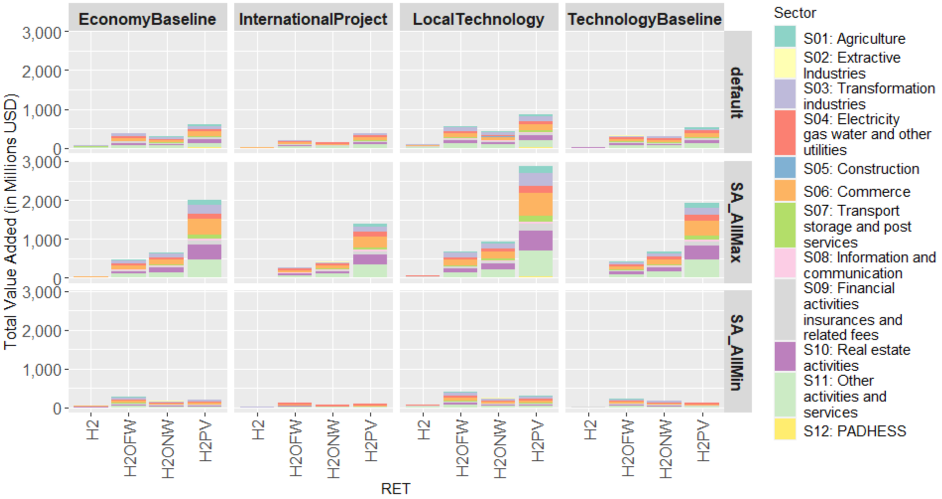


Figure 12- Summary from sensitivity analysis for value added in the operation phase

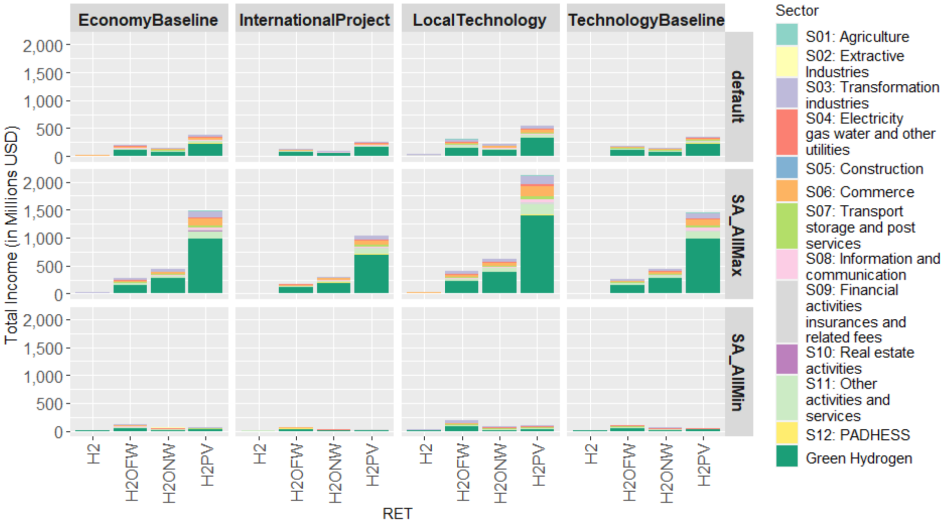


Figure 13 - Summary from sensitivity analysis for income in the operation phase

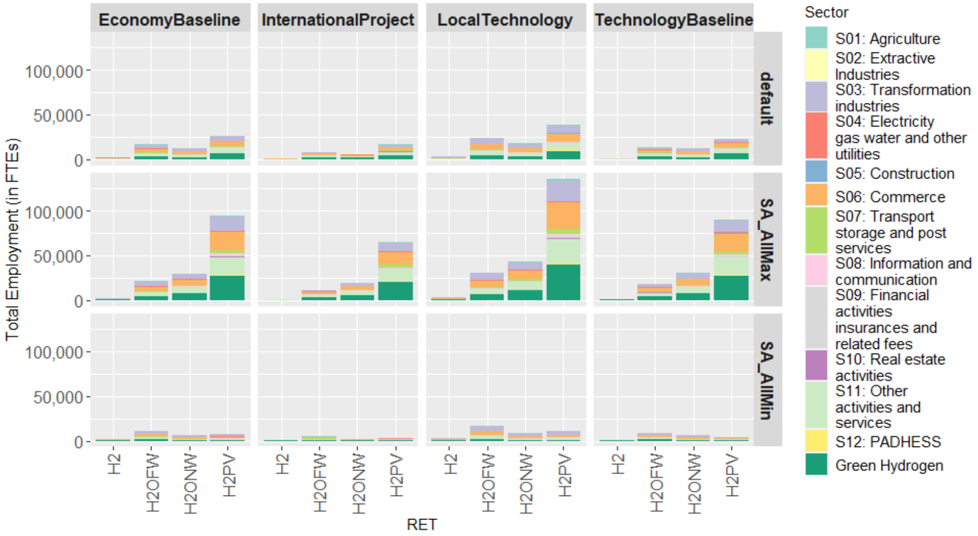


Figure 14 - Summary from sensitivity analysis for employment in the operation phase

5. Discussion

5.1 Construction vs Operation

Impacts during the planning and construction phase were considerably higher than for operation and maintenance phase but were temporary, lasting for a maximum of 2.5 years. This would imply that most economic opportunities from a green hydrogen hub would be temporary, lasting between 1 and 3 years depending on the duration of the construction phase.

5.2 Impacts of electrolysis versus impacts of renewable energy generation

Most estimated economic co-benefits of a green hydrogen hub were in the renewable electricity generation, both for construction and operation phases. The largest share of value added during the operation phase would in fact come from the operation of the renewable energy generation unit: while the operation of an electrolysis plant excluding electricity inputs would lead to 5-19 USD million in value added (0.003-0.014% increase compared to 2018) in international and technology-specific scenarios, adding the impact of the electricity production would lead to impacts around 30 times higher, that is, between 151-509 USD million (0.11-0.37% increase) in the same scenarios.

5.3 Potential for regional development and industrialization

Interviews indicated great expectations that the hub will be a "game changer" that will promote a "gigantic leap" and "wide transformation" of Ceará's economy by helping to industrialize it (Interviews 1,11,12,14,19,20,21). Given that Ceará's state is in one of the least developed Brazilian regions, the North-East, the hub is expected to help reduce long-standing regional inequalities and promote a more (regionally) just transition in Brazil. Nevertheless, scenarios would have different implications for the potential of green hydrogen to promote regional industrialization. International Project scenarios for all technologies and Solar PV specific scenarios show a considerably lower impact on the transformation industry sector. Importantly, impacts on these scenarios are heavily concentrated in fewer sectors.

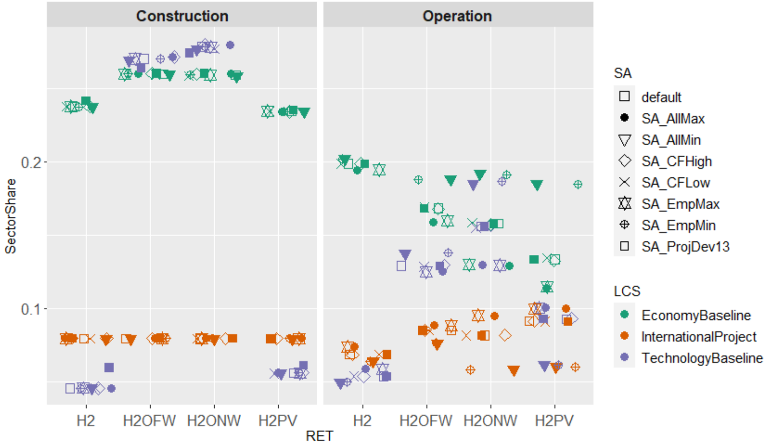


Figure 15 - Share of Sector 03 (Transformation industries) in total value added impacts

Especially on the operation phase, this would be concentrated on a green hydrogen sector that is dominated by foreign capital, higher income sectors, with very few linkages to the rest of economy, these scenarios would more likely lead to situations of "enclaves" instead of promoting regional industrial development. This would mean that foreign direct investments in developing countries for a green hydrogen economy would in fact lead to further dependencies instead of economic catch-up, as has been observed for other "promising" sectors in the past (see e.g., Gallagher and Zarsky 2007).

5.4 Distributional issues

There are important distributional implications from the different scenarios regarding income, gender and regional inequalities, especially for the international scenarios. In these scenarios, impacts during both the construction and O&M phases would be heavily concentrated in single sectors. This could have distributional impacts between income groups for three main reasons. Firstly, construction jobs had an average remuneration of R$2,274/month, lower than the state's average of $2,847/month, while the Electricity and Gas sector had one the highest average incomes in the state at R$10,585/month. Secondly, these sectors had different employment coefficients: while the utilities sector creates 0.87 jobs/million of R$ output, the construction sector creates 4.11 job/million of R$ output, on average. Thirdly, while around 48% of employees in the Electricity and Gas sector had tertiary education in Ceará in 2018, only 5% of those in the construction sector did.

Scenarios with lower shares of local content would could further reinforce inequalities between gender and income groups. While during the construction phase job creation would be concentrated in a more labour-intensive sector employing people from lower-income groups, jobs creation during the O&M phase would be concentrated in a less labour intensive and higher income sector. Importantly, given that construction jobs are temporary while O&M jobs are (more) permanent, there would also be a difference in the quality of the jobs, with temporary jobs being mainly for lower-income groups and permanent jobs for high-income groups. This issue would also apply for the differences between technology-specific scenarios in the O&M phase due to the large differences in the potential for indirect jobs between wind and solar pv given current industry capabilities.

5.5 The need for technology specificity in impact assessment

When comparing to *International* scenarios, impacts in *Technology-specific Baseline* scenarios were considerably higher for both Onshore and Offshore Wind, while estimates for Solar PV were closer. Especially for O&M phase, Solar PV technology-specific scenario would be more similar to the *International* scenario, while Wind specific scenarios were closer to the *Baseline* scenario. This would suggest that the organization of project activities could have less influence on outcomes when capabilities are anyway non-existent, but can significantly decrease the potential for economic benefits where capabilities do exist but are not leveraged. Moreover, for Technology-specific scenarios, impacts from wind technologies were higher, whereas in scenarios that do not differentiate between technology-specific local capabilities, the impacts from Solar PV were higher. This is aligned to the literature that found that benefits are higher for industries with already existing capabilities (Milani et al., 2020; e.g. Vasconcellos & Caiado Couto, 2021), indicating the need to tailor impact assessments to local capabilities in a technology-specific way. Differences between technologies for the same local content scenarios further reinforce the need for incorporating technology-specific cost data for changes in final demand. The fact that impacts from *Local* scenarios were highest in all cases would indicate that local economic benefits could have been higher were local capabilities further developed.

5.6 Limitations

Despite advantages related to transparency and data requirement, that are limitations associated with a static Leontief model. Firstly, the Leontief's approach is based on fixed technical coefficients (Miller & Blair, 2021). However, green hydrogen production structure is expected to be highly affected by future economies of scale. Another widely-known limitation of the Leontief's model is that it does not incorporate structural change or learning effects (Miller & Blair, 2021), reason why results in this study should only apply for the first projects in the shorter term.

Moreover, the Leontief model is considered to provide a realistic assessment only under situations of oversupply. As it does not incorporate labour market adjustments, it often leads to higher effects than general equilibrium models. It is hence important to put these numbers into context. Regarding employment creation, total effects were between 0.1-11% for the construction phase and 0.015-1.5% for the operation phase, considering the two most realistic scenarios (*International Project* and *Technology Baseline*). These would require between 900 and 160,000 full-time workers during the construction phase and between 225 and 22,000 full-time workers during the operation phase. Given that 420,000 people were unemployed in Ceará in 2018 and 1.3 million underemployed, there does not seem to be a constraint in the domestic labour market. This could be true even when considering skills requirements since the local government is already providing training to meet this future skills demand. Nevertheless, industrial capacity in the wind and solar supply chain may be a constraint (Interviews).

5.7 Areas for further research

5.7.1 Industry relocation

Despite an initial export-orientation, stakeholders also consider the possibility of attraction of industries in the value-chain (Interviews 1,3,11,13,16,19). High availability of low-cost renewable energy, labour market characteristics, and favourable tax regimes from industrialization programmes in Ceará could allow firms to reduce costs and carbon foot-print by relocating production activities there, especially in energy-intensive industries (Interviews 13,16). EU carbon pricing regulations, current energy crisis, and labour market shortages further increase attractiveness of relocation for these industries (Interviews13,16). Current trainings could further influence this decision by showing that there would be enough skilled workforce (Interviews). Due to complexity and costs in transport of green hydrogen, producing green hydrogen derivatives locally and then shipping the final products (e.g., green ammonia, green steel and green methanol) to consumer markets could bring substantial cost reductions (IRENA, 2022a), at levels around 35-42% (Interview16). This could facilitate the formation of three industrial clusters: one hydro-chemical, with the production of green ammonia, synthetic fuels and other chemicals; one metal-mechanic, with the production of green steel, wind turbines and other metallic and electrical equipment; and one on fertilizers (Interviews 1,11,12,15,16,19,20,21).

This study was unable to estimate changes from this industry relocation. A different model specification based on the complete inclusion of the new industry could have helped to overcome this limitation, but data availability constraints for the structure of the new industries and uncertainty regarding hydrogen sales prices, substitution from fossil-fuel based hydrogen, as well as the potential for domestic consumption would have made results highly uncertain and not very informative. This could be an area for further research as more information and data becomes available.

5.7.2 Multi-regional approach

The economic benefits that are not leveraged locally are not inexistent: they are simply being captured elsewhere. Here, this could be the South-East of Brazil in case technologies would come from national suppliers based in these regions, or other countries if technologies would be imported. A similar analysis using a multi-regional I-O instead of a single region I-O could provide further insights into this aspect.

6. Conclusions

This study has estimated the potential for economic co-benefits from export-oriented green hydrogen projects in promoting regional economic development in the state of Ceará. It did so by combining qualitative semi-structured interviews with economic modelling techniques. It estimated impacts according to four local content share scenarios and three renewable energy generation technologies for electrolysis (onshore wind, offshore wind and solar photovoltaics). By doing so, it provided quantitative support to how outcomes from international renewable energy projects ultimately depend on existing local capabilities, technology characteristics and project design.

While the *International* scenario seemed to be the most likely based on the interviews, results from the input-output analysis showed that local economic benefits would be lowest in this scenario, often by an order of magnitude. Furthermore, the international scenario would not only present the lowest local benefits, but would also likely be the most gender unequal and could potentially further reinforce inequalities between income groups.

When considering local technology-specific capabilities, impacts when capabilities were already existing were considerably higher than international scenarios (Onshore and Offshore Wind), while estimates for technologies where local capabilities were absent were more similar. This would suggest that the organization of project activities could have less influence on outcomes when capabilities are anyway non-existent, but can significantly decrease the potential for economic benefits where capabilities do exist but are not leveraged. Moreover, the wide range of results reinforced the need to tailor impact assessment to both local capabilities and technology-specific data.

Scenarios would have different implications for promoting regional industrialization and hence for green hydrogen to fulfil expectations of "changing the face of Ceará". Scenarios where the local capabilities are not leveraged (i.e. the International and Solar PV scenarios) were heavily concentrated in a more foreign capital-intensive, higher income sectors during the O&M phase, presenting very few linkages to the rest of economy. Therefore scenarios would bring the risk of forming "enclaves" instead of promoting regional industrial development.

7. Bibliography

Aeris. (2023). *Institutional presentation: Nosso jeito de ser.* https://www.ri.aerisenergy.com.br/apresentacoes/

Cameron, L., & van der Zwaan, B. (2015). Employment factors for wind and solar energy technologies: A literature review. *Renewable and Sustainable Energy Reviews*, *45*, 160–172. https://doi.org/10.1016/j.rser.2015.01.001

Danish Energy Agency. (2022). *Technology data.* https://ens.dk/en/our-services/projections-and-models/technology-data

Eicke, L., & De Blasio, N. (2022). *The Future of Green Hydrogen Value Chains*. Harvard Kennedy School Belfer Center for Science and International Affairs.

European Commission. (2023). *Commission Delegated Regulation (EU) 2023/1184 of 10 February 2023 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council by establishing a Union methodology setting out detailed rules for the production of renewable liquid a.*

Fearnehough, H., & Skribbe, R. (2022). *Economic Impact Model for Electricity Supply Methodology Note* (February 2). New Climate Institute. https://newclimate.org/sites/default/files/2022-03/economic_impact_model_methodologynote_feb22_0.pdf

Gallagher, K. P., & Zarsky, L. (2007). *The Enclave Economy: Foreign Investment and Sustainable Development in Mexico's Silicon Valley*. MIT Press.

Glasson, J., Durning, B., Welch, K., & Olorundami, T. (2022). The local socio-economic impacts of offshore wind farms. *Environmental Impact Assessment Review*, *95*, 106783. https://doi.org/10.1016/j.eiar.2022.106783

Hanusch, F., & Schad, M. (2021). Hydrogen research: technology first, society second? *GAIA - Ecological Perspectives for Science and Society*, *30*(2), 82–86. https://doi.org/10.14512/gaia.30.2.5

IEA. (2022). *Global Hydrogen Review 2022*. IEA. https://www.iea.org/reports/global-hydrogen-review-2022

Instituto Brasileiro de Geografia e Estatística - IBGE. (2022a). *Portal das cidades e estados*. https://www.ibge.gov.br/cidades-e-estados/es.html

Instituto Brasileiro de Geografia e Estatística - IBGE. (2022b). *System of Regional Accounts: Ceara*. https://www.ibge.gov.br/estatisticas/economicas/contas-nacionais/9054-contas-regionais-do-brasil.html?edicao=34530

International Labor Organization. (2017). *How To Measure and Model Social and Employment Outcomes of Climate and Sustainable Development Policies*. www.ilo.org

IRENA. (2020). *Green hydrogen cost reduction: Scaling up electrolysers to meet the 1.5oC climate goal.*

IRENA. (2022a). *Global Hydrogen Trade to Meet the 1.5oC Climate Goal Part II - Technology Review of Hydrogen Carriers*. IRENA.

IRENA. (2022b). *Global Hydrogen Trade To Meet The 1.5oC Climate Goal Part III - Green Hydrogen Cost and Potential*. IRENA.

IRENA. (2022c). *Renewable Power Generation Costs.* https://www.irena.org/publications/2022/Jul/Renewable-Power-Generation-Costs-in-2021

IRENA. (2022d). The geopolitics of the Energy Transformation: The Hydrogen Factor. In *International Renewable Energy Agency*. IRENA. https://doi.org/10.1177/014459879501300502

ISPT. (2020). *Gigawatt green hydrogen plant: state of the art design and total installed capital costs*.

Jenniches, S. (2018). Assessing the regional economic impacts of renewable energy sources – A literature review. *Renewable and Sustainable Energy Reviews*, *93*, 35–51. https://doi.org/10.1016/j.rser.2018.05.008

JIM. (2021). *Joint Impact Model: Methodology paper*. Joint Impact Model. https://www.jointimpactmodel.org/methodology

Kalt, T., & Tunn, J. (2022). Shipping the sunshine? A critical research agenda on the global hydrogen transition. *GAIA - Ecological Perspectives for Science and Society*, *31*(2), 72–76. https://doi.org/10.14512/gaia.31.2.2

Kattumuri, R., & Kruse, T. (2019). Renewable technologies in Karnataka, India: jobs potential and co-benefits. *Climate and Development*, *11*(2), 124–137. https://doi.org/10.1080/17565529.2017.1410085

Lazard. (2021). *Levelized cost of hydrogen analysis*. Lazard.

Lema, R., Bhamidipati, P. L., Gregersen, C., Hansen, U. E., & Kirchherr, J. (2021). China's investments in renewable energy in Africa: Creating co-benefits or just cashing-in? *World Development*, *141*, 105365. https://doi.org/10.1016/j.worlddev.2020.105365

Macedo, S. F., & Peyerl, D. (2022). Prospects and economic feasibility analysis of wind and solar photovoltaic hybrid systems for hydrogen production and storage: A case study of the Brazilian electric power sector. *International Journal of Hydrogen Energy*, *47*(19), 10460–10473. https://doi.org/10.1016/j.ijhydene.2022.01.133

Mallampalli, V. R., Mavrommati, G., Thompson, J., Duveneck, M., Meyer, S., Ligmann-Zielinska, A., Druschke, C. G., Hychka, K., Kenney, M. A., Kok, K., & Borsuk, M. E. (2016). Methods for translating narrative scenarios into quantitative assessments of land use change. *Environmental Modelling & Software*, *82*, 7–20. https://doi.org/10.1016/j.envsoft.2016.04.011

Meyer, I., & Sommer, M. W. (2016). Employment effects of renewable energy deployment - a review. *International Journal of Sustainable Development*, *19*(3), 217. https://doi.org/10.1504/IJSD.2016.078274

Milani, R., Caiado Couto, L., Soria, R., Szklo, A., & Lucena, A. F. P. (2020). Promoting social development in developing countries through solar thermal power plants. *Journal of Cleaner Production*, *246*, 119072. https://doi.org/10.1016/j.jclepro.2019.119072

Miller, R. E., & Blair, P. D. (2021). *Input-Output Analysis*. Cambridge University Press. https://doi.org/10.1017/9781108676212

Ministry of Employment. (2022). *RAIS database*. Ministry of Employment. http://pdet.mte.gov.br/rais

Müller, F., Tunn, J., & Kalt, T. (2022). Hydrogen justice. *Environmental Research Letters*, *17*(11), 115006. https://doi.org/10.1088/1748-9326/ac991a

Nadaleti, W. C., Borges dos Santos, G., & Lourenço, V. A. (2020). The potential and economic viability of hydrogen production from the use of hydroelectric and wind farms surplus energy in Brazil: A national and pioneering analysis. *International Journal of Hydrogen Energy*, *45*(3), 1373–1384. https://doi.org/10.1016/j.ijhydene.2019.08.199

Nasirov, S., Girard, A., Peña, C., Salazar, F., & Simon, F. (2021). Expansion of renewable energy in Chile: Analysis of the effects on employment. *Energy*, *226*, 120410. https://doi.org/10.1016/j.energy.2021.120410

NREL. (2018). *H2A: Hydrogen Analysis Production Models*. Current Central Electrolysis Version 3.2018. https://www.nrel.gov/hydrogen/h2a-production-models.html

NREL. (2022). *JEDI Models*. https://www.nrel.gov/analysis/jedi/models.html

Pai, S., Emmerling, J., Drouet, L., Zerriffi, H., & Jewell, J. (2021). Meeting well-below 2°C target would increase energy sector jobs globally. *One Earth*, *4*(7), 1026–1036. https://doi.org/10.1016/j.oneear.2021.06.005

Pflugmann, F., & De Blasio, N. (2020). The Geopolitics of Renewable Hydrogen in Low-Carbon Energy Markets. *Geopolitics, History, and International Relations*, *12*(1), 7. https://doi.org/10.22381/GHIR12120201

Port of Rotterdam. (2022). *Green hydrogen corridors transforming the future: two ports connecting to change the world*. https://www.portofrotterdam.com/en/port-future/edition-february-2022/green-hydrogen-corridors-transforming-the-future

Port of Rotterdam. (2023). *#WHS2023: Ports of Rotterdam and Pecém (Brazil) join Brazilian-Dutch cooperation*. https://www.portofrotterdam.com/en/news-and-press-releases/ports-of-rotterdam-and-pecem-brazil-join-brazilian-dutch-cooperation

Secretariat for Economic Development and Employment. (2022). *Presentation: green hydrogen in Ceará*. https://www.sedet.ce.gov.br/wp-content/uploads/sites/15/2021/06/Apresentacao-H2V-VersaoCIMEIRA.pdf

Simas, M., & Pacca, S. (2014). Assessing employment in renewable energy technologies: A case study for wind power in Brazil. *Renewable and Sustainable Energy Reviews*, *31*, 83–90. https://doi.org/10.1016/j.rser.2013.11.046

Sooriyaarachchi, T. M., Tsai, I.-T., El Khatib, S., Farid, A. M., & Mezher, T. (2015). Job creation potentials and skill requirements in, PV, CSP, wind, water-to-energy and energy efficiency value chains. *Renewable and Sustainable Energy Reviews*, *52*, 653–668. https://doi.org/10.1016/j.rser.2015.07.143

Tegen, S., Keyser, D., Flores-Espino, F., Miles, J., Zammit, D., & Loomis, D. (2015). *Offshore Wind Jobs and Economic Development Impacts in the United States: Four Regional Scenarios*.

Van de Graaf, T., Overland, I., Scholten, D., & Westphal, K. (2020). The new oil? The geopolitics and international governance of hydrogen. *Energy Research & Social Science*, *70*, 101667. https://doi.org/10.1016/j.erss.2020.101667

Vasconcellos, H. A. S., & Caiado Couto, L. (2021). Estimation of socioeconomic impacts of wind power projects in Brazil’s Northeast region using Interregional Input-Output Analysis. *Renewable and Sustainable Energy Reviews*, *149*, 111376. https://doi.org/10.1016/J.RSER.2021.111376

Vestas. (2023). *Our locations*. https://www.vestas.com/en/about/our-locations/production

Wappler, M., Unguder, D., Lu, X., Ohlmeyer, H., Teschke, H., & Lueke, W. (2022). Building the green hydrogen market – Current state and outlook on green hydrogen demand and electrolyzer manufacturing. *International Journal of Hydrogen Energy*. https://doi.org/10.1016/j.ijhydene.2022.07.253

SUPPLEMENTARY MATERIAL

Can green hydrogen exports contribute to regional economic development? Exploring scenarios from the Dutch-Brazilian green hydrogen corridor for the state of Ceará

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Contents

1. Model specification

In ordinary input-output models with *n* industry sectors, z_{ij} is an element of the *n* × *n* inter-industry transactions matrix Z $[z_{ij}]$, representing the value of purchases of industry *i* output by industry *j*. The *n*-element vector of total industry outputs is defined as x = $[x_i]$, where

$$x_i = z_{i1} + \cdots + z_{in} + f_i \quad \text{(Eq. 7-1)}$$

and f_i is industry *i*'s sales to final demand. Moreover, the matrix of direct technical coefficients A = $[\alpha_{ij}]$ represents the value of dollars' worth of input from sector *i* per dollars' worth of output of sector *j*, where

$$\alpha_{ij} = z_{ij}/x_j \quad \forall\, i,j = 1, 2, \ldots n \quad \text{(Eq. 7-2).}$$

The total requirements matrix L = $[l_{ij}]$, also known as the Leontief inverse, is defined by, in matrix notation,

$$\mathrm{L} = (\mathrm{I} - \mathrm{A})^{-1} \text{ (Eq. 7-3)}$$

where A is the matrix of direct technical coefficients and I is an identity matrix of *n x n* dimension (Miller & Blair, 2021). In matrix notation:

$$\mathrm{x} = \mathrm{Z} + \mathrm{f} \ \text{ (Eq. 7-4)}$$

$$\mathrm{A} = \mathrm{Z}\hat{\mathrm{x}}^{-1} \ \text{ (Eq. 7-5)}$$

$$\mathrm{x} = \mathrm{Ax} + \mathrm{f} \ \text{ (Eq. 7-6)}$$

$$\mathrm{x} = (\mathrm{I} - \mathrm{A})^{-1}\mathrm{f} = \mathrm{Lf} \ \text{ (Eq. 7-7)}$$

Following Miller and Blair (2021), in Input-Output models the impact on output from industry sector *j* (Δx_j) given a change in final demand from sector *i* (Δf_i) will be given by:

$$\Delta\mathrm{x} = \mathrm{L}\Delta\mathrm{f} \ \text{ (Eq. 7-8)}$$

In addition to output effects, this study estimates impacts on value added, employment and household income from salaries.

The following sections summarize the methodology in this study (see also Figure 1). Starting from the right side of the Eq.1-8, we first explain the model specification regarding the Leontief inverse (L) and the change in final demand (Δf) in Section 1.1. We then explain how the output, value-added, income and employment effects are determined in Section 1.2.

1.1 Model inputs: determining L and f

To determine the Leontief inverse for the state of Ceára, this study uses the Supply and Use tables for state of Ceará in the year of 2018 provided by the Brazilian Institute of Geography and Statistics (IBGE), the most recent economic data available at the sub-national level (Instituto Brasileiro de Geografia e Estatística - IBGE, 2022). These tables are organized in a 12x12 commodity-by-industry matrix. The methodology to transform the tables into an industry-by-industry format is based on Guilhoto and Sesso Filho (2010; 2005) Miller and Blair (2021). This is explained in 2.1.1.

Since there was no green hydrogen production in the state of Ceará in the year of 2018, we follow the method for assessing the impacts of a new industry through a final demand approach as described by Miller and Blair (2021). This approach is preferred to the complete inclusion of the new industry for two reasons. Firstly, based on the interviews, green hydrogen production is assumed to be almost entirely for exports. Interviewees estimate at least 95% of production would be exported. Secondly, data for the future sales structure of green hydrogen to the domestic industry are currently unavailable. These two reasons make this method an adequate approach (Miller & Blair, 2021). The details of the approach are explained in 2.1.2.

In order to capture induced effects, households are endogenized following a similar approach as described by Vasconcellos and Caiado Couto (2021) and Vale and Perobelli (2020). Data for employment and income, disaggregated by gender and sector, is taken from the RAIS database from the Brazilian Ministry of Employment (2022). The methodology for endogenization is explained in 2.1.3.

1.1.1 Estimating an industry-by-industry I-O table for the state of Ceará

According to Guilhoto and Sesso Filho (2010; 2005), the IBGE provides Use Tables in consumer prices and Supply Tables in producers prices. Moreover, in the Use Tables they show the total use of a certain industry, not differentiating on whether the commodity is supplied domestically or imported. We estimate Use Tables in producers prices following Guilhoto and Sesso Filho (2010; 2005). The method consists in first estimating the trade margins (MGC), transport margins (MGT) and taxes net of subsidies (IIL) and remove these from the Use Tables at consumer prices to obtain the use tables in basic prices.

$$\mathrm{TSBP} = \mathrm{TSCP} - \mathrm{MGC} - \mathrm{MGT} - \mathrm{IIL} \quad \text{(Eq. 7-9)}$$

where:

TSBP = Total Supply at Basic Prices
TSCP = Total Supply at Consumers Prices
MGC = Trade margins
MGT = Transport margins
IIL = Taxes net of subsidies

Secondly, to obtain the domestic supply only, imports from rest of Brazil (IOB) and imports from rest of the world (IOW) are estimated and also removed from the Use table:

$$\mathrm{DSBP} = \mathrm{TSBP} - \mathrm{IOB} - \mathrm{IOW} \quad \text{(Eq. 7-10)}$$

where:

DSBP = Domestic Supply at Basic Prices
TSBP = Total Supply at Basic Prices
IOB = Imports from the rest of Brazil
IOW = Imports from the rest of the World

With the Use Table including only the domestically available supply at basic prices (U), we estimate an industry-by-industry table following an industry-technology model, as explained by Miller and Blair (2021). The vector of total industry output can be estimated by

$$\mathrm{x} = (\mathrm{I} - \mathrm{DB})^{-1}\mathrm{f} \quad \text{(Eq. 7-11)}$$

where:

x is the vector of total industry output;

B is the matrix of the coefficients representing the value of inputs of each commodity by dollars' worth of industry j's output, defined by $B = U\hat{x}^{-1}$;

D is the market shares matrix, defined by $D = S'\hat{q}^{-1}$, where q is the total commodity output and S the supply matrix transposed;

I is an identity matrix;

f is the vector of industry final demand, defined by $f = De$, where e is the commodity final demand.

The total requirements matrix $(I - DB)^{-1}$ becomes hence the equivalent of the Leontief's inverse (L), where DB is the equivalent of the industry-by-industry technical coefficient matrix A. The impact on output can then be estimated by Eq. 1-8.

i	Sector
1	S01: Agriculture
2	S02: Extractive Industries
3	S03: Transformation industries
4	S04: Electricity, gas, water and other utilities
5	S05: Construction
6	S06: Commerce
7	S07: Transport, storage and post services
8	S08: Information and communication
9	S09: Financial activities, insurances and related fees
10	S10: Real estate activities
11	S11: Other activities and services
12	S12: Public administration, defence, healthcare, education and social security

Table 10 - Sectors in the final industry-by-industry table

1.1.2 Introducing a new industry sector

As explained by Miller and Blair (2021, pp. 692–694), this approach consists in introducing a new column and row for the new sector in the technical coefficients matrix A, and hence, in the Leontief inverse L. This is done by estimating the direct input coefficients of the new sector (that is, $\alpha_{i,n+1}$, where *i* = the existing sectors in Ceará's economy and n+1 is the new sector, that we call "GH2"). For instance, for *i=3,* $\alpha_{3,GH2}$ would represent the share of total investments in green hydrogen that are directed to sector 3, in this case the transformation industry.

Based on Eq. 2-2, the direct technical coefficients are found by dividing the amount of domestic sector i outputs required as inputs for the new green hydrogen sector (z_{iGH2}^{D}) by the total outlay of the new sector (x_{GH2}). This is done by disaggregating green hydrogen investment cost data into component parts and then allocating these components to specific economic sectors. Investment cost data is considered for two project phases (*p*) (Construction and Operation) and four technology assumptions (*t*) (electrolysis alone, electrolysis with dedicated onshore wind, electrolysis with dedicated offshore wind, and electrolysis with dedicated solar photovoltaics). This ensures that the impact assessment is technology-specific (Fearnehough & Skribbe, 2022; NREL, 2022). Sectoral allocation of investment cost data is explained in detail in Section 3.2.

Since not all inputs will be sourced from the local industry, total expenditures have to first be disaggregated into domestic industry transactions and imports:

$$z_{iGH2}^{T,p,t} = z_{iGH2}^{D,p,t} + z_{iGH2}^{M,p,t} \quad \text{(Eq. 7-12)}$$

where

z_{iGH2}^{T} is the total expenditure of the green hydrogen investment allocated to industry sector *i*

z_{iGH2}^{D} is the expenditure of the green hydrogen investment in the domestic industry sector *i*

z_{iGH2}^{M} is the expenditure of the green hydrogen investment allocated to industry sector *i* spent in imports

p is the project phase (Construction or Operation)

t is the technology assumption

The shares of each investment component that is spent in Ceará is estimated via local content scenarios (s). In these scenarios, local content shares (lcs_i) are used to separate total expenditures into domestic expenditures and imports (for scenario formulation, see Section 3.3). The allocation of investment to each domestic industry sector *i* can be estimated by

$$z_{iGH2}^{D,p,s,t} = z_{iGH2}^{T,p,t} * lcs_i^{p,s,t} \quad \forall\, i = 1,2, \dots n \quad \text{(Eq. 7-13)}$$

where $lcs_i^{p,s,t}$ refers to the local content share for domestic sector *i,* during project phase *p,* according to technology assumption *t* and local content share scenario *s.* Once $z_{iGH2}^{D,p,s,t}$ is determined, $\alpha_{iGH2}^{p,s,t}$ can be found by dividing $z_{iGH2}^{D,p,s,t}$ for each productive sector *i* by the total investment expenditure (x_{GH2}) in the respective project phase and technology assumption:

$$\alpha_{iGH2}^{p,s,t} = z_{iGH2}^{D,p,s,t} / x_{GH2}^{p,t} \quad \forall\, i = 1, 2, \dots n \quad \text{(Eq. 7-14).}$$

Then the direct technical coefficients can be added to a new (*n+1)* x (*n+1)* technical coefficients matrix $\bar{A}^{p,s,t}$, which will contain the *n* x *n* A matrix, $\alpha_{iGH2}^{p,s,t}$ as the *n+1* column, and zeros as the *n+1* row, since we assume no green hydrogen is used as inputs for the domestic industry (i.e. export assumption):

$$\bar{A}^{p,s,t} = \begin{bmatrix} a_{11} & \dots & a_{1n} & \alpha_{1GH2}^{p,s,t} \\ \vdots & \ddots & \vdots & \vdots \\ a_{n1} & \dots & a_{nn} & \alpha_{nGH2}^{p,s,t} \\ 0 & \dots & 0 & 0 \end{bmatrix} \quad \text{(Eq. 7-15)}$$

To isolate the impacts of the new industry sector, we let the change in final demand for the existing sectors to be 0. In this case, as demonstrated by Miller & Blair (2021, p. 693), the final demand of the new sector will be equal to its total expenditures. The vector of final demand can then be

$$\Delta\bar{f}_i^{p,t} = \begin{bmatrix} 0 \\ \vdots \\ 0 \\ x_{GH2}^{p,t} \end{bmatrix} \quad \text{(Eq. 7-16)}$$

The Leontief inverse for each project phase *p*, technology assumption *t,* and local content scenario *s,* can determined by

$$\bar{\mathrm{L}}^{\,p,s,t} = (\mathrm{I} - \bar{A}^{p,s,t})^{-1} \quad \text{(Eq. 7-17)}$$

1.1.3 Endogenizing households

Similarly to the introduction of a new industry, households are endogenized by adding a new row and column to the technical coefficients matrix. By doing so, households become the *n+2* sector in the input-output model, that is now formed by *n* existing productive sectors, a green hydrogen sector (*n+1*) and households (*n+2*). Following a similar approach as to Vasconcellos and Caiado Couto (2021) and Vale and Perobelli (2020), coefficients for household remunerations (*hr*) and consumption (*hc*) are added as the *n+2* row and column in the inter-industry technical coefficients matrix $\bar{A}^{p,s,t}$ to obtain

$$\bar{\bar{A}}^{p,s,t} = \begin{bmatrix} \bar{A}^{p,s,t} & \bar{h}_c^{p,s,t} \\ \bar{h}_r^{p,s,t} & 0 \end{bmatrix} \quad \text{(Eq. 7-18)}$$

where

$\bar{h}_r^{p,s,t}$ is a vector with household remuneration coefficients for the n+1 productive sectors

$\bar{h}_c^{p,s,t}$ is the vector with household consumption coefficients for the n+1 productive sectors

These vectors include the household remuneration and consumption of the *n* existing sectors plus the remuneration and consumption coefficients for the new green hydrogen sector, as can be seen in

$$\bar{h}_r^{p,s,t} = \begin{bmatrix} hr & hr_{GH2}^{p,s,t} \end{bmatrix} \quad \text{(Eq. 7-19)}$$

and

$$\bar{h}_c^{p,s,t} = \begin{bmatrix} hc & hc_{GH2}^{p,s,t} \end{bmatrix} \quad \text{(Eq. 7-20)}$$

The vectors with the coefficients for household remunerations can be found by

$$hr_j = \frac{r_j}{x_j} \quad \forall\, j = 1,2,\dots,n \quad \text{(Eq. 7-21)}$$

and

$$hr_{GH2}^{p,s,t} = \frac{\bar{r}_{GH2}^{s,p,t}}{\bar{x}_{GH2}^{p,t}} \quad \text{(Eq. 7-22)}$$

where $r' = [\, r_1 \quad \cdots \quad r_n]$ is the vector of annual employment remuneration (salaries in millions of USD) in sector j and $\bar{r}_{GH2}^{s,p,t}$ is the investment expenditure spent on direct employment in project phase p, technology assumption t, and local content scenario s. Similarly, the coefficients for household consumption can be found by

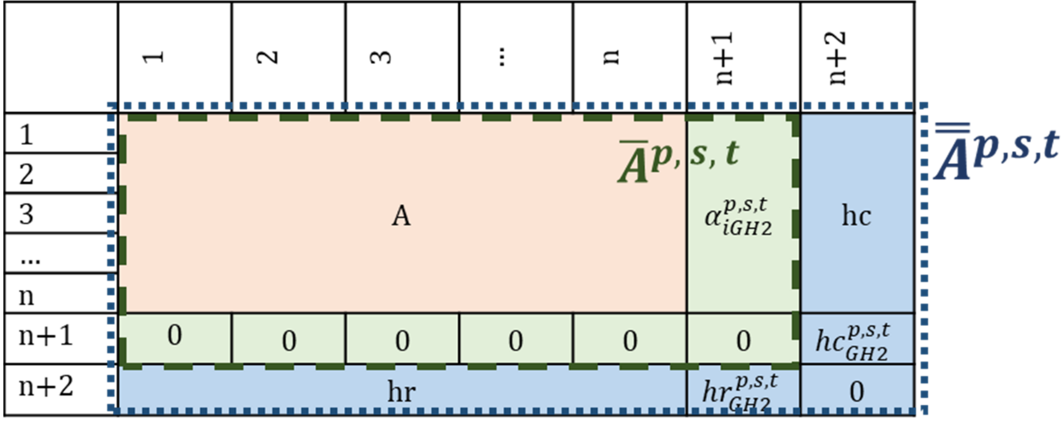
$$hc_j = \frac{c_i}{\sum_{j=1}^{n} r_j} \quad \forall\, i,j = 1,2,\ldots,n \quad \text{(Eq. 7-23)}$$

$$hc_{GH2}^{p,s,t} = \frac{c_{GH2}^{s,p,t}}{\bar{r}_{GH2}^{s,p,t}} \quad \text{(Eq. 7-24)}$$

where $c = [\, c_1 \quad \cdots \quad c_n]$ is the vector of household consumption of domestic sector i taken from the industry-by-industry input output table, $\sum_{j=1}^{n} r_j$ is the total household income (salaries) associated to the n productive sectors, and $c_{GH2}^{s,t,p}$ is the household consumption of the green hydrogen sector in project phase p, technology assumption t, and local content scenario s. The domestic consumption of green hydrogen by households is considered to be 0, since this is not a final product and green hydrogen production is assumed to be for exports.

Figure 1 illustrates the three direct technical coefficient matrixes: A, with the n existing productive sectors, $\bar{A}^{p,s,t}$ with n+1 productive sectors (n existing sectors plus green hydrogen), and $\bar{\bar{A}}^{p,s,t}$ with n+2 sectors, including n+1 productive sectors and households.

Figure 16 - Technical coefficients table with n, n+1 and n+2 sectors



	1	2	3	…	n	n+1	n+2
1	A					$a_{iGH2}^{p,s,t}$	hc
2							
3							
…							
n							
n+1	0	0	0	0	0	0	$hc_{GH2}^{p,s,t}$
n+2	hr					$hr_{GH2}^{p,s,t}$	0

The Leontief inverse for the model with households endogenized (the semi-closed model) can then be estimated in the same way as in Eq. 2-18, namely:

$$\bar{\bar{\mathrm{L}}}^{p,s,t} = (\mathrm{I} - \bar{\bar{A}}^{p,s,t})^{-1} \quad \text{(Eq. 7-25)}$$

An extra row is added to the vector for the change in final demand in Eq. 2-16 to obtain $\bar{\bar{\Delta \mathrm{f}}}^{p,t}$. The value for the household sector is also set to 0, similarly to all other existing sectors.

$$\Delta\bar{\bar{f}}_i^{p,t} = \begin{bmatrix} 0 \\ \vdots \\ 0 \\ x_{GH2}^{p,t} \\ 0 \end{bmatrix} \quad \text{(Eq. 7-26)}$$

1.2 Model outputs

This section explains how sectoral output, value added, income, and employment effects are estimated and disaggregated into direct, indirect and induced effects.

1.2.1 Output effects

The change in industry output from the new green hydrogen sector in the open model (without households) can be estimated by adapting Eq.2-8. In matrix notation:

$$\Delta\bar{\mathrm{x}}^{p,s,t} = \bar{\mathrm{L}}^{p,s,t}\,\Delta\bar{\mathrm{f}}^{p,t} \quad \text{(Eq. 7-27)}$$

The change in output from the new green hydrogen industry in the semi-closed model (households endogenized) is estimated by

$$\Delta\bar{\bar{\mathrm{x}}}^{p,s,t} = \bar{\bar{\mathrm{L}}}^{p,s,t}\,\overline{\overline{\Delta\mathrm{f}}}^{p,t} \quad \text{(Eq. 7-28)}$$

The vector $\Delta\bar{\bar{\mathrm{x}}}^{p,s,t}$ includes total effects in sector output, that is, all direct, indirect and induced effects. In this study, results are disaggregated into direct, indirect and induced effects as following. Direct output effects can be found by post-multiplying the matrix of direct technical coefficients by the change in final demand (Eq. 2-29). Indirect effects can be found by subtracting direct effects from total output effects in the open model ($\Delta\bar{\mathrm{x}}^{p,s,t}$) (Eq. 2-30). Induced output effects can be found by subtracting $\Delta\bar{\mathrm{x}}^{p,s,t}$ from total output effects in the semi-closed model ($\Delta\bar{\bar{\mathrm{x}}}^{p,s,t}$) (Eq. 2-31) (Miller & Blair, 2021; Vale & Perobelli, 2020):

$$DirectOutputEffects = \bar{\bar{\mathrm{A}}}^{p,s,t}\,\overline{\overline{\Delta\mathrm{f}}}^{p,t} \quad \text{(Eq. 7-29)}$$

$$IndirectOutputEffects = \Delta\bar{\mathrm{x}}^{p,s,t} - DirectOutputEffects \quad \text{(Eq. 7-30)}$$

$$InducedOutputEffects = \Delta\bar{\bar{\mathrm{x}}}^{p,s,t} - \Delta\bar{\mathrm{x}}^{p,s,t} \quad \text{(Eq. 7-31)}$$

1.2.2 Value-Added

Following Miller and Blair (2021), a vector with value added values for the base year 0 can be defined as $w' = [\,w_1 \;\; \cdots \;\; w_n]$. A vector of value added coefficients w'_c can be found by dividing the base-year value added in each sector *j* by the sector *j* base-year gross output:

$$\mathrm{w}_{c_j} = \frac{w_j}{x_j} \;\forall\, j = 1,2,\dots,n \quad \text{(Eq. 7-32)}$$

The vector of total *value added* generated in sector *j* at time 1 can then be found by multiplying the value added coefficients by the new sectoral output in sector *j*:

$$\omega = \hat{\mathrm{w}}_{\mathrm{c}}\,\mathrm{x}^1 = \begin{bmatrix} \mathrm{w}_{\mathrm{c}1}\mathrm{x}_1^1 \\ \vdots \\ \mathrm{w}_{\mathrm{cn}}\mathrm{x}_{\mathrm{n}}^1 \end{bmatrix} \quad \text{(Eq. 7-33)}$$

The disaggregation of total value added effects can then be done in similar way was for output effects (Eqs 1.19-1.31).

1.2.3 Employment and income

Impact on employment and income are estimated as explained in Vale & Perobelli (2020). The approach consists in first defining the vector of direct employment and income coefficients and then pre-multiplying the total requirements matrixes by these vectors to obtain the employment-generation (E) and income-generation (R) matrixes, respectively. The vector of income coefficients is $\bar{h}_r^{p,s,t}$, or the n+2th row of the direct coefficient matrix $\bar{\bar{A}}^{p,s,t}$, as defined in the previous section. The vector of employment coefficients $\overline{ec}^{p,s,t}$ is determined in the same way as $\bar{h}_r^{p,s,t}$(Eq. 2-21 and 2-22), but with total employment in stock in full-time equivalent jobs (FTE) instead of salaries in dollar-worth values.

$$\bar{\mathrm{E}}^{\mathrm{p,s,t}} = \overline{\mathrm{ec}}^{\mathrm{p,s,t}}\,\bar{\mathrm{L}}^{\mathrm{p,s,t}} \text{ (Eq. 7-34)}$$

$$\bar{\bar{\mathrm{E}}}^{\mathrm{p,s,t}} = \bar{\bar{\mathrm{ec}}}^{\mathrm{p,s,t}}\,\bar{\bar{\mathrm{L}}}^{\mathrm{p,s,t}} \text{ (Eq. 7-35)}$$

$$\bar{\mathrm{R}}^{\mathrm{p,s,t}} = \bar{\mathrm{h}}_{\mathrm{r}}^{\mathrm{p,s,t}}\,\bar{\mathrm{L}}^{\mathrm{p,s,t}} \text{ (Eq. 7-36)}$$

$$\bar{\bar{\mathrm{R}}}^{\mathrm{p,s,t}} = \bar{\bar{\mathrm{h}}}_{\mathrm{r}}^{\mathrm{p,s,t}}\,\bar{\bar{\mathrm{L}}}^{\mathrm{p,s,t}} \text{ (Eq. 7-37)}$$

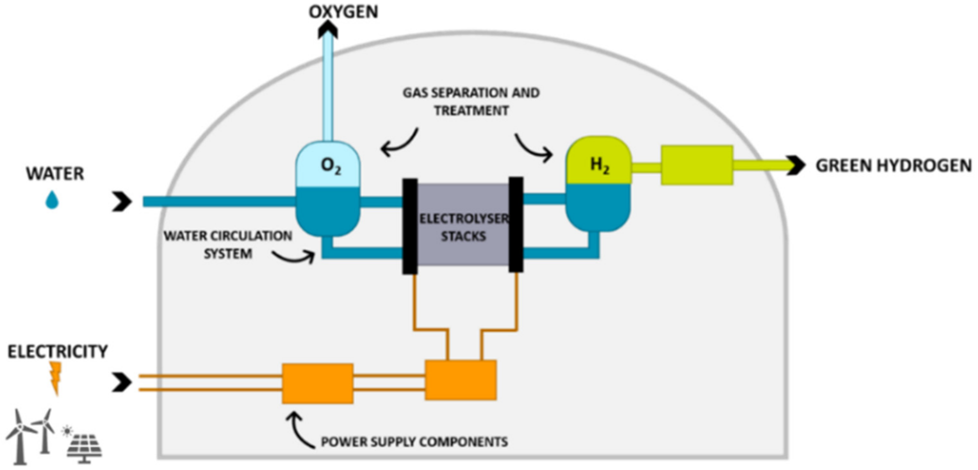
The direct, indirect, and induced effects on employment and income can then be found by using the employment and income direct coefficients instead of A and by replacing L by E and R, respectively, in Equations 2-27 to 2-31.

Finally, the impacts on employment are disaggregated by gender. This is done by taking the share of each gender (male and female) in total occupation (FTEs) and in total remunerations (income) of each sector and then multiplying the employment and income effects by these shares.

2. Project-level data and assumptions

Green hydrogen is produced via electrolysis (AEC) using renewable electricity – usually from solar and wind – to separate water into oxygen and hydrogen (IEA, 2022; Macedo & Peyerl, 2022). Figure 2 shows a simplification of a typical electrolysis plant (IRENA, 2020).

Figure 17 - A simplified typical design of an electrolysis plant. Adapted from IRENA (2020)



For green hydrogen exports to qualify for green certificates required for imports in the European Union, renewable electricity generation has be to "additional" to what is already connected to the grid (European Commission, 2023). This means that every investment in a new electrolysis plant would be expected to lead to investments on a new renewable energy generation unit to meet the electricity requirements for green hydrogen production (Interviews).

Therefore, the total expenditures from the green hydrogen sector ($z_{iGH2}^{T,p,t}$) will be estimated for hydrogen electrolysis alone (HEC), but also for electrolysis with electricity coming from solar photovoltaics, onshore wind, and offshore wind. The total expenditures are calculated as following:

$$if\ t = 1,\ \ z_{iGH2}^{T,p,t} = exp_i^{p,HEC} * MW^{HEC},$$

$$else\ \ z_{iGH2}^{T,p,t} = \left(exp_i^{p,HEC} * MW^{HEC}\right) + \left(exp_i^{p,t} * MW^t\right)\ \text{(Eq. 7-38)}$$

where

t is the technology assumption, being t = 1 electrolysis alone (HEC), t = 2 electrolysis with onshore wind, t = 3 electrolysis with offshore wind, and t = 4 electrolysis with solar photovoltaics

p is the project phase

exp is the expenditure during phase *p* in dollars per MW of installed capacity of technology *t* allocated to industry sector *i*

MW^t is the installed capacity of technology *t* in mega-watts

The required installed capacity for solar photovoltaics, onshore wind and offshore wind is calculated for each mega-watt of electrolysis capacity, based on technology assumptions available from the Danish Energy Agency (DEA) (2022) and adapting it to the local capacity factors for renewable energy in the state of Ceará (Government of Ceará, 2022) as explained in Section 2.1. Project expenditures are determined by investment cost data, as explained in Section 2.2. Domestic expenditures are obtained from total expenditures according to local content scenarios, as outlined in Eq 1-13. Section 2.3 explains the scenario formulation.

2.1 Required renewable energy capacities

According to the Danish Energy Agency (2022), for a 100MW electrolysis plant to operate for 1h, 100MWh of electricity is required. Moreover, a 100MW plant can be assumed to have 2 planned outage days per year (PlanOut), plus 2% of forced outage (ForcOut). Based on the parameters provided by DEA, the total annual electricity input (AEI) of the electrolysis plant is calculated as following:

$$AEI_{\ HEC} = \ Op.Hours_{AEC} * MW_{HEC} \text{ (Eq. 7-39)}$$

$$AEI_{\ HEC} = [(365 - PlanOut_{AEC}) * 24\text{h} * (1 - ForcOut_{AEC})] * MW_{HEC} \text{ (Eq. 7-40)}$$

$$AEI_{\ HEC} = [(365 - 2) * 24\text{h} * (1 - 0.2)] * MW_{HEC} \text{ (Eq. 7-41)}$$

$$AEI_{\ HEC} = 8538\text{h} * MW_{HEC} \text{ (Eq. 7-42)}$$

Therefore, for each 1MW of installed electrolysis capacity, we assume a required electricity input of 8538MWh/year. This is similar to the value proposed by Lazard (2021) of 8585MWh/year. To find out how much of each renewable energy source would be needed, we assume the Annual Energy Production (AEP) of the renewable energy (RE) plant would need to be equal to the annual electricity requirement for the electrolysis plant (AEI_{HEC}). Potential transmission and distribution losses are not taken into account, since renewable energy plants would likely be placed next to the electrolysis plant as a dedicated generation unit according to the expert interviews.

For each technology, the required installed capacity is estimated based on 1MW of electrolysis capacity installed. The required installed capacity for renewable energy technology *t* can be found by setting the left side of Eq.3-6 to 8538MWh (since $AEP_t = AEI_{GH2}$) and then solving for $Capacity_t$:

$$AEP_t = Capacity_t * Op.Days_t * CF_t * 24h \text{ (Eq. 7-43)}$$

where

AEP_t is the annual electricity production of the renewable energy technology t
$Capacity_t$ is the required installed capacity for RE technology t
$Op.Days_t$ is the amount of operation days of the RE plant in a year
CF_t is the local capacity factor for the for RE technology t

Table 2 summarizes the results from Eq.3-6 for all three renewable energy technologies.

RET (t)	**Conditions[1]**	**TechPotential[1]**	**CF**	**Construction[2]**	**Capacity requirement [4] for 1MW AEC**
Solar PV	Global horizontal irradiance (GHI) of 2075 kWh/m2/year	642 GW	24%[3]	0.5 years	4.06 MW
Onshore wind	Wind speed >7m/s at 150m height	94 GW	44%[1]	1.5 years	2.22 MW

Offshore wind	Wind speed >7m/s at 150m height Up to 50m depth Up to 24 nautical miles from the coast	117 GWMw.	62%[1]	2.5 years	1.57 MW

Table 11 - Renewable energy capacity requirements. [1]Based on Ceará Solar and Wind Atlas [2] Based on Danish Energy Agency [3]Calculated based on Full load hours (kWh/kWp)= GHI (kWh/m2/year)*Transposition Factor *Performance ratio (measure of combined losses) and Capacity factor = Full load hours / Total number of hours per year (8760 h/y), using DEA data for technology factors and Ceará's GHI as provided in the Ceará Solar and Wind Atlas [4] Calculated based on Eq.3-6

Investment cost data

Investment cost data is grouped into Capital Expenditures (CAPEX) and Operational Expenditures (OPEX) to estimate effects during two phases (p), respectively: 1) Planning and Construction; and 2) Operation and Maintenance. This is a similar approach as followed by other studies and models (Fearnehough & Skribbe, 2022; Milani et al., 2020; NREL, 2022; Vasconcellos & Caiado Couto, 2021). Impacts for the construction phase are estimated for the entire construction period, and are not recurrent. Different technologies have different construction times: for instance, only 0.3 and 0.5 years are needed for building an electrolysis and a solar PV plant, respectively, while 2.5 years are needed for an offshore wind park (Danish Energy Agency, 2022; Fearnehough & Skribbe, 2022). These differences are not taken into account, but results are reported separately for electrolysis alone and electrolysis with renewable energy. Impacts for the operation phase are estimated by year, and are recurrent during the project lifetime (Fearnehough & Skribbe, 2022; International Labor Organization, 2017). The lifetime of all technologies in this study are between 20-25 years (Danish Energy Agency, 2022; NREL, 2018, 2022)· Interpretation for years far in the future should be made carefully, since technology/economic structure may have changed by then compared to the base year.

2.1.1 Planning and construction phase: capital expenditures (CAPEX)

The total installation costs for an electrolysis plant comprise direct, indirect and owner costs. Direct costs refer to the investment costs for acquiring the electrolyzer system and building the facility (IRENA, 2020; ISPT, 2020). Costs for electrolyzer systems include the electrolyser stack plus all necessary balance of plant (drier, cooling, de-oxo and water de-ionisation equipment) and power supply (IRENA, 2020; UK BE&IS, 2021). Some estimates for direct costs also include installation on-site, interconnecting piping and other materials, and services from contractors and suppliers (ISPT, 2020). Indirect costs refer to expenses for engineering, project management, construction supervision and management, and commissioning costs. Owner costs include owner project management and land lease during construction, as well as insurances, grid fees and electricity consumption. Studies often estimate contingency costs to cover risks of unknown scope (ISPT, 2020; NREL, 2018). Estimates for costs can be found in the Table 3 below.

Study	**Direct costs**		**Indirect costs**		**Owner costs**	
	Definition	**Value**	**Definition**	**Value**	**Definition**	**Value**

International Renewable Energy (IRENA, 2020)	Electrolyser system	500-1000 USD/kW	n.a	n.a.	n.a.	n.a
United Kingdom BE&IS Department (UK BE&IS, 2021)	Electrolyser system and civil works	720-960 USD/kW	n.a	n.a	n.a	n.a
Danish Energy Agency (DEA) (Danish Energy Agency, 2022)	Electrolyzer system plus 10% installation costs	440-880 USD/kW	n.a	n.a	n.a	n.a
Institute for Sustainable Process Technology (ISPT, 2020)	Electrolyzer system plus 3% of civil works	600-1160 USD/kW	Expenses for engineering, project management, construction supervision and management, and commissioning costs (no cost break-down) (90-218 USD/kw) and Contingency (184 USD/kw)	90-218 USD/kW	Owner project management, electricity consumption and land lease during construction, as well as insurances and grid fees (no cost break-down)	36-70 USD/kW
Lazard (Lazard, 2021)	Electrolyzer system	310-920 USD/kW	n.a	n.a	n.a	n.a
National Renewable Energy Laboratory (NREL) (NREL, 2018)	Electrolyzer system (460 USD/kW) plus 9.3 USD/kW for construction (site preparation) (2%)	470 USD/kW	Up-front permitting costs (70USD/kW), Engineering and design (46USD/kW) Contingency (70USD/kW)	116-186 USD/kW	5 acres of land for 131MW electrolysis at USD 50,000.00 the acre	1.90 USD/kW

Table 12 - Comparison of low and high estimates for electrolysis systems CAPEX costs.Based on conversion of 1GBP = 1.2 USD and 1EUR = 1.10USD.

Cost assumptions in this study are as following. For direct costs, we take the average of the costs mentioned in Table 3 to find a value of 736 USD/kW. These are split between system costs (714 USD/kW) and construction costs (22 USD/kW or 3% of direct costs). All costs for electrolyzer systems are allocated as demand for the Transformation Industry sector (S3), while construction costs are allocated to the Construction sector (S5). Indirect and owner costs are grouped and allocated to the S11 (Other services and activities). An initial value of 168 USD/kW is assumed. While the ISPT (2020) study considers 23% of contingency costs (184 USD/kw), NREL (2018) estimates much lower values (70USD/kW). This can be explained by the fact that the NREL model is based on a 131MW plant, while the ISPT study is based on a

1GW plant, which entails a much higher level of uncertainties since there are currently no giga-scale plants in operation. As the project taken in to account in this study represents the first large-scale green hydrogen hub in Brazil, entailing considerable first-of a kind project risks, but that first phase investments would still be in the 100-500MW scale, an average value of 120 USD/kW is assumed for contingency costs.

Table 4 summarizes the cost assumptions for electrolysis plant CAPEX. Considering the level of uncertainty, some robustness checks are carried out later in the process to see impacts of other allocation structures (see Section 2.4).

Electrolysis Cost Item	**Sector (i)**	**USD/kW**	**%Total**
Direct Costs			
Electrolyzer (Stack)	S03: Transformation industries	321	31%
Balance of plants (Gas separation, compression and gas treatment)	S03: Transformation industries	110	11%
Civil, Structural & Architectural (Construction)	S05: Construction	22	2%
Utilities and Process Automation (Water, piping, ICT)	S03: Transformation industries	86	8%
Power supply and electronics (Electrical installations)	S03: Transformation industries	196	19%
Developer cost	S11: Other services and activities	48	5%
Indirect costs	S11: Other services and activities	120	12%
Contingency	S09: Financial activities, insurances and related fees	120	12%
Total		1024	100%

Table 13 - CAPEX assumptions electrolysis plant

Regarding renewable energy technologies, IRENA (2022) has total installed costs for onshore wind and solar photovoltaics in Brazil for the year of 2021. For Solar PV, IRENA (2022)'s costs are disaggregated by cost component. Both the EIM-ES and NREL I-JEDI models were also consulted for these costs. Since they have values for Argentina and Colombia, respectively, it was assumed they could also be a good reference for Brazil. Nonetheless, both models were over-estimating costs when compared to the IRENA (2022) report. For instance, I-JEDI had an estimation of 6557 USD/kW for the modules, compared to 369 USD/kW from IRENA (2022). This could perhaps be explained by the recent cost declines on solar photovoltaics and the older cost data in I-JEDI. EIM-ES had a similar level of costs for modules as IRENA (2022) (375 USD/kW), but included much higher developer cost (133 USD/kw instead of 8.8 USD/kW) and has costs for land (3 USD/kW) and fees and contingencies (97 USD/kW), adding up to 1101 USD/kW. Since IRENA (2022)'s costs are both more recent and country specific, IRENA (2022)'s costs are used in this study when available, and EIM-ES costs for contingency and land are taken. CAPEX for solar photovoltaics are available on Table 7.

For onshore wind, only total installed costs are available in IRENA (2022). Costs by component are hence estimated by taking the cost disaggregation from EIM-ES (Fearnehough & Skribbe, 2022), NREL (2022), and Vasconcellos & Caiado Couto (2021) and the country-specific total installed costs for Brazil from IRENA (2022). IRENA (2022) estimates total installed costs for onshore wind in Brazil to be 1150 USD/kW in 2021. In addition, we add 49 USD/kW for contingency and 49 USD/kW for transport, as estimated by Fearnehough & Skribbe (2022). Table 7 summarizes the costs.

Regarding offshore wind, IRENA (2022) does not yet have offshore wind costs specifically for Brazil. Hence, the approach to determine costs was as following. IRENA (2022) has total installed costs reported for the 5th percentile, weighted average, and 95th percentile of realized projects in 2021. These are, respectively, 2052 USD/kw, 2858 USD/kW, and 5641 USD/kW. Looking at the costs for onshore wind, costs for Brazil were below the weighted average of costs globally: 1150 USD/kW versus 1325 USD/kW. Given the similarity between onshore and offshore wind technologies, the existing Brazilian wind industry, as well as Brazil's capabilities on offshore oil & gas exploitation that could be leveraged for the offshore wind industry (Interviews), we argue that Brazil's offshore wind costs could be assumed to be similar to the weighted global average costs for offshore wind. Regarding the cost disaggregation by component, IRENA (2022) shows a review with six different sources. We take the average between these six sources and Fearnehough & Skribbe (2022) to arrive at the costs outlined in Table 5.

Technology	Cost Item	Sector (i)	USD/kW	%
Solar PV	Modules	S03: Transformation industries	369	43%
	Inverters	S03: Transformation industries	36	4%
	BoS hardware	S03: Transformation industries	129	15%
	Installation	S05: Construction	155	18%
	Design and engineering	S11: Other services and activities	9	1%
	Other (PR, permitting, customer)	S11: Other services and activities	51	6.%
	Contingency and fees	S9: Financial activities, insurances and related fees	97	11%
	Land	S10: Real estate activities	3	0.35%
	Total		**849**	**100%**
Onshore Wind	Nacelle	S03: Transformation industries	444	36%
	Blades	S03: Transformation industries	180	15%
	Tower	S03: Transformation industries	155	13%
	Construction (Civil works + Installation)	S05: Construction	189	15%
	Electrical balance of plants	S03: Transformation industries	133	11%
	Project planning and management	S11: Other services and activities	38	3%
	Contingency and finance	S9: Financial activities, insurances and related fees	49	4%
	Transport	S07: Transport, storage and post services	49	4%

	Total		**1237**	**100%**
Offshore wind	Turbine	S03: Transformation industries	1195	42%
	Installation	S05: Construction	286	10%
	Foundations	S03: Transformation industries	529	19%
	Electrical Interconnection	S03: Transformation industries	412	14%
	Development	S11: Other services and activities	145	5%
	Contingency & Other	S9: Financial activities, insurances and related fees	290	10%
	Total		**2858**	**100%**

Table 14 - CAPEX assumptions renewable energy

Table 6 summarizes the sectoral allocation of the capital expenditure for the four technologies (t): electrolysis, solar photovoltaics, onshore wind and offshore wind.

		CAPEX per kW of technology *t*			
i	Sector name	Electrolysis	Solar PV	Onshore Wind	Offshore wind
1	Agriculture				
2	Extractive industries				
3	Transformation industries	714	534	912	2136
4	Electricity, gas, water and other utilities				
5	Construction	22	155	189	286
6	Commerce				
7	Transport, storage and post services			49	
8	Information and communication				
9	Financial activities, insurances and related fees	120	97	49	290
10	Real estate activities		3		
11	Other activities and services	168	60	38	145
12	Public administration, defence, healthcare, education and social security				
13	Green hydrogen				
14	Households (direct employment)				
	Total Capital Expenditure	**1024**	**849**	**1237**	**2857**

Table 15 - Capital expenditures from green hydrogen and renewable energy technologies (in USD). Based on UK BE&IS (2021), Lazard (2021), H2A model from NREL(2022), Fearnehough and Skribbe (2022), Danish Energy Agency (2022), ISPT(2020), IRENA(2020), IRENA (2022), Vasconcellos & Caiado Couto (2021), Macedo and Peyerl (2022).

2.1.2 Operation and maintenance phase: operational expenditures (OPEX)

Different definitions for an electrolysis plant OPEX were found in the literature. There are usually two types of costs. OPEX Fixed regards yearly costs which vary independently from the level of output (here tonnes of hydrogen per year). Examples are direct labour, administration/general overheads, insurance, and local taxes. OPEX variable regards costs that vary directly with the level of final output, for instance costs for electricity and water. Approaches to stack replacement costs vary, with some studies including it as variable, depending on the amount of operating hours, and others as a fixed yearly cost (usually between 2-3%)(see Table 7). This can be more important if one is looking at cases that the annual operational hours can vary e.g., when comparing production from curtailment only. In our case, since we consider electrolysers are operating continuously with dedicated renewable energy generation, we follow the fixed yearly cost approach, since we would expect the electricity available to be roughly the same from year to year. Table 7 summarises approaches from other studies and hydrogen production models.

Study	OPEX definition
UK BE&IS (2021)	Variable OPEX as annuitized stack replacement costs, as well as costs for water and electricity inputs. Fixed OPEX including direct labour, administration/general overheads, insurance/local taxes, but excluding cost of hydrogen compression equipment.
Lazard (2021)	OPEX includes water costs, electricity costs, warranty and insurance (1% of initial CAPEX/year) and “other O&M”(1.5% of initial Capex/year).
Gallardo et al (2021)	OPEX costs including electricity cost and O&M cost (2% of initial CAPEX/ year)
IRENA (2018)	Includes OPEX as 2% of initial CAPEX/year. No definition of OPEX cost items provided.
Eichman et al (2016)	Estimates fixed O&M at 42$/kW/yr. In addition, estimates storage costs 623–1000 $/kg of hydrogen. Also adds a installation cost multiplier of 1.2.
NREL (2018)	NREL hydrogen production model (H2A) for central electrolysis (version 3.2018) provides OPEX costs for a ~110 MW PEM electrolysis plant. They estimate OPEX fixed at 5.5% of initial CAPEX, that can be disaggregated by: 2% for taxes and insurances 2% for material costs for maintenance and repairs 1.5% for labour cost and General& Administrative (G&A) costs, assuming 10FTE employees with an 50$ hourly wage and a 20% rate for G&A over labour costs. They also recognize cost components for which they do not have values, for instance for licensing, permits and fees. In addition to these fixed inputs they include energy and water costs in the OPEX.
DEA(2022)	Includes only Fixed O&M costs as 2% of CAPEX.

Table 16 - Approaches for defining operational expenditures of green hydrogen production via electrolysis

Based on these different approaches, we assume the operational expenditures to follow the structure defined on Table 9. Annuitized stack replacements are assumed to be 2% of initial CAPEX, that is, 21.76 USD/kW/year. Additionally, the 2% allocated to taxes and insurances in the NREL (2018) H2A model are split into 1% of insurance (10.88 USD/kW/yr), based on Lazard (2021), and 1% of taxes. For water requirements, DEA estimates between 170-189 kilograms of water per MWh of electricity input. By multiplying it by the annual electricity input of 8538MWh (see Section 3.1), we arrive at between 1451-1614 tonnes of water per MW of electrolysis capacity per year. Water costs are calculated based on Lazard (2021). Assuming a cost of 0.002 USD/kg of water, yearly water costs add up to 3.43 USD per kilo-watt of electrolysis capacity.

Direct labour in the electrolysis plant is estimated based on expert consultations. These indicated that a 20-100 MW electrolysis plant would employ between 5-10 FTE in the operation phase. This would lead to an employment factor of 0.25-0.5 FTE/MW for a 20 MW plant and

0.05-0.1 FTE/MW for a 100MW plant. The H2A model from NREL (2018) assumes 10 FTE for a 131 MW plant, hence 0.076 FTE/MW. Given that projects expected in the hub H2V would be at the 100-500 MW scale, and that employment factors do not increase linearly with scale, we assume a value of 0.07 FTE/MW of electrolysis capacity. The average salary is taken from RAIS data (Ministry of Employment, 2022) for the energy sector, as shown in Table 8.

Sector: Electricity and Gas	Value	Unit
Sector share FTEs		
Men	80.5	%
Women	19.5	%
Average yearly income		
Men	145 067	R$/year
Women	106 678	R$/year
Weighted average	137 573	R$/year
Salary per FTE	35 510	USD/year

Table 17 - Employment data for green hydrogen based on RAIS data for electricity and gas sector in the state of Ceará. Based on RAIS data (Ministry of Employment, 2022).

Cost Item	Definition	Sector	Value	Unit
Materials for maintenance	Annuitized stack replacement costs	S3: Transformation industries	21.76	USD/kW/year
Insurance	Warranty & Insurance	S9: Financial sector	10.88	USD/kW/year
Direct labour	Number of full-time employees	S14: Households	0.07	FTE/MW
	Annual salaries expenses		2.49	USD/kW/year
Water	Input water costs	S4: Electricity, gas, water and residue management	3.43	USD/ kW/yr
Electricity	Marginal cost for operating electricity generation system	S4: Electricity, gas, water and residue management		

Table 18 - Green hydrogen electrolysis OPEX allocation to Ceará's economic sector. Based on UK BE&IS (2021) Lazard (2021) NREL (2018)

Electricity costs are estimated as the marginal costs for operating the renewable energy plant. OPEX for solar PV, onshore wind and offshore wind is available on Table 10. For onshore wind, IRENA (2022) reports a total O&M cost of 49-53 USD/kW/year for Denmark and Germany. Vasconcellos & Caiado Couto [ref] estimate a total of 45 USD/kW/year for onshore wind in Brazil. The EIM-ES assumes 18 USD/kW/year for maintenance and 12 USD/kW/year for operation, as well as 2.5 USD/kW/year for land lease, considering materials only. Regarding employment factors, the literature has estimated values between 0.1-10.7 FTE/MW of installed capacity, with a median of 0.64 FTE/MW and an average of 2.13 FTE/MW (Cameron & van der Zwaan, 2015; Kattumuri & Kruse, 2019; Meyer & Sommer, 2016; Nasirov et al., 2021; Simas & Pacca, 2014). We take the median value for this study, which leads to an annual direct labour expenditure of 22.78 USD/kW/year.

For Solar PV, the EIM-ES estimates 9.5 USD/kW/year for operation and 11.5 USD/kW/year for maintenance, comprising materials only (Fearnehough & Skribbe, 2022). IRENA (2022) does not provide O&M data for Solar PV. Regarding employment factors, the literature reports values between 0.12-4.8 FTE/MW, with a median of 1.1 FTE/MW and an average of 1.4 FTE/MW (Cameron & van der Zwaan, 2015; Kattumuri & Kruse, 2019; Meyer & Sommer, 2016; Nasirov et al., 2021). Assuming the median value of 1.1 FTE/MW and salaries for the energy sector in Ceará, salary expenditures for solar PV is assumed to be 39 USD/kW/year.

For offshore wind, the EIS-EM assumes 42 USD/kW/year for maintenance and 19 USD/kW/year for operation, considering material costs only (Fearnehough & Skribbe, 2022). The only study for employment factors in offshore wind found is the one from Tegen et al (2015) which reports values between 0.7-1.7 FTE/MW for different regions in the United States. We take the median of the reported values (1.3 FTE/MW) as the assumption in this study, leading to a salary expenditure of 46.2 USD/kW/year.

Tech	Cost Item	Value	Unit	% Total	Sector
Onshore wind	Operation	12	USD/kW/yr	22%	S4: Electricity, gas, water and residue management
	Maintenance	18	USD/kW/yr	33%	S3: Transformation industries
	Land lease	2.5	USD/kW/yr	4%	S10: Real estate
	Direct labour				
	Salaries	22.78	USD/kW/yr	41%	S14: Households
	Emp factor	0.64	FTE/MW		
Solar PV	Operation	9.5	USD/kW/yr	16%	S4: Electricity, gas, water and residue management
	Maintenance	11.5	USD/kW/yr	19%	S3: Transformation industries
	Direct labour				
	Salaries	39.06	USD/kW/yr	65%	S14: Households
	Emp factor	1.1	FTE/MW		
Offshore wind	Operation	19	USD/kW/yr	18%	S4: Electricity, gas, water and residue management
	Maintenance	42	USD/kW/yr	39%	S3: Transformation industries
	Direct labour				
	Salaries	46.2	USD/kW/yr	43%	S14: Households
	Emp factor	1.3	FTE/MW		

Table 19 - OPEX cost assumptions renewable energy

2.2 Defining local content scenarios

To determine the expenditure allocated to domestic sectors of Ceará the CAPEX and OPEX sectoral allocation is multiplied by the local content share of sector *i* in each scenario *s*:

$$z_{iGH2}^{D,p,t,s} = \begin{cases} z_{iGH2}^{T,p,t} * lcs_i^{p,s,t}, \ t = 1 \\ \left(z_{iGH2}^{T,p,s,H2} * lcs_i^{p,s,H2}\right) + \left(z_{iGH2}^{T,p,t} * lcs_i^{p,s,t}\right), \ t \neq 1 \end{cases} \quad \text{(Eq. 7-7)}$$

Where t= 1 is electrolysis alone, and t=2, 3, and 4 is electrolysis plus onshore wind, offshore wind, and solar photovoltaics.

Four local content share scenarios (s) are estimated: The "*Local*" scenario is based on the assumption that 100% of goods and services required in the investment would be sourced locally in Ceará. This scenario provides an idea of what could have been the maximum benefits in such a project. The "*Economy Baseline*" scenario takes the share of between the local supply of each sector divided by the total supply available in Ceará, that is, the local supply plus imports from the rest of Brazil and the rest of the world. This is done by taking the share of domestic supply in the total supply for each sector *i* from the supply-use tables of Ceará. However, since sectors are highly aggregated, baseline scenarios may not be representative of specific technologies. The "*International Project*" scenario assumes the lowest possible shares of local content. That is, technologies are imported, project development activities are undertaken in multinational headquarters and insurances and fees are also taken abroad. Only construction expenditures are assumed to be local, where the baseline value is taken instead. The "*Technology-specific baseline*" hence adapts the baseline scenario where necessary to incorporate the specific local capabilities for each technology (electrolysis, onshore wind, offshore wind and solar photovoltaics). The tables below summarize the local content shares for each sector under each scenario.

	Local Technology	**Economy Baseline**	**International Project**	**Technology Baseline H2**	**Technology Baseline ONW**	**Technology Baseline OFW**	**Technology Baseline PV**
S01: Agriculture	1	0.587	0.000	0.587	0.587	0.587	0.587
S02: Extractive Industries	1	0.648	0.000	0.648	0.648	0.648	0.648
S03: Transformation industries	1	0.635	0.000	0.000	1.000	0.700	0.000
S04: Electricity, gas, water, and other utilities	1	0.775	0.000	0.775	0.775	0.775	0.775
S05: Construction	1	0.595	0.595	0.595	0.595	0.595	0.595
S06: Commerce	1	0.809	0.000	0.809	0.809	0.809	0.809
S07: Transport storage and post services	1	0.729	0.000	0.729	0.729	0.729	0.729
S08: Information and communication	1	0.868	0.000	0.868	0.868	0.868	0.868
S09: Financial activities, insurances, and related fees	1	0.703	0.000	0.703	0.703	0.703	0.703
S10: Real state activities	1	0.608	0.000	0.608	0.608	0.608	0.608
S11: Other activities and services	1	0.748	0.000	0.500	0.500	0.500	0.500
S12: Public administration, defense, healthcare, education, and social security (PADHESS)	1	0.791	0.000	0.791	0.791	0.791	0.791
Green Hydrogen	1	0.000	0.000	0.000	0.000	0.000	0.000
Households	1	0.699	0.000	0.699	0.699	0.699	0.699

Table 20 - Local content shares during the construction phase

	Local Technology	**Economy Baseline**	**International Project**	**Technology Baseline H2**	**Technology Baseline ONW**	**Technology Baseline OFW**	**Technology Baseline PV**
S01: Agriculture	1	0.587	0.0	0.587	0.587	0.587	0.587

S02: Extractive Industries	1	0.648	0.0	0.649	0.649	0.649	0.649
S03: Transformation industries	1	0.635	0.0	0.000	1.000	0.377	0.000
S04: Electricity, gas, water, and other utilities	1	0.775	1.0	1.000	1.000	1.000	1.000
S05: Construction	1	0.595	0.0	0.596	0.596	0.596	0.596
S06: Commerce	1	0.809	0.0	0.809	0.809	0.809	0.809
S07: Transport storage and post services	1	0.729	0.0	0.730	0.730	0.730	0.730
S08: Information and communication	1	0.868	0.0	0.869	0.869	0.869	0.869
S09: Financial activities, insurances, and related fees	1	0.703	0.0	0.500	0.500	0.500	0.500
S10: Real estate activities	1	0.608	0.0	0.609	0.609	0.609	0.609
S11: Other activities and services	1	0.748	0.0	0.500	0.500	0.500	0.500
S12: Public administration, defense, healthcare, education, and social security (PADHESS)	1	0.791	0.0	0.792	0.792	0.792	0.792
Green Hydrogen	1	0.000	0.0	0.000	0.000	0.000	0.000
Households	1	0.699	0.5	0.699	0.699	0.699	0.699

Table 21 - Local content shares during operation phase

3. Sensitivity analysis

3.1 Scenario set-up

Since input-output analysis is a linear model, changes in absolute values for the total final demand would lead to an equivalent change in total impacts. Hence, it is instead more insightful to look at the different sectoral allocations of the change in final demand since sectors have different multipliers and impacts could hence change depending on the sectoral allocation. Therefore, regarding the uncertainties concerning the CAPEX for green hydrogen electrolysis, we estimate results with a different sectoral allocation, where project development is allocated directly to households reflecting the possibility of direct employment instead of outsourcing, and the indirect costs are disaggregated into owner management and supervision, land costs, permitting costs, insurance, and grid fees. These costs are estimated based on the previous literature review on investment costs (see Table 13).

Cost.Item	**Sector**	**Value.kW**
Electrolyzer (Stack)	3	321
Balance of plants (Gas separation, compression and gas treatment)	3	110
Civil, Structural & Achitectural (Construction)	5	22
Utilities and Process Automation (Water, piping, ICT)	3	86
Power supply and electronics (Electrical installations)	3	196
Owner project management and supervision	13	48
Engineering, project management, construction supervision and management	13	46
Land costs	10	0.008
Permitting costs	11	2
Insurance	9	69

Grid fees and electricity consumption	4	38
Total		**938**

Table 22 - Disaggregated costs for sensitivity analysis

Moreover, another area of uncertainty concerned the employment factors, given the wide ranges reported on the literature. We hence re-estimate impacts by varying employment factors into a "low impacts" and a "high impacts" scenario. Similarly, we look at the sensitivity of our results for the capacity factors since higher capacity factors leads to lower installed capacity for renewable energy per electrolysis capacity and hence overall lower expenditures. Table 14 summarizes the configuration of these sensitivity analysis.

Finally, we estimate one scenario combining all aforementioned variations that increase economic impacts when compared to the default configuration ("AllMax") and one scenario combining the values that negatively affect economic impacts when compared to the default configuration ("AllMin"). All of these scenarios are estimated in combination with the local content scenarios (LocalTechnology, EconomyBaseline, TechnologyBaseline, and InternationalProject).

Dimension	**Scenario**	**Scenario name**	**Project phase**	**Baseline**	**Lower impacts**	**Higher impacts**
Project	Project development in-house during construction phase (Households)	ProjDev13	Construction	Costs aggregated and allocated to "Other activities and sectors"		
Technology	Different employment factors	EmpMax and EmpMin	Operation	0.7 0.64 1.1 1.3	0.05 0.1 0.1 0.7	0.1 2.2 4.0 1.7
Local context	Capacity factors	CFHigh and CFLow	Construction and Operation	24% 44% 62%	27% 48% 68%	20% 40% 56%

Table 23 – Summary of sensitivity analysis

3.2 Results from sensitivity analysis

Figure 3 shows the results from a different sectoral allocation in the construction phase, as explained in Table 13. As it can be seen, a different sectoral allocation will only impact the sectoral shares from the Technology Baseline scenario. No substantial change in the level of impacts can be observed for any of the local content scenarios.

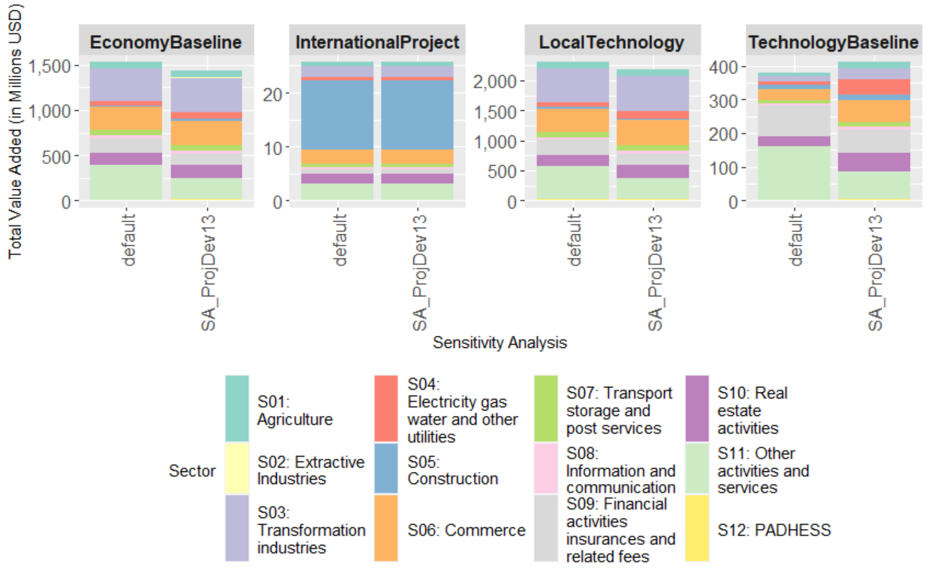


Figure 18 -Impact on value added from different sectoral aggregation, construction phase

Figure 4 shows the impacts from different capacity factor assumptions. The scenarios with *lower* capacity factors (20%, 40% and 56 %) have led to slightly higher impacts on value added than the default scenario, while the scenario with *higher* capacity factors (27%, 48%, and 68%) led to slightly lower impacts than the default scenario. Impacts remained at the same order of magnitude and the ranking between technologies and local content scenarios remained unchanged. This was already expected given the linearity in the model.

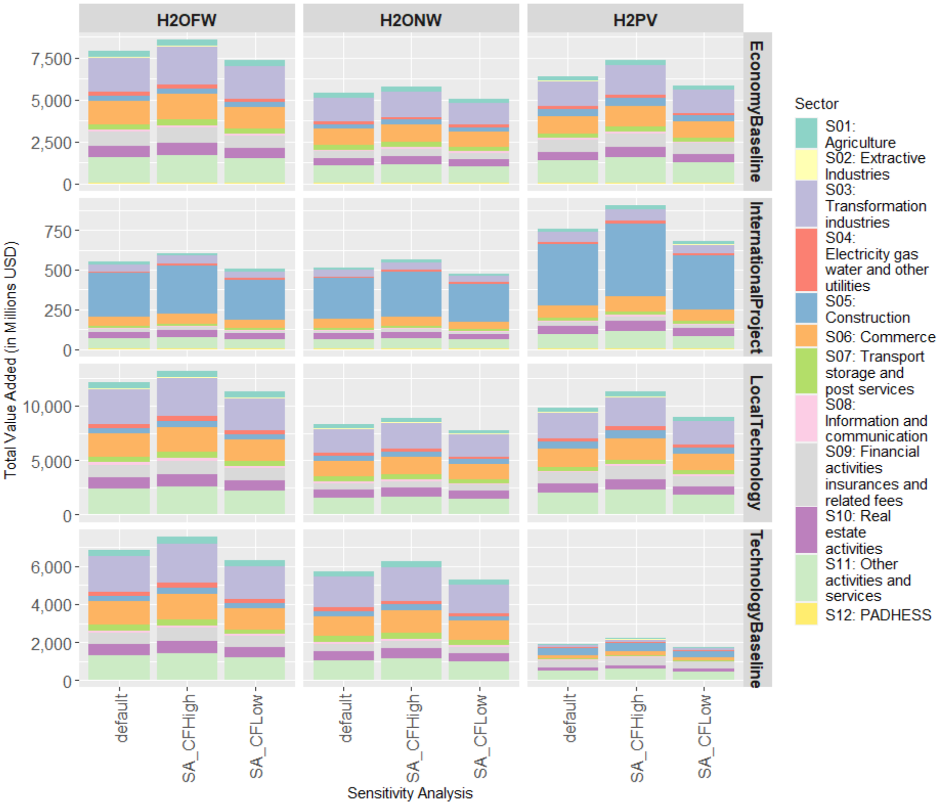


Figure 19 - Impact on value added from different capacity factors, construction phase

Figure 5 summarises the impacts on total value added by the different sensitivity analysis scenarios. As it can be seen, the results are robust to all of them, as the differences in total impacts between these scenarios is not substantial and the order of technology and local content scenarios remain unchanged.

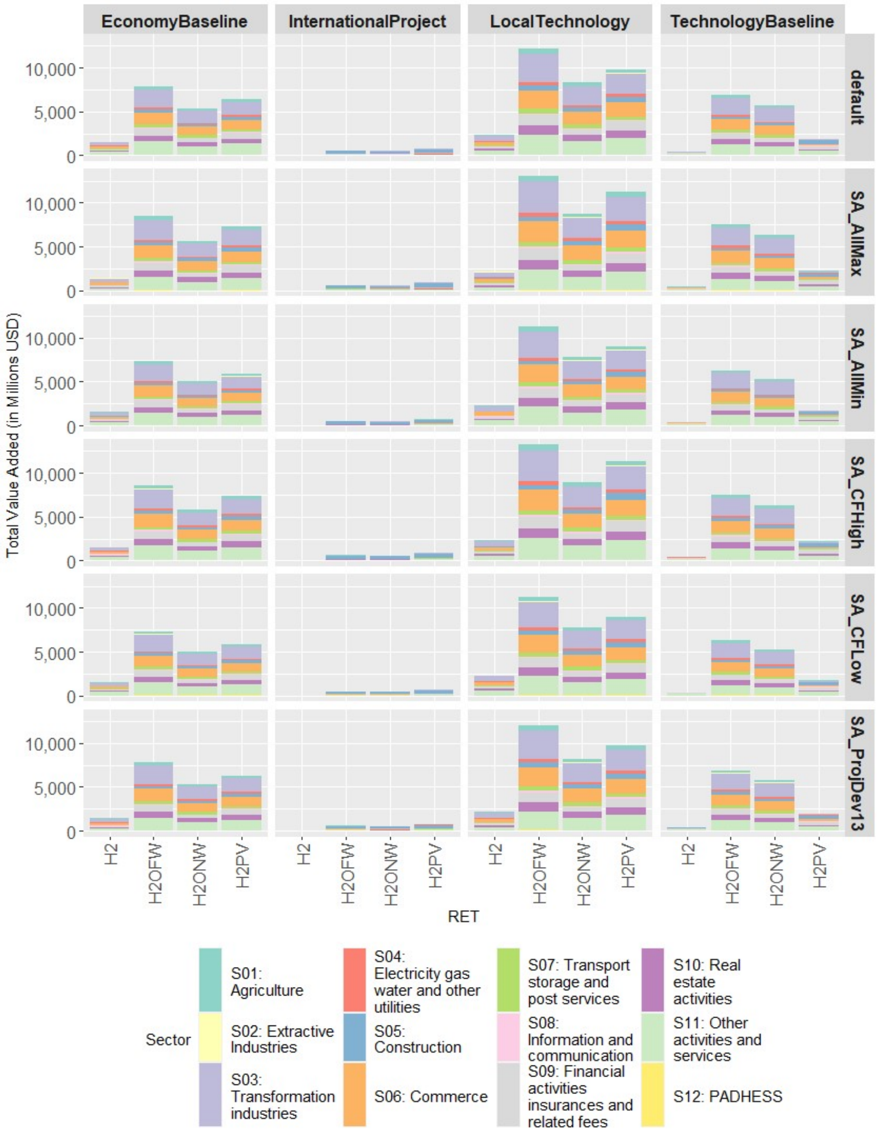


Figure 20 - Summary impacts on value added from sensitivity analysis, construction phase

Figures 6 and 7 summarise the impacts on total income and total employment from the different sensitivity analyses during the construction phase. Similarly to the case of value added, there are some oscillations between the different scenarios, but differences are not substantial to the point of altering the main results.

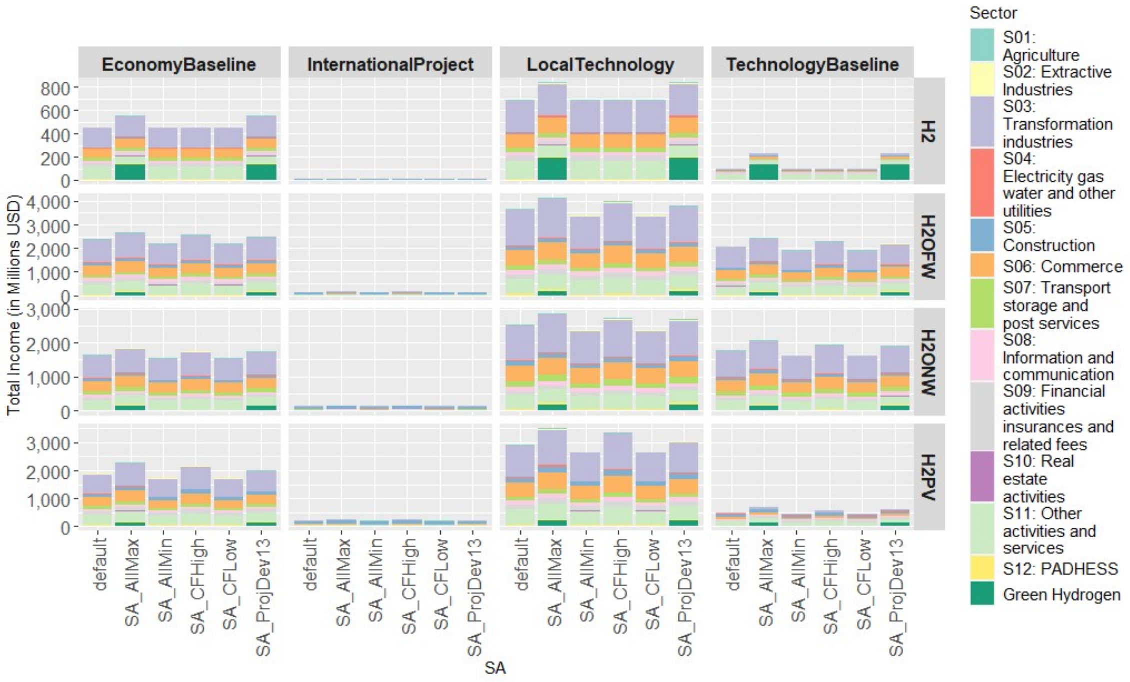


Figure 21 - Impacts on income, construction phase

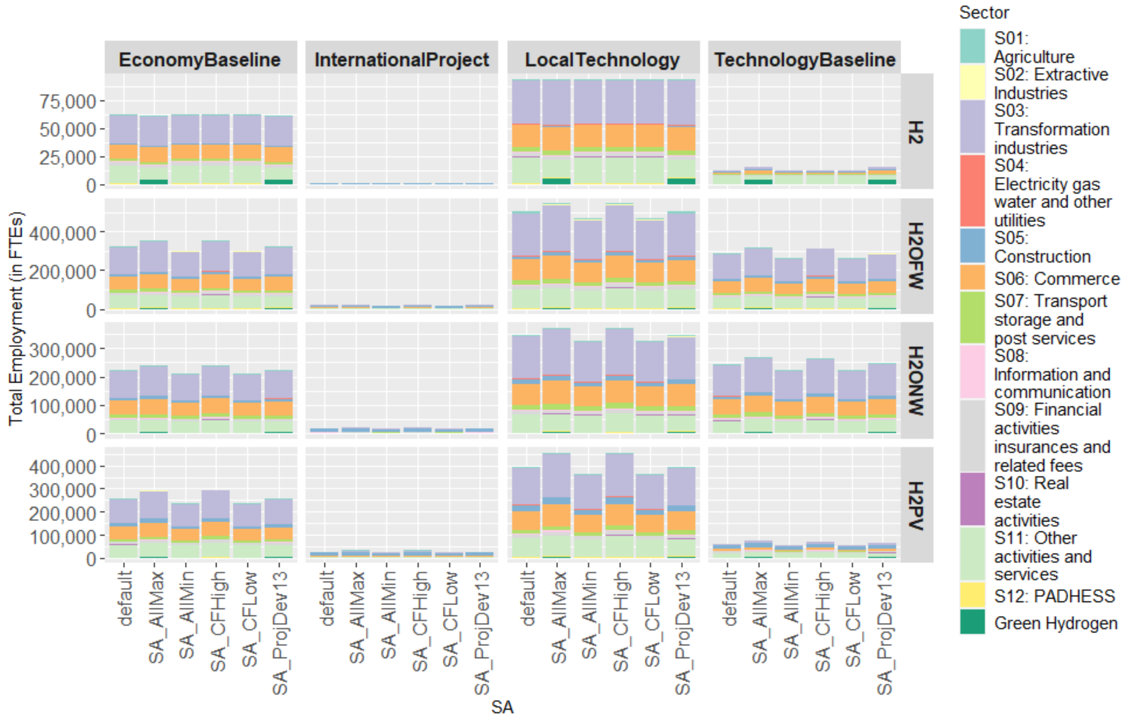


Figure 22 - Impacts on employment, construction phase

Regarding the operation phase, Figure 8 shows that employment factor assumptions are very important for assessing total impacts, especially for onshore wind and solar photovoltaics. Figures 9 and 10 show how results for income and employment during the operation phase are highly sensitive to assumptions regarding employment factors.

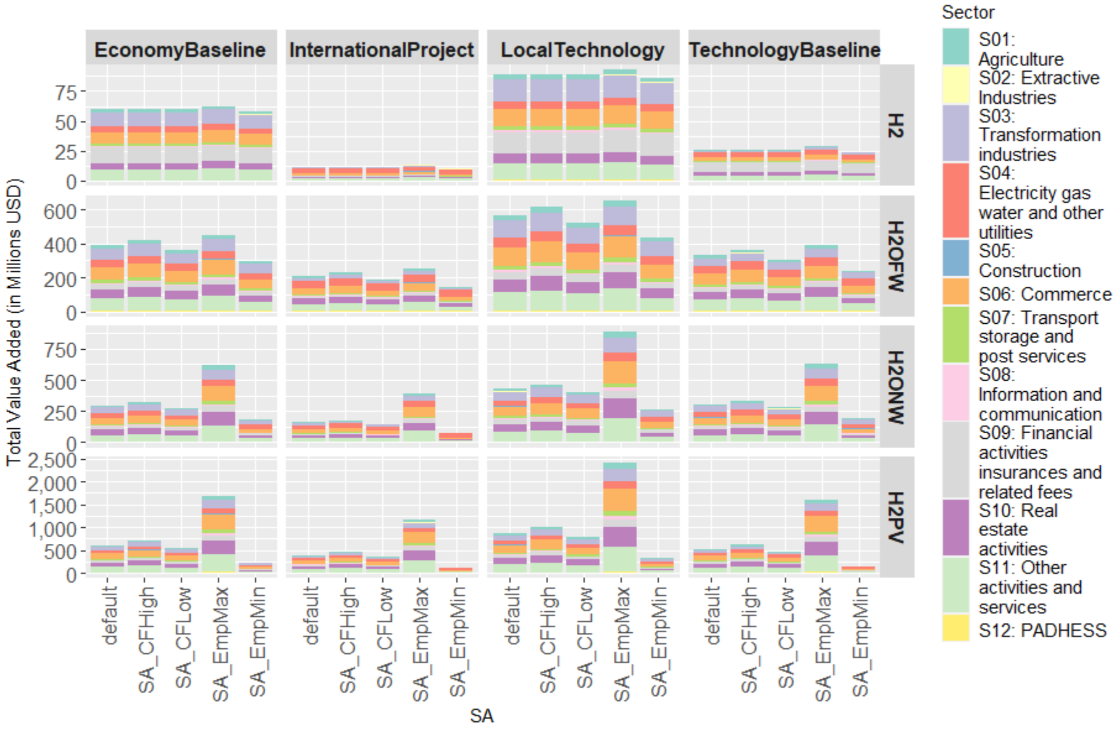


Figure 23 - Impact on value added from different employment and capacity factors, operation phase

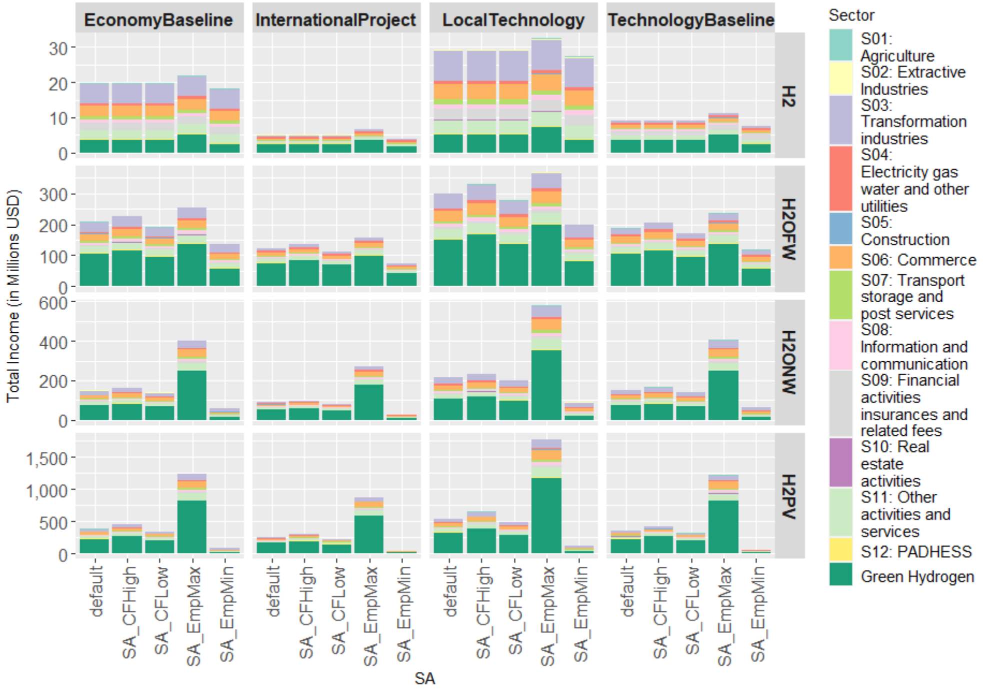


Figure 24 - Impact on income from different employment and capacity factors, operation phase

Figure 25 - Impact on employment from different employment and capacity factors, operation phase

4. References

Cameron, L., & van der Zwaan, B. (2015). Employment factors for wind and solar energy technologies: A literature review. *Renewable and Sustainable Energy Reviews*, *45*, 160–172. https://doi.org/10.1016/j.rser.2015.01.001

Danish Energy Agency. (2022). *Technology data*. https://ens.dk/en/our-services/projections-and-models/technology-data

Eichman, J., Townsend, A., & Melaina, M. (2016). *Economic Assessment of Hydrogen Technologies Participating in California Electricity Markets*. National Renewable Energy Laboratory (NREL).

European Commission. (2023). *Commission Delegated Regulation (EU) 2023/1184 of 10 February 2023 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council by establishing a Union methodology setting out detailed rules for the production of renewable liquid a*.

Fearnehough, H., & Skribbe, R. (2022). *Economic Impact Model for Electricity Supply Methodology Note* (February 2). New Climate Institute. https://newclimate.org/sites/default/files/2022-03/economic_impact_model_methodologynote_feb22_0.pdf

Gallardo, F. I., Monforti Ferrario, A., Lamagna, M., Bocci, E., Astiaso Garcia, D., & Baeza-Jeria, T. E. (2021). A Techno-Economic Analysis of solar hydrogen production by electrolysis in the north of Chile and the case of exportation from Atacama Desert to Japan. *International Journal of Hydrogen Energy*, *46*(26), 13709–13728. https://doi.org/10.1016/j.ijhydene.2020.07.050

Government of Ceará. (2022). *Atlas eólico e solar do estado do Ceará*. http://atlas.adece.ce.gov.br/User?ReturnUrl=%2F

Guilhoto, J. J. M., & Sesso Filho, U. A. (2010). Estimação da matriz insumo-produto utilizando dados preliminares das contas nacionais: aplicação e análise de indicadores econômicos para o Brasil em 2005. *Revista Economia & Tecnologia*, *6*(4), 1–23. https://doi.org/10.5380/ret.v6i4.26912

Guilhoto, J., & Sesso Filho, U. A. (2005). Estimação da matriz insumo-produto a partir de dados preliminares das contas nacionais. *Economia Aplicada*, *9*(1), 1–23.

IEA. (2022). *Global Hydrogen Review 2022*. IEA. https://www.iea.org/reports/global-hydrogen-review-2022

Instituto Brasileiro de Geografia e Estatística - IBGE. (2022). *System of Regional Accounts: Ceara*. https://www.ibge.gov.br/estatisticas/economicas/contas-nacionais/9054-contas-regionais-do-brasil.html?edicao=34530

International Labor Organization. (2017). *How To Measure and Model Social and Employment Outcomes of Climate and Sustainable Development Policies*. www.ilo.org

IRENA. (2020). *Green hydrogen cost reduction: Scaling up electrolysers to meet the 1.5oC climate goal*.

IRENA. (2022). *Renewable Power Generation Costs*. https://www.irena.org/publications/2022/Jul/Renewable-Power-Generation-Costs-in-2021

ISPT. (2020). *Gigawatt green hydrogen plant: state of the art design and total installed capital costs*.

Kattumuri, R., & Kruse, T. (2019). Renewable technologies in Karnataka, India: jobs potential and co-benefits. *Climate and Development*, *11*(2), 124–137. https://doi.org/10.1080/17565529.2017.1410085

Lazard. (2021). *Levelized cost of hydrogen analysis*. Lazard.

Macedo, S. F., & Peyerl, D. (2022). Prospects and economic feasibility analysis of wind and solar photovoltaic hybrid systems for hydrogen production and storage: A case study of the Brazilian electric power sector. *International Journal of Hydrogen Energy*, *47*(19), 10460–10473. https://doi.org/10.1016/j.ijhydene.2022.01.133

Meyer, I., & Sommer, M. W. (2016). Employment effects of renewable energy deployment - a review. *International Journal of Sustainable Development*, *19*(3), 217. https://doi.org/10.1504/IJSD.2016.078274

Milani, R., Caiado Couto, L., Soria, R., Szklo, A., & Lucena, A. F. P. (2020). Promoting social development in developing countries through solar thermal power plants. *Journal of Cleaner Production*, *246*, 119072. https://doi.org/10.1016/j.jclepro.2019.119072

Miller, R. E., & Blair, P. D. (2021). *Input-Output Analysis*. Cambridge University Press. https://doi.org/10.1017/9781108676212

Ministry of Employment. (2022). *RAIS database*. Ministry of Employment. http://pdet.mte.gov.br/rais

Nasirov, S., Girard, A., Peña, C., Salazar, F., & Simon, F. (2021). Expansion of renewable energy in Chile: Analysis of the effects on employment. *Energy*, *226*, 120410. https://doi.org/10.1016/j.energy.2021.120410

NREL. (2018). *H2A: Hydrogen Analysis Production Models*. Current Central Electrolysis Version 3.2018. https://www.nrel.gov/hydrogen/h2a-production-models.html

NREL. (2022). *JEDI Models*. https://www.nrel.gov/analysis/jedi/models.html

Simas, M., & Pacca, S. (2014). Assessing employment in renewable energy technologies: A case study for wind power in Brazil. *Renewable and Sustainable Energy Reviews*, *31*, 83–90. https://doi.org/10.1016/j.rser.2013.11.046

Tegen, S., Keyser, D., Flores-Espino, F., Miles, J., Zammit, D., & Loomis, D. (2015). *Offshore Wind Jobs and Economic Development Impacts in the United States: Four Regional Scenarios*.

UK BE&IS. (2021). *Hydrogen Production Costs*. Government of the United Kingdom.

Vale, V., & Perobelli, F. (2020). *Análise Insumo-Produto: Teoria e Aplicações no R*.

NEDUR/LATES.

Vasconcellos, H. A. S., & Caiado Couto, L. (2021). Estimation of socioeconomic impacts of wind power projects in Brazil's Northeast region using Interregional Input-Output Analysis. *Renewable and Sustainable Energy Reviews*, *149*, 111376. https://doi.org/10.1016/J.RSER.2021.111376