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HYPATH: Hydrogen Pathways Domestic Policies and International Strategies for Switzerland's Energy Future

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Summary

The HYPATH project investigates the role of renewable hydrogen in Switzerland's path to net zero by 2050. It investigates both domestic hydrogen production in Switzerland and the participation of Swiss companies in international hydrogen markets. In its first year, the project focused on Work Package 1, combining techno-economic modeling with a case study to assess the costs of domestic hydrogen production compared to hydrogen import costs. Preliminary results show that Switzerland's hydrogen demand is dominated by hydrogen use as a feedstock at the Cressier refinery, and that future demand is uncertain. Modeling shows that plant-level challenges to the cost competitiveness of domestic production, such as the cost of storage, are significant. The publication of the Swiss Hydrogen Strategy in December 2024, focused on hydrogen uses as an energy vector, confirmed the timeliness of the project. Exchanges with national stakeholders and research partners have reinforced the project's relevance. Two publications are in preparation, and the techno-economic model and related data will be made openly available. In the next year, Work Package 2 will assess the options for Swiss firms to participate in international hydrogen markets.

Zusammenfassung

Das HYPATH Projekt untersucht die Rolle von erneuerbarem Wasserstoff auf dem Weg zu Netto-Null bis 2050 in der Schweiz. Es analysiert die inländische Wasserstoffproduktion in der Schweiz und die Beteiligung schweizerischer Unternehmen an internationalen Wasserstoffmärkten. Im ersten Projektjahr lag der Schwerpunkt auf Arbeitspaket 1, das techno-ökonomische Modellierungen mit einer Case Study verbindet, um die Kosten der inländischen Wasserstoffproduktion im Vergleich zu den Importkosten zu bewerten. Erste Ergebnisse zeigen, dass der Wasserstoffbedarf der Schweiz hauptsächlich durch die stoffliche Nutzung von Wasserstoff in der Raffinerie Cressier entsteht ist und dass Unsicherheiten beim zukünftigen Bedarf bestehen. Die Modellierungen verdeutlichen, dass die Herausforderungen für die Wettbewerbsfähigkeit der inländischen Produktion auf Anlagenebene, wie beispielsweise die Speicherkosten, weiterhin erheblich sind. Die Schweizer Wasserstoffstrategie von Dezember 2024, die sich auf die energetische Nutzung von Wasserstoff fokussiert, bestätigte die Aktualität des Projekts. Der Austausch mit nationalen Akteuren und Forschungspartnern hat die Relevanz des Projekts zusätzlich gestärkt. Zwei Publikationen sind in Vorbereitung, und das techno-ökonomische Modell sowie die zugehörigen Daten werden öffentlich zugänglich gemacht. Im nächsten Jahr wird Arbeitspaket 2 die Optionen für Schweizer Unternehmen zur Teilnahme an internationalen Wasserstoffmärkten analysieren.

Résumé

Le projet HYPATH recherche le rôle de l'hydrogène renouvelable dans la trajectoire de la Suisse vers la neutralité carbone à l'horizon 2050. Il analyse des options de production domestique ainsi que la participation des entreprises suisses aux marchés internationaux de l'hydrogène. La première année a été dédiée au Paquet de travail 1, qui combine modélisation techno-économique et un Case Study afin d'évaluer les coûts de la production d'hydrogène en Suisse par rapport aux coûts d'importation. Les premiers résultats montrent que la demande actuelle d'hydrogène en Suisse est dominée par la consommation d'hydrogène comme matière première à la raffinerie de Cressier, et soulignent l'incertitude quant à l'évolution future. Les analyses indiquent que des défis subsistent au niveau des installations individuelles, notamment le coût du stockage. La Stratégie hydrogène de la Suisse de décembre 2024, axée sur les applications énergétiques de l'hydrogène, a confirmé l'actualité du projet. Les premiers échanges avec les acteurs nationaux et les partenaires scientifiques ont renforcé la pertinence du projet. Deux publications sont en préparation, et le modèle techno-économique développé ainsi que les données associées seront mis en accès libre. L'an prochain, le Paquet de travail 2 analysera les options de participation des entreprises suisses aux marchés internationaux de l'hydrogène.

Contents

List of abbreviations

SFOE	Swiss Federal Office of Energy
PV	Solar photovoltaics
WP	Work Package

1 Introduction

1.1 Context and motivation

Switzerland's commitment to achieving net-zero emissions by 2050 requires the decarbonization of all economic sectors, including those with applications where electrification might be difficult or costly. In some of those cases, hydrogen produced with renewable energy could be an important tool for reducing emissions and maintaining a secure energy system.[1,2]

Although electrification will deliver most of the needed emission reductions,[3] renewable hydrogen could help address important niches for a clean and secure energy system. As the share of renewable electricity generation in Switzerland increases, the future electricity grid is expected to experience a seasonal energy imbalance, with excess domestic generation in the summer months and insufficient production during the winter months.[3] Energy storage, including through modest amounts of hydrogen, could help address the gap.[4–6] Another important niche for hydrogen could be in sectors such as aviation and industry, which will likely require synthetic fuels to achieve a complete decarbonization.[7,8] Although uncertainty is high, with estimates suggesting that Switzerland could need from 8 to 65 times the current hydrogen demand, some amount of clean hydrogen will be required to achieve net zero by 2050.[9–12]

Today, however, hydrogen production remains part of the climate problem rather than being a solution. Globally, hydrogen production relies almost entirely on fossil fuels, resulting in emissions roughly equivalent to those of Indonesia and the United Kingdom combined.[13] Similarly, current hydrogen needs in Switzerland are concentrated in the use of hydrogen as a feedstock in one refinery plant and are almost entirely met by hydrogen produced from fossil fuels.[10] Besides the environmental impact it generates, a continued reliance on fossil fuels for hydrogen production perpetuates the dependence on energy imports of non-fossil fuel producing countries.

Several energy system models have assessed the potential role of hydrogen in Switzerland.[5,6,9,11,14–20] Studies highlight that heavy-duty transport could be a near-term application for hydrogen in Switzerland due to favorable tax policies and public procurement programs,[9,11,14,19–21] although favorable tax policies will be phased out between 2029 and 2035. Hydrogen can also decarbonize industrial processes[3] and seasonal electricity storage through power-to-gas applications.[9,11,21] One study finds that hydrogen imports could help bridge Switzerland's winter energy gap by supplying up to 20% of Switzerland's winter electricity needs,[11] though a more recent analysis finds that this would be uneconomical.[6] Lastly, the European Hydrogen Backbone, proposed by European energy infrastructure operators, envisions a transnational pipeline network that could be an option for importing hydrogen into Switzerland.[12]

In many parts of Europe and in Switzerland, the limited availability of low-cost renewable electricity makes large-scale domestic production of hydrogen economically challenging.[9,22] As a result, long-term strategies for hydrogen consider imports from regions with abundant solar or wind potential, such as North Africa or the Middle East.[12,23,24] These visions are based on the fact that renewable hydrogen could be traded globally,[25] allowing trade partners to access cheaper low-carbon hydrogen than they could produce domestically.[26] Initiatives like the European Hydrogen Backbone propose the development of a hydrogen pipeline network throughout Europe to facilitate such trade.[27]

Global hydrogen production, however, is highly localized, with more than 85% produced and consumed on site.[25] Hence, international hydrogen trade will require establishing entirely new value chains.[28] This possibility has already triggered a race for green industrial leadership,[29] shaped by national policy choices on energy security, autonomy, and cost-efficiency.[22] Countries with abundant renewable resources face a strategic decision: whether to focus on hydrogen exports or on expanding into the industries that could use hydrogen to decarbonize such as iron and steel production. Meanwhile, countries with fewer renewable energy resources have to weigh the trade-offs between large-scale hydrogen imports and domestic production.[25,30] Countries capable of establishing domestic hydrogen value chains are likely to obtain the most substantial geopolitical and economic benefits.[29]

Therefore, Switzerland should examine what policies and regulations could pave the way for competitive, secure, and sustainable hydrogen supplies. Given the country's renewable energy resources, policies will have to combine inward and outward-looking considerations to address domestic hydrogen value chains[31]—for example, with rules for producing hydrogen[32–34] or requirements to switch to clean hydrogen consumption[35]—and the participation of Swiss companies in international markets where hydrogen may be available at lower costs.[22] Even if today's hydrogen needs are modest and future ones remain uncertain, delayed action could put Switzerland's emission targets at risk and compromise future energy security, as the required infrastructure, knowledge, and expertise can take decades to build.

Despite the growing literature, little is known about which hydrogen policies and regulations are needed in Switzerland. This project addresses this gap in two ways. First, it considers domestic value chain options for Switzerland, investigating their costs and exploring the needs of Swiss supply and demand actors through modeling and interviews. Second, it evaluates the economic and security implications of different policy strategies for international hydrogen and synthetic fuel imports. In both cases, particular attention is paid to understanding and finding ways to manage uncertainty.

In December 2024, shortly after this project began, the Federal Council published a hydrogen strategy for Switzerland.[12] The strategy states that hydrogen could be an important tool to achieve a carbon-neutral energy system in Switzerland. It also highlights that future demand of hydrogen for energetic uses is highly uncertain and is expected to grow larger only after 2030. Aligned with this project's motivation, the strategy lays out a vision to develop enough hydrogen production within Switzerland to meet hydrogen consumption for energy uses at least until the mid-2030s. It also emphasizes the need for Switzerland to connect with European hydrogen infrastructure to ensure future access to international hydrogen markets, which are expected to develop after 2035. In contrast to the initial motivation of this project, Switzerland's hydrogen strategy places less attention on the impact on jobs and more on the development of the necessary technologies that could position Switzerland as a center for research and innovation.

The Swiss hydrogen strategy does not set any explicit targets for the development of hydrogen in Switzerland, nor does it include major measures to support its deployment (beyond examining individual cases that could merit public support). Therefore, major open questions remain about what policies and regulations could align the development of hydrogen in Switzerland with the broad goals set in the national strategy.

1.2 Project objectives

This project aims to investigate how policies and regulations could support the development of competitive, secure, and sustainable hydrogen supplies under the hypothesis that some renewable hydrogen will be needed for Switzerland to achieve net-zero emissions by 2050. First, the project focuses on assessing domestic hydrogen production through a techno-economic analysis and an illustrative case study, comparing them with the estimated cost of imports. Next, the project focuses on international hydrogen markets, where the main objective is to evaluate the economic and security implications of importing hydrogen and synthetic fuels compared to domestic production. Finally, future impacts on skills and jobs are assessed.

To meet these objectives, three research questions are addressed: (1) What are the costs of domestic hydrogen production plants in Switzerland compared to imports? (2) What economic and security implications do different paths into international hydrogen markets have? (3) Which skills and jobs are needed to develop hydrogen value chains in Switzerland?

2 Approach, method, results and discussion

2.1 Approach and research method

In a rapidly changing and uncertain energy transition, investigating the policies and regulations required to support new technologies needs a comprehensive approach that can benefit from diverse types of data and knowledge. For this reason, this project combines qualitative and quantitative tools, paying special attention to uncertainty.

This project has three Work Packages (WP). Each addresses one of the project's research questions through different research methods. This section briefly describes the research approach and highlights the novelty of WP1 and WP2, as the most relevant packages at this stage of the project.

WP1 focuses on assessing the cost of domestic hydrogen production through a techno-economic analysis and an illustrative case study, and then, comparing domestic production with imports. WP1's approach includes two methods: (1) techno-economic modeling, and (2) case study. First, techno-economic modeling of domestic hydrogen production quantifies its costs and the framework conditions required for its economic viability under different scenarios. The modeling provides a preliminary assessment of the economic viability of domestic hydrogen production in Switzerland. The results are then compared to estimates of the costs of imported hydrogen into Switzerland. To complement this analysis, a case study will illustrate specific challenges and opportunities of an existing project in Switzerland.

Uncertainty about future hydrogen needs and regulatory changes is investigated throughout the two steps in WP1. The case study includes questions about uncertainty sources and impacts, while the techno-economic model analyzes parametric uncertainty (e.g., future technology costs). One additional source of uncertainty, the availability of different electricity sources, is also considered through a scenario analysis.

WP1's approach has two key novelties. First, it combines qualitative and quantitative data in innovative ways. Several studies have conducted hydrogen policy reviews,[36–38] stakeholder interviews[39–41], and techno-economic modeling.[42,43] However, we found no study combining techno-economic modeling and case studies to investigate domestic hydrogen production. Combining these methods will allow us to assess the required framework conditions for the economic viability of domestic hydrogen production in Switzerland and illustrate their relevance for a specific project. Second, WP1 focuses on Switzerland. Most studies of hydrogen policies focus on countries like Germany, whose energy system and industrial base are likely to result in significantly different hydrogen needs compared to those of Switzerland.[31,44] Instead, WP1 focuses on Switzerland and specifically investigates hydrogen policies.

WP2 shifts attention to the international dimension of hydrogen supply chains, focusing on the strategic options for Swiss companies to participate in international hydrogen markets. WP2's core methodological tool will be an optimization model of international renewable hydrogen trade. A novel optimization model will be developed and published with open access. The model will be tailored to explore the strategic implications of various scenarios for the participation of Swiss firms in international hydrogen trade. Besides the optimization results, WP2 will include a comprehensive uncertainty analysis of parameter values (e.g., technology costs) and hydrogen demand levels.

By studying the potential pathways for importing renewable hydrogen from countries with more abundant renewable resources, WP2 aims to identify the most advantageous pathways for Swiss firms in international hydrogen markets, while considering both economic and security implications.

Work on WP3 is planned to begin at the end of 2026. A detailed description of the approach and methods for the work package will be included in next year's interim report.

2.2 Preliminary results

During the first year of the project, work was primarily concentrated on WP1. Initial efforts focused on consolidating a comprehensive understanding of the existing body of literature on renewable hydrogen and its potential role within Switzerland's future energy system. This review encompassed both international and national studies addressing production pathways, cost trajectories, infrastructure requirements, and possible applications, with particular emphasis on the industrial and mobility sectors.

In parallel, we began developing a methodological framework for assessing hydrogen integration from a bottom-up perspective, consistent with the project's aim of bridging techno-economic modelling with real-world applicability. This foundation will ensure that subsequent modelling activities are both scientifically rigorous and directly relevant to the Swiss context. By establishing this foundation, the project is positioned to deliver analyses that are firmly anchored in the state of the art while also responsive to the specific needs of the Swiss energy transition.

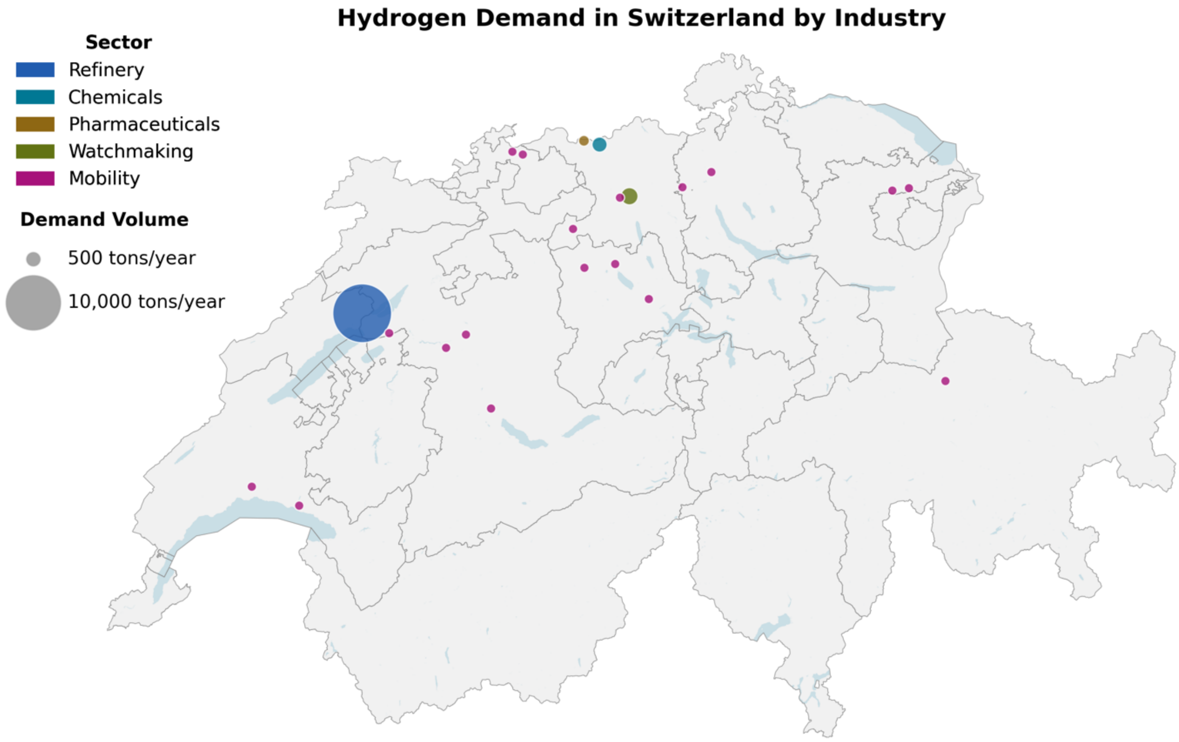

Figure 1: Current hydrogen demand in Switzerland by industry. Data: E4tech, 2018.[10] European Hydrogen Observatory, 2022.[46] Hydrogen Mobility Switzerland, 2025.[47]

A key outcome of this first phase has been an improved understanding of current and projected hydrogen demand in Switzerland (see Figure 1). Based on the most recent available data (from 2018), Switzerland's hydrogen demand is relatively low, estimated at around 13 kilotons (kt) per year (compared to 116 kt in neighbouring Austria, where hydrogen is used mainly as feedstock to produce ammonia 61% and in refining 31%[48]). Demand is concentrated in a limited number of sectors and mostly for feedstock uses, as illustrated in Figure 1. Since the termination of fertilizer production in Visp in 2018, the Cressier refinery has become Switzerland's largest hydrogen consumer, with approximately 11 kt (nearly 85% of Switzerland's total hydrogen demand). The remaining demand is distributed among smaller applications, including high-quality glass for the watchmaking industry (0.7 kt), the chemical and pharmaceutical sectors (0.6 kt), as well as limited use in metal processing and other industries (<0.1 kt).[10] Mobility applications, mainly through hydrogen refilling stations, were estimated to consume 400 tons of hydrogen per year in 2018.[10] Hydrogen use in synthetic stone production ceased in 2021.[20]

Future hydrogen demand in Switzerland remains highly uncertain.[49,50] Some projections suggest that hydrogen demand could double or even triple by 2030, with a significant increase anticipated until 2050. The Swiss hydrogen strategy foresees a reduction in the use of hydrogen as a feedstock (from around 13 kt to 1.5 kt in 2050) and growth in energetic uses for high-temperature industrial processes, mobility, and peak shaving (from between 11 and 42 kt in 2030 to between 107 and 302 kt in 2050).[12] Estimates range widely, with estimates of the annual demand in 2050 ranging between 100 and 850 kt.[9,11,12,18]

In terms of hydrogen production, several renewable hydrogen projects have emerged since 2020, producing hydrogen through water electrolysis, primarily for mobility applications. These projects represent a combined capacity of roughly 3.5 kt per year, though more than 30% of this capacity is under construction.[46] Despite these projects, the majority of hydrogen production in Switzerland is concentrated in the refinery at Cressier and based on fossil fuels.[10]

The Swiss hydrogen strategy envisions that domestic production of hydrogen will meet the demand of hydrogen for energy uses until 2035. Further, it envisions that hydrogen will be produced next to power plants and directly at large consumers to minimize the need for transportation.[12] However, it is unclear what the costs of domestic hydrogen production are under different plant configurations and how they compare with the cost of importing hydrogen from abroad.Therefore, during the initial part of this project, we have focused on evaluating the challenge of increasing the production of renewable hydrogen within Switzerland and comparing it with estimates of hydrogen import costs.

Renewable hydrogen production is widely seen as a promising solution, particularly for replacing fossil-based hydrogen in industry.[51] Yet, its roll-out has been slower than expected.[13,52] Key barriers include high costs, limited infrastructure, and uncertain demand, all of which are reinforced by the infrastructure "chicken-and-egg" problem: high costs inhibit demand, low demand discourages scale-up and infrastructure investment, which in turn limits the realization of cost reductions.[52,53]

At the system level, renewable hydrogen production is often portrayed as beneficial beyond emission reductions, as it enhances energy system flexibility while being part of the least-cost solution for the energy system. For instance, recent analyses suggest that renewable hydrogen could become cost-competitive with fossil alternatives in the short term, which would also help balance the electricity grid.[54] However, such conclusions are drawn at the national level.

At the plant level, the challenges of deploying renewable hydrogen production appear more pronounced, as investment decisions depend on local factors such as demand volumes and profiles, site-specific electricity costs, and policy conditions.[55] This contrast raises an essential question for Switzerland: Do the system-level advantages of renewable hydrogen also hold when examined at the plant level? WP1 aims to address this question by considering the plant-level perspective using a mixed-integer linear programming optimization model developed in Python.

The model determines the optimal combination of renewable energy technologies (photovoltaics and wind), electrolyzer capacity, and storage systems (batteries and hydrogen storage) to meet current hydrogen demand while minimizing total costs at the plant level. The optimization considers multiple electricity sources, including on-site renewables and grid electricity. The model incorporates realistic operational constraints such as minimum load requirements for the electrolyzer, hourly data for electricity generation and prices, and storage dynamics, while accounting for economies of scale in electrolyzer sizing through piecewise linear cost approximations. The solution provides an economically optimal plant configuration that balances capital investments in renewable generation and storage infrastructure against operational costs, for example, from grid electricity purchases.

The model's objective is to minimize the total annualized cost, which includes: (1) capital and operational costs for the electrolyzer, renewable generation, and storage technologies, and (2) variable operational costs, including water consumption, grid electricity purchases, and fossil hydrogen procurement. This formulation captures both investment decisions (capacity sizing) and operational decisions (hourly dispatch) in a single cost-minimization framework (see Equation 1).

Equation 1: Objective function

$$(1) \qquad \min Total\ cost = \underbrace{C_{el,capex} + C_{el,opex}}_{\text{Electrolyzer costs}} + \underbrace{C_{ren}}_{\substack{\text{Renewables}\\\text{generation}\\\text{cost}}} + \underbrace{C_{stor}}_{\substack{\text{Storage}\\\text{costs}}} + \underbrace{C_{water} + C_{grid} + C_{fossilh2}}_{\text{Variable operational costs}}$$

Where:

- $C_{el,capex}$ Annualized capital cost of electrolyzers (CHF)
- $C_{el,opex}$ Fixed operation and maintenance cost of electrolyzers (CHF)
- C_{ren} Annualized capital and operational costs of on-site renewable generation (CHF)
- C_{stor} Annualized capital and operational costs of on-site battery and hydrogen storage systems (CHF)
- C_{water} Cost of water consumption for electrolysis (CHF)
- C_{grid} Cost of electricity purchased from the grid (CHF)
- $C_{fossilh2}$ Cost of procuring fossil fuel-based hydrogen (CHF)

Current industrial hydrogen offtakers in Switzerland consume around 13 kt per year, with the Cressier refinery accounting for the largest share. Refineries require a continuous hydrogen supply to sustain their processes, which is why we initially model demand as constant across all hours of the year.[56] This assumption reflects the operational reality of refinery processes while also creating a contrast with the variable nature of renewable electricity supply. In practice, it highlights the importance of storage or complementary electricity sources to ensure that constant demand can be reliably met by renewable hydrogen. In the following months, we will try to represent the hydrogen use of other types of offtakers by considering other hourly demand profiles in the model whenever sufficient data is available.

The model ensures that the hydrogen supply meets demand every hour of the year. The left side of Equation 2 represents total hydrogen production from three sources: electrolytic hydrogen can be produced directly from renewable, grid, or battery discharge power. The hourly demand can further be met by hydrogen released from storage or purchased fossil hydrogen. This hourly balance guarantees demand satisfaction while allowing flexible sourcing strategies.

Equation 2: Demand constraint

$$(2) \quad \underbrace{\frac{\eta}{LHV}(x_t^{ren} + b_t^{out}) + s_t^{out}}_{\text{Renewable hydrogen}} + \underbrace{\frac{\eta}{LHV} * x_t^{grid}}_{\text{Hydrogen from grid electricity}} + \underbrace{y_t}_{\text{Fossil hydrogen}} \geq \underbrace{d_t}_{\text{Hydrogen demand}} \quad \forall t \in T$$

Where:

- η Electrolyzer efficiency (-)
- LHV Lower heating value of hydrogen (33.33 MWh/ton)
- x_t^{ren} On-site renewable power consumed in hour t (MWh)
- b_t^{out} Battery discharge power consumed in hour t (MWh)
- s_t^{out} Hydrogen discharge from storage in hour t (tons)
- x_t^{grid} Grid power consumed in hour t (MWh)
- y_t Fossil hydrogen consumed in hour t (tons)
- d_t Hydrogen demand in hour t (tons)

The model further ensures that the total electricity input to the electrolyzer in any given hour does not exceed its installed capacity Cap_{el} in Equation 3 and that the minimum load requirement is met every hour (see Equation 4). The left side represents the total electricity input from all sources, including renewables, grid electricity and battery discharge in both constraints. This physical limitation links the capacity investment decision with hourly operational decisions, preventing overloading of the electrolyzer system and detrimental start-and-stop operation.

Equation 3: Electrolyzer capacity constraint

$$(3) \quad x_t^{ren} + x_t^{grid} + b_t^{out} \leq Cap_{el} \quad \forall t \in T$$

Equation 4: Minimum load constraint

$$(4) \quad x_t^{ren} + x_t^{grid} + b_t^{out} \geq load_{min} * Cap_{el} \quad \forall t \in T$$

As part of WP1, the model explores the preliminary operation of electrolyzers collocated with hydrogen demand. Figure 2 shows an illustrative preliminary result for how an electrolyzer plant powered by on-site renewables and grid electricity would operate when collocated with Cressier's refinery. The model considers minimum and maximum loads, as can be seen by the flat lines around 10% and 100% load capacities, which substantially impact the economics of the plant. These operating ranges are linked to the flexibility of the electrolyzer and serve to limit degradation and ensure safety. The results shown in this report are preliminary and for illustrative purposes only.

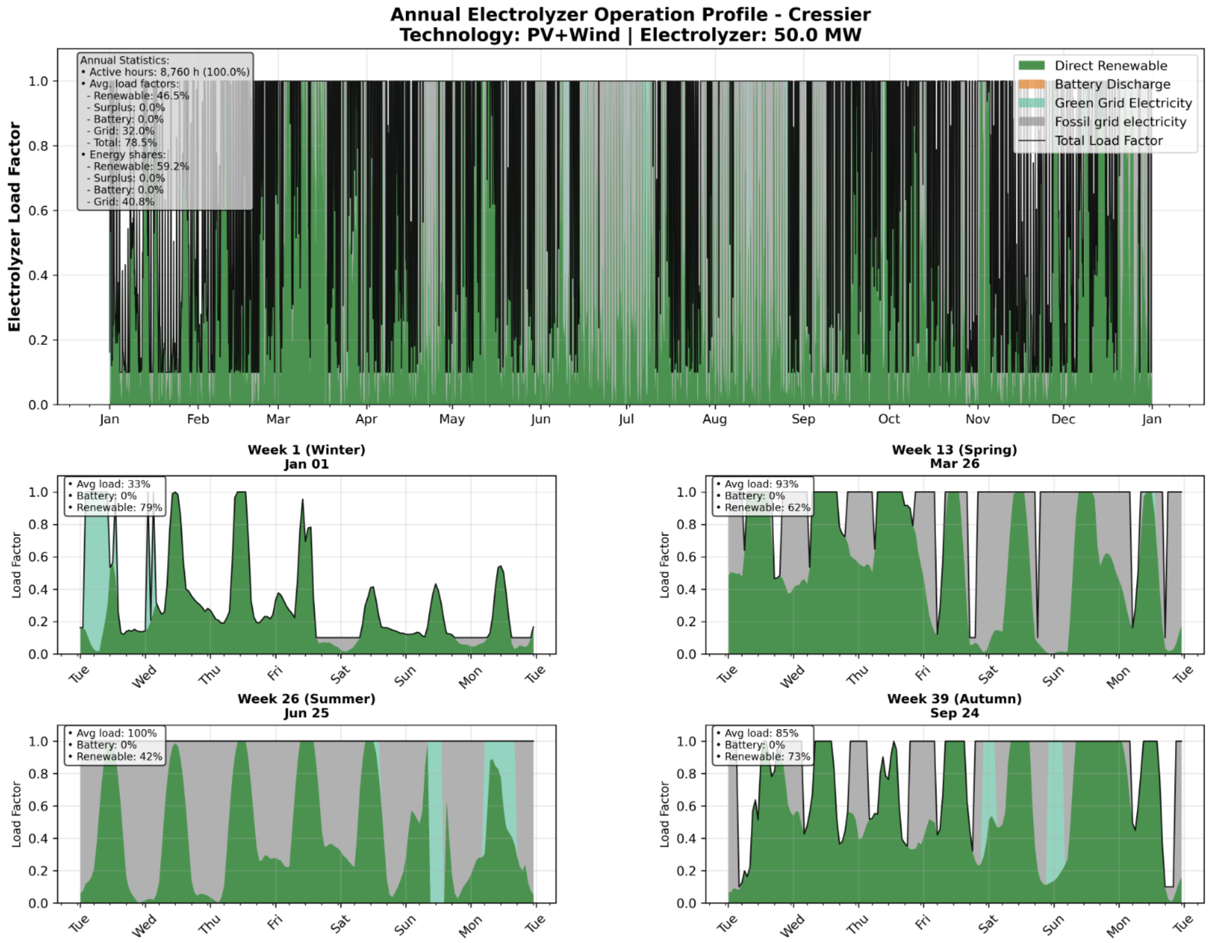

Figure 2: Illustrative example of the annual operation of a renewable hydrogen production plant at the Cressier refinery to replace 40% of fossil hydrogen.
Top subplot: hourly operation profile of the electrolyzer during the year. Bottom subplots: hourly operation profile of the electrolyzer during representative weeks in winter (top, left), spring (top, right), summer (bottom, left), and autumn (bottom, right). Green indicates operation powered by on-site renewables. Grey and teal indicate operation powered by fossil and renewable grid electricity.

As we continue working on WP1, several scenarios are being considered to test how different configurations of renewable supply, grid interaction, and storage could influence costs and operational patterns. In addition, different demand scenarios will be considered, and domestic production costs will be compared against estimates for the cost of imported hydrogen.

In parallel to the modelling work, we are preparing qualitative research activities. An interview guide is being developed to structure discussions with stakeholders, with the aim of capturing practical perspectives on hydrogen deployment. At the same time, we are mapping existing power-to-X projects in Switzerland, which will serve as a basis for identifying relevant case studies.

2.3 Discussion

Our preliminary modelling results highlight that the choice of electricity supply mix has important implications for the cost of hydrogen production in Switzerland. In particular, scenarios relying exclusively on solar photovoltaics (PV) require substantially more storage capacity to ensure a stable hydrogen supply, due to intraday variations. This storage requirement increases overall plant costs, making a PV-only strategy less attractive compared to a more diversified mix of renewables.

The preliminary results also underline a key finding from the literature: optimizing renewable hydrogen production at the country level underestimates the actual cost of hydrogen at the plant level, to a large degree due to scaling effects.[54,57] This raises the question of how policy and market mechanisms can be designed so that plant owners also benefit from the broader system-level advantages of renewable hydrogen, such as energy system flexibility.

Overall, our preliminary results suggest that renewable hydrogen produced in Switzerland is more costly than fossil-based hydrogen in the near term. Production costs depend strongly on access to renewable electricity from wind and solar, as well as on the scale of the installation. This highlights the challenges of realising the vision presented in the Swiss Hydrogen Strategy of domestic production meeting the demand of hydrogen for energy uses until at least the 2030s.[12] Based on these preliminary results, the near-term roll-out of renewable hydrogen in Switzerland may depend more on dedicated policy support rather than on market forces because of its higher cost compared to fossil-fuel based hydrogen.[13]

The insights from WP1 provide useful input for WP3 by clarifying the likely pace and scale of hydrogen deployment in Switzerland. The Swiss Hydrogen Strategy[12] and current technology trends indicate that significant growth in domestic hydrogen demand is unlikely before 2035. This delayed uptake has implications for workforce and skills development: while the immediate need for large-scale training may be less pressing, there is an opportunity to build capabilities in a more targeted way and to align education and training pathways with evolving industrial and research priorities.

3 Preliminary conclusions and outlook

Several preliminary conclusions can be drawn from the HYPATH project's first year. First, the publication of the hydrogen strategy for Switzerland in December 2024 has provided the project with important new information. On the one hand, the strategy acknowledges hydrogen as a potentially important tool for achieving a net-zero emissions energy system in Switzerland, and it emphasizes the relevance of connecting to future European infrastructure. This confirms the timeliness of the project. On the other hand, the expectation that hydrogen demand could be significantly smaller than anticipated and the small role of imports until after 2035 provide a different outlook on the technology than the prevailing one during the project's preparation.

One important implication of the Swiss hydrogen strategy is that imports are not expected to play a role until the 2030s. The strategy lays out a vision in which hydrogen would be produced within Switzerland at the plants consuming it, or nearby, limiting the need for infrastructure to transport hydrogen and meeting the hydrogen demand for energy uses.

Based on this vision from the Swiss government, the focus of WP1 has paid increased attention to the domestic production of hydrogen in Switzerland, with plants co-located with consumption. The framework conditions necessary for the development of these installations are now even more central to our work in WP1 than previously anticipated.

A second preliminary conclusion relates to the international outlook for hydrogen, which has become less favorable over the past year. Technology costs have fallen more slowly than expected, while several major projects — including some supported with public funds — have been delayed or cancelled. Even so, hydrogen continues to grow, albeit at a slower pace than anticipated.[13] Most importantly, the premises of this project remain unchanged: although part of the current hydrogen demand (e.g., in refineries) may shrink as countries make progress towards net-zero emissions, other parts of the existing hydrogen demand must still be decarbonized. This requires new hydrogen production and, with it, the consideration of new value chains within Switzerland and in connection to international markets.

A third conclusion is that there can be significant differences between results at the system level and those at the plant level, which can strongly influence the implications of different studies. National-level analyses often highlight hydrogen's broader system benefits, such as flexibility and cost efficiency when integrated into the energy mix. However, when examined at the level of an individual plant, challenges such as minimum load requirements, storage needs, and site-specific electricity costs become much more important. These differences suggest that while hydrogen may appear attractive in aggregate studies, the economics for individual producers can look very different. This highlights the importance of combining system-level and plant-level perspectives, as done in WP1, to ensure that conclusions are realistic and useful for both policymakers and industry.

A fourth conclusion is that Switzerland already hosts a wide variety of hydrogen-related projects at different stages of development. During our preliminary search for interview partners for the case study in WP1, we identified several dozen announced power-to-X initiatives across the country. These projects vary widely in size, technology focus, and intended applications, ranging from mobility to industrial uses.[58] Although not all of them will necessarily reach completion, the breadth of activity reflects interest in hydrogen innovation and deployment. This diversity provides valuable opportunities for learning, benchmarking, and collaboration, underscoring the importance of maintaining flexible policy and research approaches that can adapt to different technological pathways and local conditions.[59]

Outlook

The techno-economic model for the analysis in WP1 is nearly complete. At the time of writing, different analyses are being conducted using the model. In parallel, the selection of partners for the case study and the development of the interview guide are being implemented. By the end of 2025, the analysis will be complete, and efforts will turn to the submission of a scientific article (S1) and a practitioner's article (P1) based on the results.

By the end of Q4 2025, we plan to begin work on WP2 by developing an optimization model for international hydrogen imports to Switzerland.

Additionally, the second advisory group meeting (A2) is scheduled for Q4 2025.

4 National and international cooperation

During the first year of the project, particular attention was given to establishing a dialogue with relevant national stakeholders in the hydrogen sector. These interactions have provided valuable insights into current developments in Switzerland and have helped position the project within the broader national context. Key activities included:

- **Advisory group meeting (A1):** The inaugural meeting of the advisory group convened multiple stakeholders representing diverse parts of the Swiss hydrogen value chain. This exchange facilitated constructive feedback on the project's objectives and fostered alignment with other ongoing projects and initiatives.
- **Engagement with the Coalition for Green Energy and Storage (CGES):** Discussions were held with members of the CGES, an association led by ETH Zurich and EPFL. These exchanges provided an opportunity to explore how well the project aligns with the broader research and innovation efforts in energy systems and storage technologies.
- **Coordination with ETH Zurich colleagues:** Targeted discussions were conducted with ETH Zurich researchers actively engaged in hydrogen-related projects. These interactions contributed to the exchange of scientific perspectives and the identification of complementary research activities within the national research community.

While the focus during the first reporting period was on strengthening national connections, no formal international collaborations were initiated. Nevertheless, the groundwork laid during this phase provides a strong basis for exploring options for international cooperation in subsequent years, particularly as the project progresses and interfaces with European and global research initiatives in hydrogen and energy systems.

5 Publications and other communications

As the project approaches the completion of WP1, no publications have yet been produced. However, both a scientific article and a practitioner-oriented article are currently in preparation and are expected to be finalized in the coming months. The data collected for WP1 consists primarily of secondary, publicly available sources. Following the publication of the first scientific paper, the techno-economic model developed in the project, along with the data required to run it, will be made publicly accessible to support transparency and facilitate further research.

In addition to forthcoming publications, several communication activities have already been undertaken:

- **International academic exchanges:** Two presentations and discussions were held with research groups working on hydrogen policies in Germany, namely the Geopolitics of Energy and Industrial Transformation Group at RIFS Potsdam and the Digital Transformation in Energy Systems Group at TU Berlin. These exchanges enabled constructive dialogue on methodological approaches and policy perspectives.
- **Internal academic presentations:** Two internal seminars were conducted at ETH Zurich to present interim findings and to collect peer feedback on different aspects of the project. These sessions provided valuable input that has informed ongoing research activities.

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