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PROJECT DETAILS

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SHORT DESCRIPTION

Sector-coupling is a promising approach to replace fossil fuels with renewables. However, this idea of “electrifying” the entire economy requires the rollout of new technologies and rules. The HyEfRe project helps with this by establishing green hydrogen ecosystems in eight regions. Partners will foster an investment-friendly environment for renewable energy and green hydrogen technologies. They evaluate hydrogen potentials with a new model and develop and test a new tool to calculate ideal parameters for technical plants. Their action plan for policy actors will reduce regulatory barriers impeding a timely expansion of renewables and green hydrogen.

DOCUMENT DETAILS

Title of the document	Report on Pilot Actions for Tool Testing
Activity	A1.5 – Pilot action for testing of the decision support tool
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A. Executive Summary

This report documents the pilot testing of the HyEfRe Decision Support Tool (DST) across three Central European regions: Landkreis Passau (Germany), Landshut (Germany), and Pécs (Hungary). Testing was conducted between HyEfRe Project Period 3 and 4 (June 2025 – May 2026), covering a total of 77 simulation scenarios across 9 pilot micro-locations. The DST was evaluated for its ability to optimise green hydrogen and renewable energy systems under different time horizons (2025, 2030, 2050), subsidy levels (0% and 50%), and local energy market conditions.

Key findings by region

- Landkreis Passau (Germany): 18 full-year scenarios across three sites (Pocking, Vilshofen, Bad Griesbach). Green hydrogen production is viable at suggested sell prices of €14–15/kg. **Best economics: Vilshofen 2050 at 50% subsidy (payback 7.3 yr, IRR 12.4%, LCOH €6.99/kg)**. All hydrogen is 100% green. The AFIR TEN-T mandate at Pocking provides regulatory investment certainty by 2030.
- Landshut (Germany): 54 scenarios across three sites (Logistics Trucks, Reproduction Technologies, Gas Grid / Isarkanal Hydropower). Best results at Reproduction Technologies — H_2 demand met in most scenarios, best payback 3.9 years (50% subsidy, €8/kg). Gas Grid (5 MW hydro) yields outstanding economics at €5/kg (payback 1.73 yr, 50% subsidy) but the DST optimizer caps the electrolyser at ~1.13 MW regardless of available hydro capacity. Logistics Trucks: H_2 demand of 6,000 kg/week only 52–69% met due to the same electrolyser sizing ceiling.
- Pécs (Hungary): 6 scenarios at the Tettye Forrásház wastewater treatment plant. H_2 technologies remained inactive in all scenarios, the optimizer consistently preferred BESS+PV under no-grid-export constraints and current cost assumptions. The project is financially viable as a BESS+PV system (payback 6.98–8.73 yr, IRR 9.6–12.9%).

Cross-regional observations

- Subsidy is universally impactful: 50% CAPEX subsidy reduces payback by 30–50% and approximately doubles IRR across all three regions.
- H_2 viability requires demand: Passau (truck fleet) and Landshut Reproduction Technologies / Gas Grid (industrial and grid injection demand) activate H_2. Pécs doesn't show external demand neither grid exports.
- Critical DST issues confirmed across regions: (1) component cost database inaccuracies (compressor, heat exchanger); (2) LCOH not returned for gas grid injection scenarios; (3) fuel cell CF = 0% when H_2 sell price is high; (4) local software installation blocked by NIS2.
- All three regions confirm the DST is a useful early-stage planning tool. Targeted improvements are needed before unsupported use by non-expert stakeholders is recommended.

B. Introduction

Central Europe holds significant untapped potential for green hydrogen, yet most regional and municipal authorities lack the practical tools to move from aspiration to investment. Feasibility studies are expensive, technical expertise is scarce outside major cities, and the gap between national hydrogen strategies and local project development remains wide. The **HyEfRe Decision Support Tool** was built to close that gap, a free, open-access platform allowing planners, operators, and municipalities to optimise and financially evaluate integrated renewable energy and hydrogen systems for their specific site, without requiring specialist modelling expertise.

Pilot testing under Activity A1.5 is the step that determines whether the tool works in practice. Running real scenarios at real sites, with real data and stakeholders, exposes the gaps between a model and the complexity of actual energy planning. The results documented in this report go beyond validating the DST, since they constitute a concrete evidence base for hydrogen investment in three Central European regions, ready to be used by project developers, municipalities, and funding bodies.

Three regions were selected to cover the range of contexts typical of Central Europe. **Landkreis Passau** (Bavaria, Germany) is an already-active hydrogen corridor: it is home to one of Europe's largest mid-duty hydrogen truck fleets and a planned TEN-T filling station on the A3/A94 motorway. The region has a published hydrogen strategy and a completed HyExpert feasibility study, making it the strongest demand environment of the three. **Landshut** (Bavaria, Germany) tests three entirely different business models in parallel: a logistics truck depot, a small industrial process heat application, and a hydropower-to-grid-injection concept at the Isarkanal canal, covering the breadth of hydrogen use cases relevant to Central European manufacturing and logistics regions. **Pécs** (Hungary) represents a public utility perspective: a wastewater treatment plant with a planned PV and battery installation, constrained by no-grid-export rules where hydrogen's role is long-term and the immediate business case rests on battery storage alone.

The pilot action was co-created by the Lead Partner HAW Landshut, PP5 (DST development), PP7 (HyFuture), and PP9 (coordination), with support from partners across all involved countries. Associated partners were guided through the tool by project partners, supported by transnational and eight national workshops designed to promote DST uptake across Central Europe.

Each region ran multiple simulation scenarios across three planning horizons (2025/2026, 2030, and 2050) and two subsidy assumptions (0% and 50% CAPEX support), producing a total of 77 scenarios across 9 micro-locations. Scenarios cover the full system: photovoltaic and wind generation, battery storage, electrolyser sizing, hydrogen and oxygen storage, fuel cell CHP, waste heat recovery, and grid connection - jointly optimised by the DST's linear programming solver at hourly resolution over a full simulation year.

The process was documented end to end: data inputs, DST configuration, simulation outputs, financial results, and critically structured user feedback identifying what the tool does well and where it needs improvement. Annex A of the full report lists 17 specific improvement requests arising from the pilot, ranging from some bugs (H_2 compressor cost 60× below market price) to accessibility barriers, to missing features (fuel cell self-consumption mode; multi-peak electricity tariffs). This feedback loop between pilot testing and tool development is the mechanism by which Activity A1.5 directly improves the DST for broader replication across Central Europe

C. Pilot Region: Landkreis Passau

Regional Overview

Energy and mobility context

Landkreis Passau is a rural district in south-eastern Bavaria at the confluence of the Danube, Inn and Ilz rivers. The district benefits from Bavaria's strong solar resource (1,050–1,250 full-load PV hours/yr) and active wind zones. The A3/A94 motorway corridor is a TEN-T priority axis subject to the AFIR Regulation, which mandates H_2 refuelling infrastructure every 200 km on the core network by 2030. Landkreis Passau is home to one of Europe's most active regional H_2 mobility ecosystems, anchored by Paul Nutzfahrzeuge GmbH's fleet of 25 mid-duty hydrogen trucks.



Figure 1: Landkreis Passau

Existing infrastructure

- Electricity grid: Bayernwerk Netz GmbH medium-voltage (10–20 kV).
- Renewable energy: Municipal PV parks with expired EEG tariffs available for PPAs. Wind energy feasible in designated Vorranggebiete.
- H_2 infrastructure: No existing stations. MaierKorduletsch Mobility Hub (Pocking) planned; Kirchham/Bad Füssing station (Bad Griesbach) in planning. RW Silicium GmbH adjacent to Pocking (<500 m for O_2 pipeline). Medical O_2 market at Bad Griesbach rehabilitation clinics (ISO 7396, €100–120/t).

Policy and regulatory environment

- AFIR Regulation (EU 2023/1804): TEN-T H_2 stations every 200 km mandatory by 2030 — Pocking qualifies.
- RED II / RFNBO: Green H_2 certification requires temporal and geographic additionality; RFNBO status enables 3× THG-quota multiplier.

- BImSchG §10: Permitting required for electrolysers >1 MW. NIP II: up to 80% CAPEX for public H_2 stations. KsNI: 80% of incremental H_2 truck cost.

Role of hydrogen in local strategies

H_2 is central to Landkreis Passau's decarbonisation agenda, documented in the HyPaLa HyExpert-Machbarkeitsstudie (October 2023). The three pilot sites represent the full value chain: **production (Pocking / TEN-T), mobility demand (Vilshofen / logistics), and sector-coupled CHP + O_2 (Bad Griesbach / spa)**. The Passau three-station network concept is designed as a mutually reinforcing supply corridor.

Pilot Testing Setup

Pilot locations and infrastructure nodes

Site	Coordinates	Key driver
Pocking (P) / A3-A94 Mobility Hub	48.400°N 13.317°E	AFIR TEN-T mandate; 42,000 veh/day
Vilshofen a.d. Donau - (V)	48.354°N 13.186°E	Paul NF — 25 H_2 trucks (163 t/yr firm)
Bad Griesbach im Rottal - (BG)	48.454°N 13.189°E	Rottal Terme spa; medical O_2 clinics

Data sources and assumptions

- HyPaLa HyExpert-Machbarkeitsstudie Landkreis Passau (GP JOULE CONNECT / CENTOURIS / EMCEL, Oct 2023): primary source for site selection, demand data and local context.
- HyEfRe DST: full-year simulation using 2024 meteorological data (DWD/PVGIS). Time step: 1 hour. Period: 2024-01-01 to 2024-12-30.
- H_2 sell price: €14-15/kg, suggested from current sold H2 in the region. Electricity tariff: €144/MWh HT (Pocking), €166/MWh HT (Vilshofen / Bad Griesbach).

DST configuration and version

HyEfRe DST - Full-year simulation mode. Components: PV, Wind Farm (2030/2050), BESS, Electrolyser, H_2 storage, O_2 storage, waste heat, fuel cell (Bad Griesbach 2030+). Subsidy applied uniformly to all CAPEX components (0% or 50%).

Scenario Analysis - Passau

Scenario 2026 - Current Status

The 2026 pilot scenarios represent pilot-scale deployments without wind energy. Three sites tested at 0% and 50% subsidy.

Scenario	Electrolyser	PV	H_2 (t/yr)	Payback	IRR	LCOH	NPV (M€)
P_2026_0	1526 kW	10.8 MWp	150	14.86 yr	3.01%	€12.38/kg	0.02
P_2026_50	1500 kW	11.3 MWp	92	13.32 yr	4.23%	€12.17/kg	1.21
V_2026_0	647 kW	4.1 MWp	86	10.70 yr	6.87%	€10.14/kg	3.78
V_2026_50	1000 kW	5.2 MWp	68	9.78 yr	8.05%	€10.43/kg	3.08
BG_2026_0	1256 kW	7.0 MWp	123	14.41 yr	3.35%	€12.16/kg	0.59
BG_2026_50	1339 kW	7.0 MWp	126	7.36 yr	12.24%	€8.56/kg	9.68

- Pocking 2026: 1,526 kW electrolyser on 10.8 MWp PV achieves 61.8% CF, producing 150 t H_2/yr. Marginally viable without subsidy (payback 14.9 yr, IRR 3.0%). At 50% subsidy, payback 13.3 yr. BESS (€7.4M) dominates CAPEX.
- Vilshofen 2026 (0%): Best electrolyser CF in the entire study, 83.8% (647 kW on 4.1 MWp PV). Optimal sizing demonstrated. H_2 output 86 t/yr covers ~13 of 25 Paul NF trucks. Payback 10.7 yr at 0%, 9.8 yr at 50%.
- Bad Griesbach 2026 (50%): Strongest pilot-scale economics; payback 7.4 yr, IRR 12.2%, LCOH €8.56/kg. High O_2 monetisation: 624 t O_2/yr sold (64% of production). CAPEX halves to €9.5M with 50% subsidy.

Scenario 2030 – Projected Expansion

Wind energy is introduced at Vilshofen and Bad Griesbach. Electrolysers scale to 5–10 MW. Fuel cell added at Bad Griesbach (1,500 kW) but operates at near-zero CF. See Section Challenges.

Scenario	Electrolyser	PV	Wind	H_2 (t/yr)	Payback	IRR	LCOH
P_2030_0	8500 kW	22.5 MWp	none	375	16.87 yr	1.68%	€13.06/kg
P_2030_50	8500 kW	22.5 MWp	none	380	8.50 yr	10.03%	€9.19/kg
V_2030_0	10000 kW	20.0 MWp	5.5 MW	422	14.87 yr	3.00%	€12.15/kg
V_2030_50	10000 kW	20.0 MWp	9.9 MW	466	8.09 yr	10.75%	€8.28/kg
BG_2030_0	5886 kW	22.5 MWp	8.0 MW	652	12.64 yr	4.83%	€10.77/kg

- Pocking 2030: 8.5 MW electrolyser on PV-only achieves only 26% CF — significant underutilisation. 0% subsidy yields negative NPV (−€6.9M). At 50% subsidy: payback 8.5 yr, IRR 10.0%, LCOH €9.19/kg. Wind integration recommended.

- Vilshofen 2030: Adding 5.5–9.9 MW wind raises H_2 to 422–466 t/yr, covering the full Paul NF fleet. At 50% subsidy: payback 8.1 yr, IRR 10.75%, LCOH €8.28/kg. 0% subsidy is marginal (NPV ≈ €0).
- Bad Griesbach 2030: 5.9 MW electrolyser + 8 MW wind achieves 62% CF; all O_2 sold (5,176 t/yr, 100% monetisation). Payback 12.6 yr at 0%.

Scenario 2050 – Full Integration

Full-scale deployment with PV + wind portfolios of 45–145 MW, electrolysers of 12–26 MW, and H_2 production of 1,184–3,214 t/yr. All hydrogen remains 100% green.

Scenario	Electrolyser	PV	Wind	H_2 (t/yr)	Payback	IRR	LCOH	NPV (M€)
P_2050_0	13845 kW	45.0 MWp	29.9 MW	1497	13.62 yr	3.98%	€10.92/kg	21.2
P_2050_50	15621 kW	45.0 MWp	51.4 MW	1539	8.80 yr	9.52%	€8.26/kg	104.2
V_2050_0	26000 kW	60.0 MWp	63.4 MW	2847	13.13 yr	4.39%	€10.19/kg	55.2
V_2050_50	26000 kW	60.0 MWp	89.2 MW	3214	7.28 yr	12.41%	€6.99/kg	269.2
BG_2050_0	11014 kW	32.6 MWp	20.0 MW	1184	15.58 yr	2.51%	€11.41/kg	-7.75
BG_2050_50	12000 kW	52.5 MWp	20.0 MW	1494	8.34 yr	10.30%	€7.82/kg	85.8

- Vilshofen 2050 (50%): Best scenario in the entire study. LCOH €6.99/kg, payback 7.28 yr, IRR 12.41%, NPV €269M. 3,214 t H_2/yr. Vilshofen becomes the regional H_2 backbone producer.
- Pocking 2050 (50%): 45 MWp + 51 MW wind + 15.6 MW electrolyser. H_2 1,539 t/yr. Payback 8.8 yr, IRR 9.5%, LCOH €8.26/kg. O_2 sales 6,128 t/yr add significant revenue.
- Bad Griesbach 2050: Only viable with subsidy (payback 8.3 yr, IRR 10.3%, LCOH €7.82/kg). Electrolyser CF reaches 70% at 50% subsidy. Fuel cell near-idle in both scenarios.

Cross-Scenario Comparison – Passau

Indicator	2026 (pilot)	2030 (scale-up)	2050 (full build-out)
Electrolyser range (MW)	0.6-1.5	5.9-10.0	11.0-26.0
H_2 production range (t/yr)	68-150	375-652	1,184-3,214
Electrolyser CF range	38-84%	25-62%	58-70%
LCOH range	€8.26-13.06/kg	€8.28-13.06/kg	€6.99-11.41/kg
Best payback	7.4 yr (BG, 50%)	8.1 yr (V, 50%)	7.3 yr (V, 50%)
Best IRR	12.2% (BG, 50%)	10.75% (V, 50%)	12.4% (V, 50%)

Wind energy used	No	Yes (2 of 3 sites)	Yes (all sites)
Fuel cell active	No	No (0.2% CF)	No (<1% CF)
100% green H_2	Yes (all)	Yes (all)	Yes (all)

Challenges and Limitations – Passau

- Fuel cell CF = 0%: Installed in BG 2030 and 2050 but never activates. At €14–15/kg H_2, direct sales always dominate over CHP reconversion. Self-consumption mode (avoided electricity cost) needed.
- O_2 sales inconsistency: Pocking 2026–2030 shows €0 O_2 revenue despite 700–3,000 t/yr production (no buyer configured in DST session). BG 2030 correctly monetises 100%. Standardised buyer templates recommended.
- Wind CF underperformance: 8–20% CF vs typical Bavarian 25–35%. Conservative DST wind profiles need calibration with Bayerischer Windatlas 2021.
- Electrolyser oversizing: Pocking in 2030-Scenario and Vilshofen in 2030-Scenario (no wind) reach only 25–26% CF on 8.5–10 MW electrolysers. DST should warn when projected CF falls below 35%.

Preliminary Recommendations – Passau

- Infrastructure development: Prioritise Pocking for first public H_2 station by 2028 (AFIR TEN-T mandate). Integrate RW Silicium O_2 pipeline and waste heat connection to Autohof in all DST runs.
- Policy actions: Apply for NIP II (up to 80% CAPEX) and KsNI concurrently. Pursue RFNBO certification from project start to activate the 3× THG-quota multiplier.
- Investment priorities: Vilshofen 2030 (50%) and Bad Griesbach 2026 (50%) are most bankable near-term scenarios. Combine Paul NF firm offtake contract with green bond structuring.

D. Pilot Region: Landkreis Landshut, Germany

Regional Overview

Energy and mobility context

Landshut is the capital of Lower Bavaria, located 70 km north-east of Munich. The city and surroundings host logistics, manufacturing, and energy infrastructure. Key assets include the Isarkanal hydropower plant (5 MW turbine, year-round baseload), a growing H_2 mobility sector (semi-trailer logistics), and proximity to the planned German hydrogen core network. Testing was conducted by HyFuture GmbH (Willi Holzapfel, CEO) in cooperation with HAW Landshut.



Figure 2: Landkreis Landshut

Existing infrastructure

- Gas Grid / Isarkanal: 5 MW hydropower turbine (reserved as Munich Airport emergency backup). Year-round 100% renewable electricity. H_2 could be fed into the hydrogen core network. O_2 and waste heat utilisation possible. Constraints: core network currently carries natural gas; no off-takers yet; flood protection zone adjacent.
- Logistics Trucks (NE Landshut): New logistics site under development. 1 MWp rooftop PV (self-consumption only; no grid export). Semi-trailer H_2 trucks tested. No nearby H_2 station. ~300 t H_2/yr demand if full fleet converted.
- Reproduction Technologies (SW Landshut): 0.5 MWp rooftop PV (grid export possible). Expansion planned (+100 kWp and +400 kWp). H_2 demand up to 6.7 t/yr. Feasibility study completed.

Policy and regulatory environment

- Grid export restriction at the Logistics site limits certified RFNBO-eligible green H_2 production.
- New PV construction rejected by the municipality at the Logistics site — a significant barrier to scaling green H_2.
- Hydrogen core network still carries natural gas; transition timeline unclear for Isarkanal grid injection.

Role of hydrogen in local strategies

Landshut tested the DST for three distinct business models: mobility (truck fleet, Logistics), industrial process (Reproduction Technologies), and grid injection (Gas Grid / Isarkanal). 54 scenarios were run in total, the largest scenario set among the three pilot regions.

Pilot Testing Setup

Pilot locations and infrastructure nodes

Site	Location	Key driver	Scenarios
Logistics Trucks	NE Landshut	H_2 truck fleet; ~300 t/yr demand	3 RESu × 3 H_2 prices × 0/50% = 18
Reproduction Technologies	SW Landshut	Industrial H_2 demand up to 6.7 t/yr	3 PV sizes × 3 H_2 demands × 0/50% = 18
Gas Grid (Isarkanal)	W Landshut (canal)	5 MW hydro → H_2 → gas network	3 H_2 demands × 3 H_2 prices × 0/50% = 18

Data sources and assumptions

- Gas Grid: RESu profile created from actual 5 MW hydro power curve. H_2 demand: expected output for 5 MW electrolyser. H_2 price: based on gas price assumptions.
- Reproduction Technologies: PV areas from feasibility study. H_2 demand: figures from feasibility study. H_2 price: feasibility study assumptions.
- Logistics Trucks: RESu data transferred from a nearby 2 MWp ground-mounted PV field. H_2 demand and H_2 price from feasibility study.

Scenario Analysis - Landshut

Site 1: Logistics Trucks — Scenario Results

18 scenarios testing 3 RESu levels × 3 H_2 prices × 0%/50% subsidy. H_2 demand: 6,000 kg/week. Key finding: the DST optimizer fixes the electrolyser at 1,128.58 kW regardless of RESu level (×1, ×2, ×5) — demand is never fully met.

Sc.	PV equiv.	H_2 €/kg	Sub%	Save 20yr (€)	Payback (yr)	Elec. (kW)	H_2 prod (kg/mo)	Note
1	680 kWp	6	0%	5,233,455	16.68	1129	13312	—
2	680 kWp	6	50%	6,431,264	10.53	1129	16243	—
3	1,370 kWp	6	0%	5,331,888	16.38	1129	13442	—

4	1,370 kWp	6	50%	6,432,655	10.20	1129	16128	—
5	3,400 kWp	6	0%	5,355,444	16.30	1129	13563	—
6	3,400 kWp	6	50%	8,421,053	6.75	1129	7260	Lower H_2 prod. at higher PV — optimizer anomaly
7	680 kWp	9	0%	18,695,518	6.45	1129	17116	—
8	680 kWp	9	50%	19,372,597	4.12	1129	17454	Best 0%+50% at mid PV
9	1,370 kWp	9	0%	18,876,964	6.37	1129	17044	—
10	1,370 kWp	9	50%	19,680,088	4.16	1129	17616	—
11	3,400 kWp	9	0%	18,905,024	6.36	1129	17088	—
12	3,400 kWp	9	50%	19,776,837	4.21	1129	17648	Best overall: €9/kg + 50%
13	680 kWp	4	0%	—	—	—	—	Not profitable at €4/kg
14	680 kWp	4	50%	—	—	—	—	Not profitable at €4/kg
15	1,370 kWp	4	0%	—	—	—	—	Not profitable at €4/kg
16	1,370 kWp	4	50%	—	—	—	—	Not profitable at €4/kg
17	3,400 kWp	4	0%	—	—	—	—	Not profitable at €4/kg
18	3,400 kWp	4	50%	—	—	—	—	Not profitable at €4/kg

- H_2 production shortfall: Expected 25,714 kg/month at 6,000 kg/week demand. Achieved: 13,311–17,615 kg/month (52–69% of demand met). Electrolyser does not scale with RESu — confirmed DST sizing ceiling.
- H_2 price sensitivity is the dominant factor: ***At €4/kg (Sc. 13–18) all scenarios return zero profit***. At €6/kg payback ranges 6.75–16.68 yr. At €9/kg payback improves to 4.12–6.45 yr.
- Best scenario: Sc. 12 (3,400 kWp RESu, €9/kg, 50% subsidy), saves €19.8M over 20 years, payback 4.21 yr.
- Partner observation: "RESu is doubled and times 5: no change of electrolyser size." This is the critical DST limitation for this site.

Site 2: Gas Grid / Isarkanal Hydropower — Scenario Results

18 scenarios testing 3 H_2 demand levels (25/50/100 kg/h) × 3 H_2 prices (€2/3/5/kg) × 0%/50% subsidy. RESu: 43,792,116 kWh/yr (constant 5 MW hydro, year-round). Key finding: electrolyser remains at ~1,159–1,259 kW despite 5,000 kW hydro being available.

Sc.	H_2 demand	H_2 €/kg	Sub%	Save 20yr (€)	Payback (yr)	Elec. (kW)	H_2 prod (kg/mo)	Note
1	400 kg/day	3	0%	6,067,682	8.05	1260	20217	—
2	400 kg/day	3	50%	6,067,682	4.03	1260	20217	—
3	800 kg/day	3	0%	6,067,682	8.05	1260	20217	—
4	800 kg/day	3	50%	6,067,682	4.03	1260	20217	—
5	200 kg/day	3	0%	5,582,268	8.05	1159	18600	Slightly smaller elec.
6	200 kg/day	3	50%	5,582,268	4.03	1159	108600	6-month sim — not comparable
7	400 kg/day	5	0%	14,157,923	3.45	1260	20217	—
8	400 kg/day	5	50%	14,157,923	1.73	1260	20217	Best: 1.73 yr payback
9	800 kg/day	5	0%	14,157,923	1.73	1260	20217	—
10	800 kg/day	5	50%	14,157,923	1.73	1260	20217	—
11	200 kg/day	5	0%	13,025,289	3.45	1159	18600	—
12	200 kg/day	5	50%	13,025,289	1.73	1159	18600	—
13	400 kg/day	2	0%	—	—	—	—	Not profitable at €2/kg
14	400 kg/day	2	50%	1,974,972	12.37	1260	20217	50% sub needed
15	800 kg/day	2	0%	—	—	—	—	Not profitable at €2/kg
16	800 kg/day	2	50%	1,974,972	12.37	1260	20217	50% sub needed
17	200 kg/day	2	0%	—	—	—	—	Not profitable at €2/kg
18	200 kg/day	2	50%	1,816,975	12.37	1159	18600	50% sub needed

- LCOH not returned: The DST shows no outputs for LCOH in all Gas Grid scenarios. This is a confirmed tool gap for grid injection business models.
- Electrolyser sizing ceiling confirmed: DST consistently selects 1,159–1,259 kW despite the user specifying 5,000 kW minimum and providing 43.8 GWh/yr hydro supply. Expected H_2: 18,000–72,000 kg/month. Achieved: 6,572–20,217 kg/month.
- H_2 demand: 50 and 100 kg/h scenarios give identical electrolyser sizes, no scaling response to doubled demand.
- Best scenario: Sc. 8 (50 kg/h demand, €5/kg, 50% subsidy), payback 1.73 yr, saves €14.2M over 20 years. Excellent economics if the electrolyser sizing is fixed.
- H_2 price €2/kg (Sc. 13–17): not profitable at 0% subsidy. Marginal with 50% subsidy (payback 12.37 yr).
- Note: Scenario 6 (6-month simulation) shows 108,600 kg H_2, not comparable to other monthly runs.

Site 3: Reproduction Technologies — Scenario Results

18 scenarios testing 3 PV sizes (498/599/1,004 kWp) × 3 H_2 demands (1,200/3,200/6,700 kg/yr) × 0%/50% subsidy × 3 H_2 prices (€4/6/8/kg). This is the most successful pilot site, H_2 demand is met in most scenarios.

Sc.	PV	H_2 demand	H_2 €/kg	Sub%	Save 20yr (€)	Payback (yr)	PV cap (kWp)	Elec. (kW)	H_2 (kg/mo)
1	498 kWp	1200 kg/yr	6	0%	126,353	8.23	37.7	7.04	3.03
2	498 kWp	1200 kg/yr	6	50%	126,353	4.11	37.7	7.04	1.99
3	498 kWp	1200 kg/yr	4	0%	76,296	13.63	37.7	7.04	3.03
4	498 kWp	1200 kg/yr	4	50%	76,296	6.81	37.7	7.04	1.99
5	498 kWp	1200 kg/yr	8	0%	176,411	5.89	37.7	7.04	3.03
6	498 kWp	1200 kg/yr	8	50%	176,411	2.95	37.7	7.04	1.99
7	599 kWp	3200 kg/yr	6	0%	336,943	8.23	100.5	18.77	3.03
8	599 kWp	3200 kg/yr	6	50%	336,943	4.11	100.5	18.77	1.99
9	599 kWp	3200 kg/yr	4	0%	203,457	13.63	100.5	18.77	3.03
10	599 kWp	3200 kg/yr	4	50%	203,457	6.81	100.5	18.77	1.99
11	599 kWp	3200 kg/yr	8	0%	470,428	5.89	100.5	18.77	3.03
12	599 kWp	3200 kg/yr	8	50%	470,428	2.95	100.5	18.77	1.99

13	1,004 kWp	6700 kg/yr	6	0%	532,033	10.98	210.0	43.53	4.16
14	1,004 kWp	6700 kg/yr	6	50%	553,699	5.77	231.5	45.09	3.15
15	1,004 kWp	6700 kg/yr	4	0%	223,893	13.72	110.8	21.64	3.05
16	1,004 kWp	6700 kg/yr	4	50%	239,698	7.30	127.0	24.51	2.10
17	1,004 kWp	6700 kg/yr	8	0%	824,646	7.55	224.1	46.22	4.33
18	1,004 kWp	6700 kg/yr	8	50%	836,099	3.90	236.4	45.92	3.19

- H_2 demand met in 15 of 18 scenarios. Scenarios 13, 15, 16 (low H_2 price €4/kg combined with high demand 6,700 kg/yr) do not produce H_2 — economically unviable.
- Best scenario: Sc. 18 (1,004 kWp PV, 6,700 kg/yr demand, €8/kg, 50% subsidy), payback 3.9 yr, saves €836k over 20 years.
- Payback range: 2.95–13.72 yr across viable scenarios. The €8/kg H_2 price drives consistently strong economics (payback 2.95–7.55 yr).
- Partner observation: "Electrolyser investment cost ~€700/kW is very very low" and "H_2 tank cost €1,200/kg is very high", cost database issues affect CAPEX reliability.

Cross-Scenario Comparison – Landshut

Indicator	Logistics Trucks	Reproduction Tech.	Gas Grid (Isarkanal)
Scenarios tested	18	18	18
H_2 demand met?	No — 52–69% only	Yes — 15 of 18 scenarios	No — optimizer caps at ~1.2 MW
Best payback (50% sub)	4.21 yr (€9/kg, ×5 RESu)	3.90 yr (€8/kg, max PV)	1.73 yr (€5/kg)
Best savings 20yr	€19.8M	€836k	€14.2M
LCOH available?	Yes	Yes	No
Key barrier	PV limited; no new PV permit; min. elec. not set.	Cost database issues; H_2 tank cost high	DST min. elec. size not set.
Financial viability	Yes at €9/kg	Yes at €6–8/kg	Excellent at €5/kg if sizing fixed

Challenges and Limitations – Landshut

- Electrolyser minimum size not set: The single most critical scenario limitation identified in Landshut. Regardless of available RESu (×1, ×2, ×5) or theoretical minimum size (5 MW for Gas Grid), the optimizer returns ~1.13–1.26 MW in all scenarios.

- Component cost database errors: H_2 compressor priced at €529 (0.88 kg/h unit) vs real market price ~€30,000. Heat exchanger at €9/kW. Electrolyser at ~€700/kW (very low). H_2 tank at €1,000–1,200/kg (very high). These errors undermine stakeholder confidence in CAPEX outputs.
- LCOH not available for gas grid injection: All Gas Grid scenarios show no LCOH. This is a fundamental output gap for pipeline/grid injection business models.
- Municipality search failure: "Choose municipality" does not find Landshut. Users must resort to manual map coordinate entry.
- RESu/LREP/PV classification unclear: The distinction between these input categories is confusing; data must be entered in Wh with no unit indication in the interface.
- H_2 demand profile: Only 7-day/week H_2 demand supported. Many industrial applications have 5-day/week demand and 7-day/week production, no workaround available.

Preliminary Recommendations – Landshut

- Infrastructure development: Pursue PPA with curtailed ground-mounted PV for the Logistics site. Explore direct H_2 pipeline connection from Isarkanal to the planned H_2 core network for grid injection.
- Policy actions: Engage Landshut municipality to reverse PV expansion refusal at the Logistics site. Apply for H_2 core network early adopter status for Isarkanal.
- Investment priorities: Focus near-term investment on Reproduction Technologies (most bankable, H_2 demand met, feasibility study complete). Logistics site is viable only after PV expansion is permitted or external PPA is secured.

E. Pilot Region: City of Pécs, Hungary

Regional Overview

Energy and mobility context

Pécs is the fifth-largest city in Hungary, located in the south of Transdanubia. Pilot testing was conducted at the Tettye Forrásház Zrt wastewater treatment plant by STRIA (South-Transdanubian Regional Innovation Agency). The site features constrained grid interaction (no feed-in to grid permitted), an operational biogas CHP plant, and a planned PV installation with battery storage.



Figure 3: Hungary Map. Source Link

Existing infrastructure

- Wastewater treatment plant: operational biogas-driven CHP.
- Planned: PV system + BESS. Capacities defined from project plans.
- 250 kW fuel cell modelled as proxy for planned biogas-hydrogen gas engine.
- On-site electricity demand: daily biogas engine consumption converted to hourly 8,760-value CSV for full-year simulation.

Policy and regulatory environment

- No grid export permitted: limits RFNBO-eligible green H_2 production to self-consumed RE only.
- NIS2 cybersecurity regulations: many Hungarian public-sector and corporate laptops cannot install external software, directly impeding DST access for the primary target user group.
- EU hydrogen support programmes emerging; Hungarian national H_2 strategy in development.

Role of hydrogen in local strategies

At Pécs, the role of H_2 is internal sector coupling: blending with biogas to improve gas engine efficiency, reduce grid dependency, and increase energy security. There is no external H_2 demand market, the value proposition is internal cost reduction. This is a fundamentally different use case from Passau and Landshut.

Pilot Testing Setup

Pilot locations and infrastructure nodes

Single pilot location: Tettye Forrásház Zrt Wastewater Treatment Plant, Pécs, Hungary (approx. 46.07°N, 18.23°E).

Data sources and assumptions

- DST default data for parameters without local equivalents (water parameters, some technology costs).
- Local data applied: grid connection parameters, real biogas engine consumption (daily → hourly CSV), planned BESS and electrolyser capacities.
- Electricity prices: not publicly available; estimated values based on Hungarian water utility industrial tariffs.
- Time-of-use pricing limited to one daily peak window (09:00–12:00). Real site has a second peak (17:00–20:00) that cannot be modelled.

Scenario Analysis – Pécs

All Scenarios Overview

Scenario	BESS (kWh)	CAPEX (€)	OPEX (€/yr)	Payback (yr)	IRR (%)	NPV (€)	H_2 active?
2025.0%	985	292,028	1,054,002	8.25	10.22	215,214	No
2025.50%	1872	356,190	1,038,380	6.98	12.90	374,824	No
2030.0%	1051	323,435	1,052,900	8.73	9.63	227,637	No
2030.50%	1980	381,802	1,037,591	7.29	12.38	397,034	No
2050.0%	1051	323,435	1,052,900	8.73	9.63	227,637	No
2050.50%	1980	381,802	1,037,591	7.29	12.38	397,034	No

- H_2 subsystem inactive in all 6 scenarios: electrolyser (250 kW) operates at 0% CF. This is the correct DST result given no external H_2 demand and no grid export. The optimizer always prefers BESS over H_2 production under these constraints.
- BESS+PV system is financially viable: payback 6.98–8.73 yr, IRR 9.6–12.9%, NPV €215k–€397k (positive in all scenarios).
- 2030 and 2050 results are identical to 2025 for each subsidy level: the DST does not incorporate declining technology cost trajectories across time horizons. This is a significant modelling gap for long-term planning.
- Best scenario: 2025.50 (50% subsidy), payback 6.98 yr, IRR 12.9%, NPV €375k. Largest BESS (1,872 kWh) and best flexibility.

Cross-Scenario Comparison – Pécs

Indicator	2025 (0%)	2025 (50%)	2030 (0%)	2030 (50%)	2050 (0%)	2050 (50%)
BESS capacity (kWh)	985	1,872	1,051	1,980	1,051	1,980
CAPEX (€)	292,028	356,190	323,435	381,802	323,435	381,802
Payback (yr)	8.25	6.98	8.73	7.29	8.73	7.29
IRR (%)	10.22%	12.90%	9.63%	12.38%	9.63%	12.38%
NPV (€)	215,214	374,824	227,637	397,034	227,637	397,034
H_2 production	0 kg	0 kg	0 kg	0 kg	0 kg	0 kg

Challenges and Limitations – Pécs

- H_2 never activated: Across all 6 scenarios, the electrolyser operates at 0% CF. Without external H_2 demand and with no grid export, battery storage is always the optimal solution under current cost assumptions. The DST result is technically correct but limits its usefulness for H_2 planning at this site.
- NIS2 accessibility barrier: The critical limitation for Pécs. Local software installation is blocked on many Hungarian public-sector and corporate laptops by NIS2 cybersecurity regulations. A browser-based platform would be useful for further development.
- No biogas-H_2 blend engine component: The planned gas engine cannot be directly modelled; a 250 kW fuel cell was used as a proxy, with different operating economics and heat profile.

Preliminary Recommendations – Pécs

- Infrastructure development: Introduce an external H_2 demand signal (municipal vehicle fleet, O_2 sale to water treatment process) to create economic justification for electrolyser operation.
- Policy actions: Advocate for grid export permission for the site's surplus RE. Even limited export rights would fundamentally change the BESS vs H_2 economic balance.
- Investment priorities: Proceed with the BESS+PV project, it is viable and should be designed H_2-ready (conduit, space reservation) for future electrolyser installation.

F. Cross-Regional Comparison and Synthesis

Comparative Insights

Key similarities and differences between Passau, Landshut, and Pécs

Dimension	Passau (Germany)	Landshut (Germany)	Pécs (Hungary)
Scenarios tested	18	54	6
H_2 demand driver	Mobility (trucks, AFIR)	Industrial + grid injection	Internal (biogas blending)
H_2 produced?	Yes - 68–3,214 t/yr	Partially (2 of 3 sites)	No (0 kg in all scenarios)
Best payback	7.28 yr (Vilshofen 2050, 50%)	1.73 yr (Gas Grid, €5, 50%)	6.98 yr (BESS, 2025, 50%)
Subsidy impact	Very high; halves payback	Very high	Moderate; improves BESS
Key barrier	FC CHP logic; O_2 configuration	Elec. min. size; cost database	No H_2 demand; NIS2 access
CO_2 reduction	High, all H_2 100% green	Partial, H_2 green where produced	BESS improves RE share
Transferability rating	High	Medium, after DST fixes	Low for H_2; High for BESS

- **Subsidy is universally impactful:** All three regions confirm that 50% CAPEX subsidy reduces payback by 30–50% regardless of country, technology, or scale. It is the single most effective policy lever for early H_2 deployment.
- **H_2 viability requires an explicit demand anchor:** Passau (trucks), Landshut Reproduction Technologies (process heat), and Landshut Gas Grid (grid injection demand) activate H_2. Pécs (no external demand, no grid export) and Landshut Logistics (DST sizing ceiling) do not. This is not a tool failure; it is a correct economic result.
- **National policy differences:** German sites benefit from well-defined subsidy frameworks (NIP II, KsNI, RFNBO) and clear regulatory pathways. The Hungarian regulatory framework is less defined, creating additional investment uncertainty beyond the technical constraints.
- **Tool accessibility is the primary adoption barrier across all regions:** NIS2 restrictions (Pécs), municipality search failures (Landshut), and complex input categories (all regions) collectively create a steep learning curve. A browser-based platform is the single most impactful improvement.

DST Robustness and Transferability

- The DST performed well across different RE portfolios (PV-only, PV+wind, hydro) and two country contexts (Germany, Hungary). The core optimization logic is technically sound and produces meaningful results for PV/BESS/electrolyser configurations.

- Critical robustness issues: (1) component cost database errors (Landshut); (2) LCOH not returned for gas grid injection (Landshut); (3) fuel cell CF = 0% in H_2-rich scenarios (Passau); (4) no technology cost trajectories across 2025/2030/2050 (Pécs).
- Full-year simulation (Passau, Pécs) produces more realistic results than monthly simulation (Landshut). **Since the Decision Support Tool was optimized, all future pilot testing should use full-year mode.**
- The 0%/50% subsidy comparison structure is consistently useful across all three regions and clearly communicates the policy lever to non-expert stakeholders.

G.Overall Conclusions

Validation of the Decision Support Tool

The HyEfRe DST has been successfully tested across three Central European pilot regions covering 9 micro-locations and 77 simulation scenarios. The tool demonstrates its core capability: optimising integrated renewable energy and green hydrogen systems under multiple future scenarios and subsidy levels.

The DST is validated for:

- PV + BESS systems (all regions): results are consistent, realistic, and financially interpretable.
- PV + Wind + Electrolyser systems (Passau): full-year results align with external literature on H_2 production costs in Bavaria.
- Industrial H_2 demand scenarios (Landshut Reproduction Technologies): requested H_2 volumes are met in most configurations.

The DST is not yet fully validated for:

- Biogas-H_2 blending applications (Pécs): no direct component model available.
- Fuel cell / H_2-CHP self-consumption scenarios (Passau Bad Griesbach): FC CF = 0% due to missing self-consumption pricing mode.

Lessons Learned from Pilot Testing

- Demand anchors are essential: H_2 production is only economically justified in the DST when there is an explicit H_2 sales input or O_2 buyer configured. Without demand, the tool correctly returns zero H_2 production.
- Accessibility is the primary adoption barrier: NIS2 regulations, municipality search failures, and confusing input categories collectively create a steep learning curve. A browser-based deployment model would address the most critical barrier.
- Full-year simulation is necessary for bankable results: Monthly simulations miss seasonal patterns critical for H_2 storage dimensioning and LCOH accuracy.
- Subsidy modelling is a core strength: The 0%/50% comparison is consistently the most useful output for all three regions and communicates the policy lever clearly

Readiness for Broader Replication

The HyEfRe DST is ready for broader application in Central European contexts subject to the following prioritised improvements:

- Priority 1 - Browser-based deployment: Eliminate local installation to address NIS2 and corporate IT barriers.
- Priority 2 - Default component cost database update: Correct H_2 compressor, heat exchanger, and fuel cell costs against 2025 and future potential market prices.
- Priority 3 - FC/CHP self-consumption mode: Add internal H_2 transfer price and avoided electricity cost inputs to justify fuel cell operation for on-site CHP. Reference to Bad Griesbach Scenarios in Germany.
- Priority 4 - Standardised O_2 buyer templates: Pre-configure industrial, medical, and wastewater O_2 buyer profiles to prevent €0 O_2 revenue defaults.
- Priority 5 - Multi-peak electricity tariff: Allow at least two high-price time windows per day.
- Priority 6 - Technology cost trajectories: Apply declining cost curves per time horizon (2025/2030/2050) for electrolyser, BESS, and PV.

H. Annexes

Annex A - Feedback Log and Tool Improvement Requests

#	Region	Issue description	Priority
1	Passau	Fuel cell CF = 0%, priority on self-consumption pricing mode	High
2	Passau	O_2 sales = €0 when no buyer configured — needs warning and pre-set defaults	High
3	Passau	Wind CF 8-20% below Bavarian norms, Windatlas calibration needed	Medium
4	Passau	BG_2030_50% empty result file, session naming/integrity check needed	Medium
5	Landshut	H_2 compressor cost €529 (0.88 kg/h) vs real market ~€30,000, critical error	Critical
6	Landshut	LCOH shows no results for all gas grid injection scenarios	Critical
7	Landshut	"Choose municipality" search does not find Landshut	Medium
8	Landshut	RESu/LREP/PV input categories confusing; units (Wh) not shown in interface	Medium
9	Landshut	H_2 demand only supports 7-day/week; 5-day industrial profiles not possible	Medium
10	Landshut	H_2 tank cost €1,000-1,200/kg flagged as very high by pilot partner	Medium
11	Pécs	DST requires local install, blocked by NIS2 on corporate/public laptops	Critical
12	Pécs	Single daily peak tariff only; site requires two peaks (09:00-12:00, 17:00-20:00)	Medium
13	Pécs	No biogas-H_2 blend engine component in DST	Medium
14	All	No technology cost trajectories across 2025/2030/2050 time horizons	High
15	All	Error messages lack diagnostics, users cannot interpret cause of some failures	Medium
16	All	Output: add editable Excel export or PowerPoint presentation summary	Low

Annex B - Glossary

AFIR — Alternative Fuels Infrastructure Regulation (EU 2023/1804). Mandates H_2 refuelling stations every 200 km along the TEN-T core network by 2030.

AEM — Anion Exchange Membrane. Electrolyser technology.

BESS — Battery Energy Storage System. Stationary battery storing surplus renewable electricity to smooth supply to the electrolyser.

BImSchG — Bundes-Immissionsschutzgesetz. German Federal Emission Control Act; §10 permitting required for electrolysers above 1 MW.

CAPEX — Capital Expenditure. One-time investment cost for all physical system components.

CF — Capacity Factor. Ratio of actual annual output to maximum possible output at rated capacity, expressed as a percentage.

CHP — Combined Heat and Power. Simultaneous production of electricity and useful heat from a single energy source, here hydrogen via fuel cell.

DHC — District Heating Connection

DoD — Depth of Discharge.

DST — Decision Support Tool.

DWD — Deutscher Wetterdienst. German Meteorological Service; source of hourly solar and wind data used in DST simulations.

EEG — Erneuerbare-Energien-Gesetz. German Renewable Energy Sources Act defining feed-in tariffs; many early PV installations have now exited the 20-year support period and are available for direct PPAs.

EGC — Electrical Grid Connection.

FC — Fuel Cell. Electrochemical device reconverting hydrogen to electricity and heat; modelled in DST as PEMFC or SOFC.

FEC — Fixed Electricity Consumption.

FLH / VLH — Full-Load Hours / Volllaststunden. Annual energy output divided by rated power, giving the equivalent hours of operation at full capacity. Target for electrolysers in HyEfRe: 3,500–5,500 h/yr.

IRR — Internal Rate of Return. The discount rate at which project NPV equals zero; the effective annual return on invested capital over the project lifetime.

KsNI — Kaufprämie für schwere Nutzfahrzeuge mit innovativem Antrieb. German federal subsidy covering up to 80% of the incremental purchase cost of hydrogen and battery heavy-duty trucks.

LCOE — Levelised Cost of Electricity. Total lifecycle cost divided by lifetime electricity output, expressed in €/MWh.

LCOH — Levelised Cost of Hydrogen. Total lifecycle cost divided by lifetime hydrogen output, expressed in €/kg. Primary economic benchmark for green hydrogen projects.

LFP — Lithium Iron Phosphate. BESS cell chemistry preferred near hydrogen installations due to superior thermal stability and fire safety compared to NMC.

NIP II — Nationales Innovationsprogramm Wasserstoff und Brennstoffzellentechnologie. German federal hydrogen subsidy programme offering up to 80% CAPEX support for public H_2 filling stations.

NIS2 — Network and Information Security Directive 2 (EU 2022/2555). EU cybersecurity regulation restricting external software installation on public-sector and corporate devices.

NPV — Net Present Value. Sum of all future project cash flows discounted at the WACC, minus the initial investment. A positive NPV indicates the project creates value above the cost of capital.

O&M — Operations and Maintenance. Routine servicing and repair costs; typically 2–4% of CAPEX per year for electrolyser systems.

OPEX — Operational Expenditure. Annual operating costs including O&M, insurance, staff, water, and electricity.

PEM / PEMFC — Proton Exchange Membrane (Fuel Cell). Dominant electrolyser technology for new projects in 2025; fast dynamic response, low minimum load (5–15%), output pressure 30–60 bar. Also used as a fuel cell for CHP at 60–80°C.

PPA — Power Purchase Agreement. Long-term contract for direct renewable electricity supply; required for RFNBO green hydrogen certification under RED II.

PV — Photovoltaic. Solar electricity generation.

PVGIS — Photovoltaic Geographical Information System. European Commission tool providing site-

specific solar irradiation and PV production estimates across Europe.

RED II — Renewable Energy Directive II (EU 2018/2001). Defines the RFNBO classification for green hydrogen and sets binding 2030 renewable energy targets for EU member states.

REP / RES — Renewable Energy Plant / Renewable Energy Sources. Electricity from solar, wind, hydro, and other non-fossil sources.

RESu — Renewable Energy Surplus. DST-specific input parameter representing the total annual renewable electricity in excess (in kWh/yr).

RFNBO — Renewable Fuel of Non-Biological Origin. EU classification for green hydrogen under RED II, requiring additionality, temporal correlation, and geographic correlation compliance. Enables the 3× THG-quota multiplier for hydrogen sold as transport fuel in Germany.

SOEC / SOFC — Solid Oxide Electrolyser Cell / Fuel Cell. High-temperature technology (600–900°C); highest efficiency but least commercially mature. SOFC provides high-grade process heat relevant for industrial applications.

TEN-T — Trans-European Transport Network. EU strategic transport infrastructure network; the core network is subject to the AFIR H_2 station mandate by 2030.

THG-Quotengesetz — Treibhausgas-Quotengesetz. German GHG quota law under §37a BImSchG; hydrogen sold as RFNBO transport fuel earns a 3× quota multiplier, significantly improving project revenue.

WACC — Weighted Average Cost of Capital. Blended cost of financing combining equity return requirements and debt interest rates. DST default: 3%, reflecting municipal financing conditions. Private equity projects typically use 6–10%.

WF — Wind Farm. Onshore wind energy component in the DST; modelled with a user-defined capacity and site-specific wind speed profile.

WGC — Water Grid Connection.