Project: Green Hydrogen Supply Chain

In recent years, sustained and coordinated strategic actions have been established to drastically reduce greenhouse gas (GHG) emissions and to accomplish emission targets and climate change goals established by the European Union (EU). The European Commission has introduced the "Fit for 55" package, a comprehensive set of legislative proposals aimed at achieving carbon neutrality by 2050, with an interim target of at least a 55% reduction in GHG emissions by 2030 (European Commission, 2021). In this context, green hydrogen has emerged as an energy carrier, and as an alternative fuel and feedstock, produced from renewable energy sources (RES), which could help to decarbonize various sectors.

Among the EU member states, Portugal has unveiled its national energy and climate plans, emphasizing its national hydrogen strategies. Due to its abundant renewable energy sources (i.e. weather and climate conditions), Portugal holds a strategic position in the European green hydrogen landscape. In line with these plans, Portugal has also adopted its National Strategy for Hydrogen (EN-H2), aiming to position the country as a major player in the global hydrogen industry. EN-H2's macro-objectives for 2030 include deploying 2% to 5% of green hydrogen in the industrial energy consumption sector.

Green Hydrogen Production Process

The most common method for producing green hydrogen is through water electrolysis, a process that uses electricity from renewable energy sources (such as solar, wind, or hydro) to split water (H_2O) into hydrogen (H_2) and oxygen (O_2). The produced hydrogen can be stored and transported in either liquid or gaseous form and is used as a clean fuel or feedstock across various sectors, including industry, transportation, and energy storage.

Project Goal

The aim of this project is to design an optimized Green Hydrogen Supply Chain (GHSC) in Portugal, addressing the country's green hydrogen demand, particularly for the industrial sector. The goal is to create a robust and efficient supply chain capable of meeting this demand while overcoming key challenges such as high infrastructure costs and evolving market penetration.

Problem Description

The considered GHSC consists of four main phases: (i) primary energy sources and feedstock; (ii) production; (iii) storage; and (iv) distribution. An overview of the supply chain structure is depicted in Figure 1. For simplification purposes, the following is assumed:

(i) **Primary energy sources and feedstock:** Only renewable energy sources are considered, specifically solar, wind, and hydro energy sources. Water availability (which is the main feedstock for water electrolysis) is not taken into account.

(ii) **Production technology**: Water electrolysis is the only possible production technology, with three potential plant sizes: small, medium or large. PEM (Proton Exchange Membrane) technology is to be used, operating at an assumed efficiency of 70%. More than one plant size can be selected for the same location.

(iii) **Storage:** It is assumed that the selected hydrogen physical form for storage will be liquid and that it will take place in the same location as the production facilities.

(iv) **Transport:** Distribution of hydrogen is also assumed to be carried out in its liquid form, using tanker trucks.

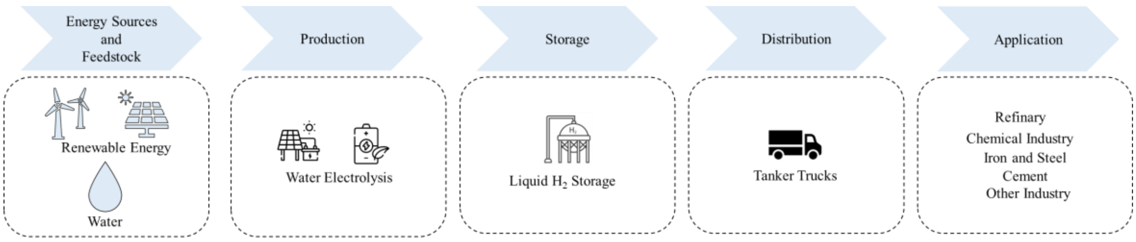

Figure 1. GHSC structure

Yearly hydrogen demand for the industrial sector as well as location and yearly availability of renewable energy is presented by district, as shown in Table 1.

Table 1. H2 demand and renewable energy sources availability.

Location	District	H2 total demand per year (TWh)	Energy Source Availability per year (TWh)		
			Hydro	**Wind**	**Solar**
L1	Bragança		7.6	0.5	0.5
L2	Viseu		3.3	4.1	
L3	Vila Real		1.1	7	0.4
L4	Coimbra	3.87	3.8	0.9	
L5	Viana do Castelo	0.67	2.7	2.4	
L6	Braga		1.5	3.9	0.1
L7	Guarda		1.1	3.3	0.1
L8	Castelo Branco	0.54			
L9	Beja		2	0.5	2.4
L10	Santarém	0.53			
L11	Lisboa	1.34			
L12	Porto				
L13	Leiria	0.63			
L14	Faro	0.62		1.4	2.1
L15	Aveiro	0.84			
L16	Setúbal	5.25			
L17	Portalegre				
L18	Évora				

The projected hydrogen demand, as outlined in Table 1 will not be fully realized immediately. It will take several years for supply to catch up with this demand. To guide this development, the EN-H2 strategy has established interim targets and indicative trajectories. These targets, shown in Table 2, specify the percentage of hydrogen that should contribute to the energy consumption of the industrial sector by 2030, 2040, and 2050.

Table 2. Requirements of H2 demand to be fulfilled by 2030, 2040 and 2050, according to European and National targets.

Year	Target
2030	3.5%
2040	12.5%
2050	22.5%

Other Technical and Economic Information:

- Hydrogen Production Facilities

A summary of the technical and economic parameters of H2 production facilities is illustrated in Table 3. Three different sizes of H2 production plants can be considered: small (S), medium (M), and large (L).

Table 3. Technical and economic parameters of H2 production facilities for H2 in liquid form

Production technology (size)	**Capital Cost (k€)**	**Capacity (tH2/d)**
Water electrolysis (S)	17 800	10
Water electrolysis (M)	267 000	150
Water electrolysis (L)	854 400	480

- Transportation

Table 4. Transportation mode costs (liquid H2, tanker truck)

Parameter	**Tanker Truck cost**
Shipping cost (€/tH2-km)	0.35 to 0.50

- Distance between districts in kilometres (km)

Table 5. Distance by road between districts, in km.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
1	0	200	118	324	274	217	178	273	542	444	510	210	383	751	272	545	363	462
2	200	0	97	94	200	176	76	170	428	225	291	127	195	528	86	327	260	360
3	118	97	0	214	164	107	171	266	536	334	400	100	273	637	162	435	355	493
4	324	94	214	0	195	171	155	138	343	141	206	122	79	443	63	242	172	300
5	274	200	164	195	0	62	273	331	521	320	385	74	258	622	148	421	365	478
6	217	176	107	171	62	0	251	309	499	298	363	57	236	600	126	399	344	457
7	178	76	171	155	273	251	0	99	369	253	318	200	262	555	159	354	189	289
8	273	170	266	138	331	309	99	0	275	159	224	257	169	461	199	260	95	195
9	542	428	536	343	521	499	369	275	0	205	176	448	283	147	389	142	181	80
10	444	225	334	141	320	298	253	159	205	0	80	245	81	307	186	117	162	163
11	510	291	400	206	385	363	318	224	176	80	0	314	150	281	255	53	230	137
12	210	127	100	122	74	57	200	257	448	245	314	0	187	551	76	349	294	407
13	383	195	273	79	258	236	262	169	283	81	150	187	0	383	119	180	172	239
14	751	528	637	443	622	600	555	461	147	307	281	551	383	0	491	244	382	226
15	272	86	162	63	148	126	159	199	389	186	255	76	119	491	0	289	234	347
16	545	327	435	242	421	399	354	260	142	117	53	349	180	244	289	0	193	100
17	363	260	355	172	365	344	189	95	181	162	230	294	172	382	234	193	0	103
18	462	360	493	300	478	457	289	195	80	163	137	407	239	226	347	100	103	0

Bearing in mind the information provided, and in a critical and complete manner, answer the following questions. **Note:** All assumptions and additional data that you consider necessary must be appropriately identified and justified.

1. Formulate a mathematical model that can be used to optimize the Green Hydrogen network design and planning while minimizing the total supply chain costs. This should be accomplished by determining the number, location, and size of production facilities, as well as the allocation of resources and product flows. Use a solver of your choice. Include a sensitivity analysis of the most relevant parameters.

2. In practice, cost is not likely to be the sole determinant of the performance of the supply chain. Considering a possible extension of the developed model to a multi-objective model, which other criteria should be included? What other data would be necessary? Justify the choice, considering the purpose of this work.

3. Water is a key input in the electrolysis process for producing green hydrogen. However, in many regions, water availability may be limited or subject to seasonal fluctuations. Discuss how water scarcity could affect the location of production facilities, the overall efficiency of the supply chain, and the cost of hydrogen production.

Report guidelines – video report

1. **Prepare a presentation using PowerPoint** with no more than 11 slides (excluding the cover slide). The structure must be as follows:
   - Cover slide: name, number, and photo of the group members
   - Short introduction about the topic and the main questions (1 slide)
   - Present the strategy used to obtain your results, as well as summary tables/charts with the main results; discuss the results and relate them with the theoretical concepts - this is the most important content of your work (maximum 9 slides)
   - Conclusions (1 slide)

2. **Record a video of the PowerPoint presentation with narration**.
   All group members must participate in the video narration. The video's maximum duration is 15 minutes. For a tutorial on how to make a video in PowerPoint you can check the following link: https://www.youtube.com/watch?v=D8JV3w4TOVw

3. **Gather all files used to reach the results** presented and discussed in the video report (e.g., excel files, gams, cplex, python).

4. **Create a zip file** that includes all the files and the video. The zip file name must be "S#1_G#2", where #1 corresponds to the Shift number and #2 corresponds to the Group number.

5. **Submit the zip file** in Fenix by the 20th of October.