Hydrogen Valley Challenge

Part I: Strategic positioning and demand allocation

Recently, different perspectives on decarbonization have been developed in the various sectors. Different approaches are suggested to achieve the decarbonization goal; one of these strategies can be considered as transition to electricity as the primary power source using hydrogen-powered fuel. This green hydrogen fuel supports the transition towards a carbon neutral society. Many countries are taking various steps to achieve this transformation.

One of the first steps of transitioning to an hydrogen economy is to identify some end uses and some potential production/supply locations. An allocation plan needs to be built accordingly.

Let's assume a consortia in a region has identified six different potential hydrogen production places. The consortia intends to meet hydrogen demand for seven energy demand points. These demand points have various use cases such as bus, waste truck, taxi, industry feedstock, industry heat use, home heat use..etc.

You know the following information, assumptions, limitations and considerations.

- Demand points have a daily requirement which must be met: there are seven demand points which have an average daily demand (in quintals) equal to 36, 42, 34, 50, 27, 30 and 43, respectively.

- Each potential hydrogen production place have a maximum (daily) throughput given below which cannot be exceeded: Six different potential places has a maximum daily throughput equal to, respectively, 80, 90, 110, 120, 100 and 120.

- For the next four years, the consortia has estimated the following fixed costs (capex) for production (in €): 321420, 350640, 379860, 401775, 350640 and 336030, respectively.

-The daily average marginal facility cost (in €) per quintal of hydrogen (including costs such as production of hydrogen from renewable energy, electricity, and storage cost..etc) for each potential hydrogen production point, is equal to 0.15, 0.18, 0.20, 0.18, 0.15 and 0.17, respectively.
- There is a distribution cost between each potential hydrogen production place and demand point. The distribution cost per quintal of hydrogen and per kilometre travelled is equal to € 0.06.

The kilometric distances for each potential hydrogen production places and energy-demand points are shown in Table 1. The daily distribution costs are computed by considering that every journey is made up of both an outward and a return journey.

Table 1. Kilometric distances between each potential hydrogen production places and demand points

	Energy-Demand Point						
Potential Hydrogen Production Places	***D1***	***D2***	***D3***	***D4***	***D5***	***D6***	***D7***
P1	18	23	19	21	24	17	9
P2	21	18	17	23	11	18	20
P3	27	18	17	20	23	9	18
P4	16	23	9	31	21	23	10
P5	31	20	18	19	10	17	18
P6	18	17	29	21	22	18	8

The consortia is planning to keep the potential hydrogen production places in operation for four years (corresponding to 365 × 3 + 366 = 1461 days).

The consortia wants to satisfy the demand of all demand points at a minimum cost. They need to decide where to build the hydrogen production locations and which production locations should serve which demand points together with the amount of flows between them.

a) Formulate a MIP optimization model and solve it using Xpress. Explain decision variableas, parameters and constraints.

b) We assume now that sixth potential hydrogen production place cannot be run economically if it produces less than a certain amount. Therefore, assume P6 has a minimum daily throughput equal to 90 quintals, whereas the maximum throughput remains unchanged at 120. Formulate it mathematically and solve it.

c) It is possible that the marginal and the fixed costs of the facilities depend on its activity level because of economies of scale. Assume that the daily average facility unit marginal cost of the sixth hydrogen production place decreases by € 0.03 per quintal of hydrogen and that the facility fixed costs are increased up to € 339536 when the level of activity is greater than 80 quintals. Formulate it and solve it. Tip: You can use artificial nodes.

d) It is possible that some hydrogen production places have no capacity constraints because they can also import hydrogen. Now assume that the hydrogen production places have no throughput constraints (i.e. the maximum average daily throughput for each production place is sufficient to satisfy the whole daily average demand for all the energy-demand place). . Formulate it and solve it..

e) The government has decided that production location at P1 should be activated. . Formulate it and solve it.

Note that the data given in this part is only representative and does not reflect real life.

Part II. Reducing the per unit cost of hydrogen in the Estonian hydrogen value chain

Now let's look at a real life case. Estonia wants to build a small scale hydrogen valley. The main challenge today is that green hydrogen price is far too expensive to produce and use without subsidies. Considering the long term zero emission goals, a consortia aims to make a business plan for a green hydrogen ecosystem along the entire value chain. The hydrogen ecosystem in focus covers different activities:

-Production: Hydrogen production in Tartu Park, Estonia via an electrolyzer. As a source of power, renewable energy and electricity from grid will be used. Solar energy is used as the renewable source to power the electrolyser that converts tap water into hydrogen that is then compressed and transferred to storage.

-Consumption: Two demand points are in plan: 1) A public hydrogen refuelling station (HRS) in Tartu city (Estonia) and 2) a mobile/modular HRS in Latvia. These demand points will demonstrate several use cases including a hydrogen fuel cell electric bus (FCEB) in Tartu city, and a hydrogen fuel cell electric waste truck in Latvia .

-Distribution: The compressed hydrogen is delivered by 1 bio-CNG delivery truck to the HRS (hydrogen refuelling stations) in Tartu and Valmiera.

The consortia has approached you because you are the supply chain and logistics expert. With their current calculations the unit price of hydrogen is too high and they would like to know what possibilities exist to lower down the unit price of hydrogen and by how much. This is very important for the project to go forward since companies need a business case that is to some extent economically manageable. This is your challenge.

Green hydrogen supply chain components – ***production, distribution, and consumption*** – will be integrated and will into feed into each other. See Figure 1 for the process flow.

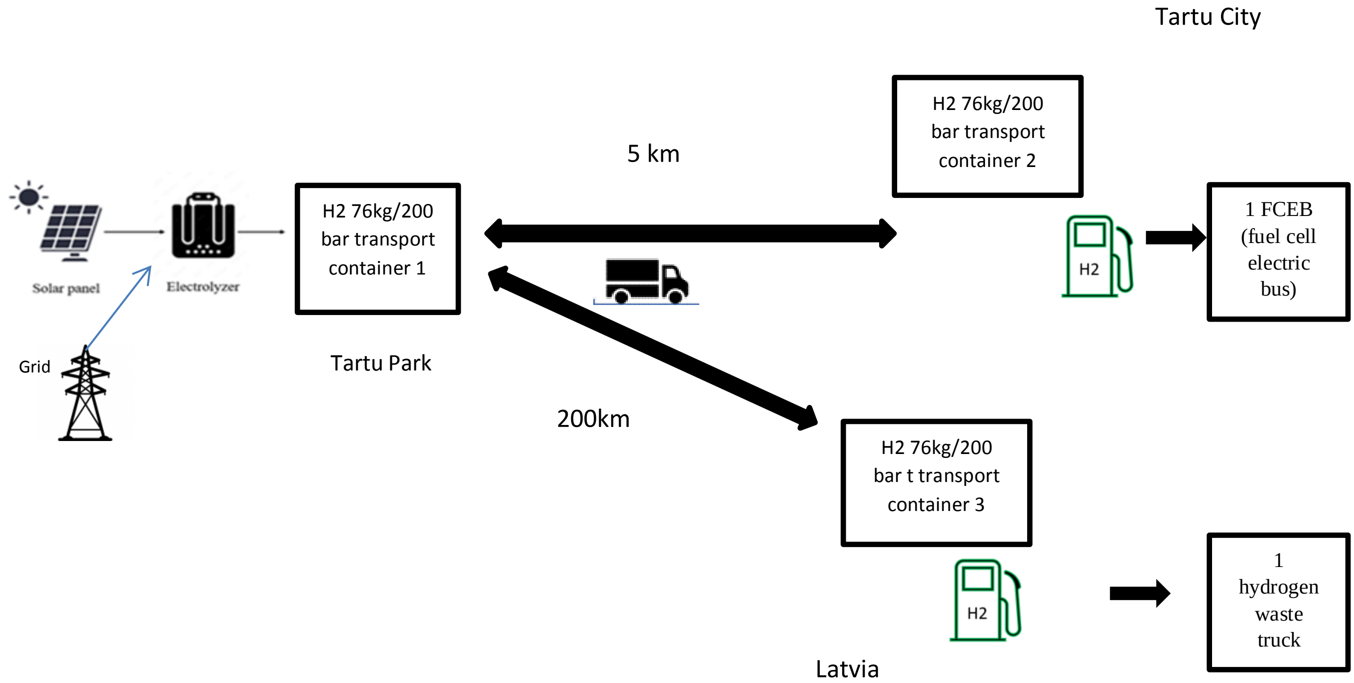

Figure 1: Hydrogen ecosystem representation

You are further given the following information, assumptions, limitations and considerations.

• There exists 850kW of solar energy capacity already in place in Tartu to produce green hydrogen for the pilot activities. However, solar energy is not always sufficient to continuously produce the hydrogen needed for the pilot demonstrations. Therefore green certified electricity from the grid (electricity produced from renewable sources) will be used to supplement the energy requirements needed for the electrolysis process.

• The plan is to develop a small-scale hydrogen production plant with an electrolyser efficiency of 55% and an estimated electrolyser capacity of 100 kg H2 per day with a pressure of 30 bar.

• The distribution is aimed to be done with the use of 3 hydrogen storage containers with 76kg/ 200 bar. One bio-CNG delivery truck will be used to deliver the full containers and take back the empty ones back to the production location to be filled up for the next use.

According to the capacity of the production plant, the maximum possible production volume of green hydrogen is 36.5 tons per year (100kg per day x365 days). In the test phase of the project, the largest consumer will be a bus in Tartu city, with an estimated 85,000 km per year, and provided that the consumption of green hydrogen on hydrogen buses is 10 kg per 100 km, it can be concluded that 8.5 tons of green hydrogen is consumed per year on Tartu city hydrogen buses. Similarly, a heavy-duty FCEV (i.e. waste truck), based on current routes provided by ZAAO, would consume 7549kg (7.549 tons) of H2/year.

Considering the given information above and the knowledge on logistics and the production of green hydrogen provide the following.

a) Estimate the unit price of (€/kg) H2. Provide 3 scenarios being low-medium-high cost. Show your model/program that helps users to calculate the cost depending on different input and scenarios. Your model should be a quantitative model. You may use an optimization model or a simple total cost calculation. Discuss why this model is relevant here.
b) Discuss and show what opportunities exist to lower down the cost considering the overall supply chain of hydrogen ecosystem. Provide three different suggestions. These options should be viable and correctly argued. Discuss the main factors affecting the price of hydrogen.

Some tips and points you should keep in mind.

- Solar energy is not continuous. The price of solar energy and grid energy is different. The production plan needs to match the demand of course.
- You have to determine the distribution schedule/plan for the truck for the two end uses to be able to estimate the distribution cost. This frequency is dependent on the consumption at end use. Consider that this also depends on the tank capacity.

- You may need to omit some minor details. You can then provide assumptions. If you do approximations, then these should not be majorly affecting the overall cost. Explain those clearly.
- Data collection and analysis is part of the challenge. Notice that not all data and information is given to you by the consortia. For example tank capacity of a bus, sunshine hours in Estonia, capex of an electrolyzer..etc. You are expected to find these. Note that this is a real life challenge! Use academic/ practical references and show them in your text. Discussions of your data and results are an important part of your grade. Show your sources for your argumentations and discussions.

Assignment delivery

For this assignment you need to show your qualitative skills as well your quantitative skills.
For part II you will be graded with the thoroughness of your calculations, reliability, correctness, creativity, discussions and argumentations.

- Your report for Part 1 should be max 1 page and should have your mathematical model, alterations for each sub-question and the numerical results (Objective function and values of decision variables).
- Your report for Part II should be about 4 pages and should have your model and the explanations.
- Hand in the program codes and data files separately. Note that the code should be neat, no hard coding, no spaghetti coding!

Grade distribution:

Part I: 50 points (a-30pts , b- 5 pts, c- 5 pts, d- 5 pts, e- 5 pts)
Part II: 50 points (a-25pts , b- 25 pts)

Success!