



Deliverable 6.1

Overview of the potential local RES, flexibility, and multi-commodity energy grids

Responsible partner: UTCN

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Executive summary

1. Purpose and scope

Deliverable 6.1 establishes the technical baseline for transitioning five European university campuses — the eduPED "Living Labs" — toward Positive Energy District (PED) status. The five Living Labs are: The Hague University of Applied Sciences (THUAS, Netherlands), Politecnico di Torino (POLITO, Italy), Universitat Politècnica de Catalunya (UPC, Spain), Universitatea Tehnică din Cluj-Napoca (UTCN, Romania), and Technische Universität Graz (TU Graz, Austria).

The report is organized around three analytical pillars: (1) quantifying local renewable energy source (RES) potential — solar, wind, and geothermal; (2) evaluating energy flexibility through techno-economic scenario simulation; and (3) assessing the feasibility of multi-commodity (sector-coupled) energy grids. A further section maps the EU and national legislative frameworks governing energy communities and prosumers in the five countries, and the deliverable closes with cross-cutting barriers, opportunities and policy recommendations.

Table 1. The five Living Labs

Living Lab	Country	Climate (Köppen–Geiger)	Dominant existing thermal supply
THUAS	Netherlands	Cfb — temperate oceanic	District heating (fossil), transitioning to Aquifer Thermal Energy Storage (ATES) heat pumps
POLITO	Italy	Cfa — humid subtropical	Fully electrified heat pumps (post- renovation)
UPC	Spain	Csa — hot-summer Mediterranean	Natural gas boilers
UTCN	Romania	Dfb — humid continental	Mixed: gas boilers, district heating, and heat pumps
TU Graz	Austria	Cfb — temperate oceanic	Geothermal heat pumps and district heating (hybrid)

2. PED typology and methodology

A PED is defined as an energy-efficient, energy-flexible urban area that achieves a net annual local surplus of renewable energy production while maintaining net-zero greenhouse gas emissions. Four typologies are distinguished — PED-Autonomous, PED-Dynamic, PED-Virtual, and Pre-PED — reflecting different ways of drawing the district's energy boundary and its degree of grid interaction. All five Living Labs currently sit at the Pre-PED stage, with PED-Dynamic identified as the realistic medium-term target for each.

The "campus-as-living-lab" methodology treats each university campus as a bounded, real-world testbed. RES potential was assessed using the Global Solar Atlas and Global Wind Atlas plus national/regional geodata and site measurements for geothermal resources. Flexibility was evaluated against a harmonized KPI set — spanning PV production, renewable

fraction, maximum renewable penetration, excess electricity, grid purchases/sales, peak grid power, battery throughput, CO₂ emissions, CAPEX, energy cost, payback period and levelized cost of energy – using scenario-based simulation in HOMER Pro (THUAS, POLITO, UPC, UTCN) and nPro (TU Graz), the latter reflecting the more complex multi-vector district network at that site. Multi-commodity grid analysis builds on the same KPI framework, adding renewable fraction, self-consumption/self-sufficiency and primary energy indicators for coupled electricity–heat systems.

3. Local RES Potential

RES potential was assessed with harmonized, internationally recognized datasets: the Global Solar Atlas (solar), the Global Wind Atlas (wind), and a combination of national/regional geodata platforms and site measurements (geothermal). The results below summarize the technical viability of each resource across the five campuses (H = High, M = Medium, L = Low, N = Not viable).

RES type	The Hague (NL)	Turin (IT)	Terrassa (ES)	Cluj-Napoca (RO)	Graz (AT)
Solar PV	M	H	H	M–H	M–H
Wind	M (constrained)	N	N	N	N
Geothermal	H	H	H	M	H

Solar PV is the universal primary RES option, reaching at least a Medium rating at every campus and High at Turin and Terrassa (specific PVOUT of 1,404.7 and 1,581.1 kWh/kWp/year respectively, versus 1,099.9 kWh/kWp/year at The Hague – the lowest of the five). The optimum panel tilt angle is remarkably consistent (36°–38°) across all sites due to their similar latitude band.

Wind energy is not a viable contributor at four of the five campuses (mean wind speeds at 100 m hub height fall within IEC Class IV, below the threshold for commercial generation). The Hague is the sole exception, with a Class III resource, though dense urban surroundings constrain deployment there as well.

Shallow geothermal energy is a strong secondary resource at most sites, valued for its ability to provide continuous, dispatchable heating and cooling that complements intermittent solar PV – a key enabler of coupling sector. Soil thermal conductivity and borehole/aquifer yield vary by site: Terrassa shows the strongest closed-loop borehole conditions (3–4 W/m·K), The Hague relies on aquifer-based storage (ATES) rather than boreholes, Turin shows good closed-loop conditions (2.0–2.7 W/m·K), and Cluj-Napoca shows the lowest mapped conductivity (1.1–1.2 W/m·K) among the closed-loop sites, warranting further site investigation. Graz's assessment benefited from a site-specific measurement campaign, providing the most detailed characterization among the five Living Labs and confirming shallow geothermal as a strong, already partly operational resource there.

Overall, the cross-campus comparison converges on a common two-pillar RES strategy – solar PV as the primary electrical generation technology and geothermal heat

pumps as the primary renewable thermal technology – applicable, with site-specific calibration, across all five national contexts.

4. Energy flexibility assessment

Energy flexibility – the ability of buildings, clusters, or districts to adjust demand and generation in response to price, CO₂ intensity, or grid-constraint signals – was evaluated through scenario-based simulation (HOMER Pro for four Living Labs; nPro for the Austrian case) against a harmonized set of techno-economic and environmental KPIs (PV production, renewable fraction, grid purchases/sales, CO₂ emissions, CAPEX, LCOE, payback period, etc.). Key results by Living Lab:

- THUAS (Netherlands): progressive scenarios move from a near-zero renewable fraction (0.7%) baseline toward thermal electrification via an Aquifer Thermal Energy Storage (ATES) heat pump system and PV expansion up to ~1,232 kWp, reaching a renewable fraction of ~24% and cutting CO₂ emissions from 1,248 to 796 t/year. Battery storage was not economically justified under the flat national tariff structure.
- POLITO (Italy): for the post-renovation, fully electrified Pavilion 1 building, additional PV expansion (to ~233 kWp total) was the minimum-cost configuration in 86% of 243 sensitivity combinations tested, lifting the renewable fraction from 51% to ~70% and cutting the levelized cost of energy by roughly a quarter. Battery storage alone was never cost-optimal in this context.
- UPC (Spain): expanding PV roughly 4.6-fold (to 575 kWp) raised the renewable fraction from 3% to 14% and cut CO₂ by about 100 t/year with a 6.5-year payback; adding a 500-kWh battery delivered useful peak-shaving but only a marginal further cost benefit. Persistent natural-gas heating remains the largest unaddressed emissions source (~410 t CO₂/year) and heat-pump electrification is identified as the highest-priority next step.
- UTCN (Romania): combining a 550 kWp PV array with full heat-pump replacement of gas boilers cut campus CO₂ emissions by 97% (from 320.5 to about 10 t/year) at a 7.9-year payback – the single largest decarbonization result in the study. A parallel analysis showed that Romania's low grid sellback tariff discourages battery-based flexibility, curtailing PV surplus rather than exporting it; tariff reform is identified as a prerequisite for unlocking storage value.
- TU Graz (Austria): scenario analysis (via the nPro platform) confirmed that combining local photovoltaic expansion, full electrification of heating and cooling via already-established geothermal heat-pump infrastructure, and certified renewable electricity procurement can reduce campus CO₂ emissions by roughly 90–97% relative to the existing baseline. Extending PV generation through a Renewable Energy Community and adding district-scale battery storage was found to deliver the best overall environmental and economic outcome among the scenarios tested, moving the campus toward a positive annual energy balance. Detailed infrastructure figures for TU Graz are treated as confidential to the partner institution and are not reproduced in this summary.

Best-performing scenario vs. baseline (selected KPIs)

Living Lab	Renewable fraction: base → best	CO ₂ reduction vs. base	Simple payback (best scenario)
THUAS (NL)	0.7% → 23.9%	~36%	– (optimized/NPV basis)
POLITO (IT)	51.2% → ~70%	~50%	variable (sensitivity-dependent)
UPC (ES)	3.1% → 14.1%	~11%	6.5–9.2 years
UTCN (RO)	0.3% → 57–58%	~97%	7.9 years
TU Graz (AT)*	moderate → high	~90–97%	assessed on NPV basis

*TU Graz figures are stated qualitatively; detailed quantitative results for this partner are withheld from this summary in line with TU Graz's data-confidentiality requirements.

Cross-cutting findings

- PV expansion is the single most robust and universally cost-effective flexibility lever across all five campuses, regardless of national context.
- Full thermal electrification via heat pumps – not battery storage – delivers the largest decarbonization gains; the Romanian and Austrian cases both confirm this independently.
- Battery storage is economically justified only under specific tariff conditions (high purchase prices, low sellback rates with sufficient peak/off-peak spread); tariff design is therefore a key policy lever.
- None of the five Living Labs currently reaches a net annual positive energy balance; all are realistically positioned at the Pre-PED stage moving toward PED-Dynamic.

5. Multi-commodity energy grids

This section examines sector coupling – the integration of electricity, heating, cooling, and (where relevant) gas within a shared, actively managed infrastructure. Integration maturity varies widely across the five campuses:

- POLITO (Italy) has achieved the most advanced building-scale integration, with heating, cooling, and domestic hot water fully electrified through high-performance heat pumps in the renovated Pavilion 1, though thermal storage capacity remains limited to short-term buffering.
- UPC (Spain) currently operates the most commodity-separated system of the five, with electricity and natural gas entirely decoupled and no thermal storage; multi-commodity integration there requires building the sector-coupling infrastructure largely from scratch, starting with heat-pump deployment.
- UTCN (Romania) operates a fragmented three-vector system (gas boilers, district heating, and heat pumps) that a recent partial building retrofit has already begun consolidating into a simpler, electrically mediated two-vector architecture; completing gas-boiler replacement across the remaining buildings is the identified priority.

- THUAS (Netherlands) is transitioning from a fossil-fuel district-heating connection toward an ATES-based system that couples summer cooling rejection with winter heating supply – a form of seasonal thermal storage – alongside planned PV expansion.

- TU Graz (Austria) has the most technically advanced multi-vector system among the five Living Labs, combining geothermal heat pumps, district heating, and a shared electrical/cooling infrastructure with continuous digital monitoring; site-specific operational details are kept general in this summary in line with the partner's data-confidentiality requirements.

Two cross-cutting conclusions emerge: first, full thermal electrification – not battery storage – is the decisive multi-commodity transition at every campus; second, the quality and granularity of digital monitoring and energy-management infrastructure is the binding constraint on realizing advanced multi-commodity control strategies at most of the five Living Labs.

6. European and national legislative framework

The deliverable maps the EU regulatory baseline – the Renewable Energy Directive (RED II/RED III), the Electricity Market Directive, the Energy Efficiency Directive, the Energy Poverty Recommendation, and the revised Building Energy Performance Directive – against country-specific transposition in the Netherlands, Italy, Spain, Romania, and Austria.

Two EU-level community models underpin most national frameworks: Renewable Energy Communities (RECs), introduced by RED II as autonomous, member-controlled entities located near the renewable projects they own, pursuing environmental/social rather than purely financial benefit; and Citizen Energy Communities (CECs), introduced by the Electricity Market Directive, which have a broader scope covering distribution, supply, aggregation and EV charging without a proximity requirement. RED III (2023) raises the binding EU renewable-energy target to 42.5% of gross final consumption by 2030 and requires Member States to simplify permitting for community renewable-energy projects – directly relevant to the campus-scale PV and heat-pump investments identified in Sections 3–5.

Dimension	NL	IT	ES	RO	AT
REC/CEC legal framework	Pending (2026 Energy Act)	Established (2021 Decrees + 2023 CER Decree)	Partial (Decree pending)	Established, rapidly evolving (OUG 59/2025)	Established early (EAG 2021)
Primary financial incentive	Tax-based ("postcoderoos")	20-yr GSE tariff + PNRR grants	Simplified compensation + CE Implementa grants	Net-metering + PNRR integration	Grid-fee reduction + investment grants
Key barrier	New framework not yet in force	Administrative complexity	Final REC/CEC decree pending	Grid capacity & local admin capacity	Fragmented DSO service areas

Austria and Italy currently offer the most complete and operationally detailed frameworks; the Netherlands and Spain are still finalizing REC/CEC operational rules; Romania's OUG 59/2025 represents the fastest recent regulatory advance, though local implementation capacity remains a constraint.

7. Barriers, opportunities, and recommendations

Cross-cutting technical barriers

- Seasonal mismatch between summer-peaking PV generation and winter-peaking heating demand — addressable only through seasonal thermal storage (ATES/BTES), which currently exists at scale in only a subset of the Living Labs.
- Absence of an integrated, district-level energy management system capable of jointly optimizing PV dispatch, storage, and grid interaction at most sites.
- Roof-space limitations that will increasingly constrain further PV expansion, pointing to façade-integrated PV and ground-mounted arrays as complementary options.

Recommendations

- Short term: deploy sub-hourly smart metering; install or expand PV where not yet done, prioritizing the highest-solar-resource campuses; pursue green-electricity procurement as an immediate, low-cost decarbonization bridge; assess energy-community eligibility under each national incentive scheme.
- Medium term: develop district-level energy management platforms; advance ATES/heat-pump electrification projects; conduct site-specific geothermal testing where mapped data leaves significant uncertainty; complete replacement of remaining fossil-fuel heating systems.

The study confirms that all five Living Labs possess the technical capacity for a PED transition, but that a supportive, adaptive legal and regulatory framework — enabling decentralized grid access, incentivizing flexibility services, and supporting multi-commodity operation — is the critical determinant of how quickly and completely that potential can be realized.

8. Roadmap toward PED certification

The deliverable closes with a forward-looking, horizon-based roadmap for each Living Lab, distinguishing near-term measures achievable within the current programme, medium-term structural transformations requiring the next funding cycle, and longer-term systemic conditions dependent on regulatory evolution or capital mobilization.

- Near term (2025–2027): initial or expanded PV installation at every campus; sub-hourly smart metering roll-out; first steps toward energy-community membership under each applicable national scheme; where relevant, green-electricity procurement as an immediate bridging measure.

- Medium term (2027–2030): commissioning of seasonal thermal storage or heat-pump systems (e.g. ATES at THUAS, ground-source heat pumps at UPC); completion of gas-boiler replacement at UTCN; development of district-level energy management systems; extension of electrified heating/cooling coverage at the more advanced sites.

- Longer term (2030+): scaling of PV capacity toward the levels identified in the flexibility scenarios; achievement of PED-Dynamic status at each campus; exploration of PED-Dynamic extension into the surrounding neighborhood or district where feasible.

Every campus's roadmap depends jointly on technical and regulatory dependency. All five Living Labs are assessed as having a technically and, with appropriate regulatory support, financially viable pathway to PED-Dynamic status within the coming decade.

9. Conclusion

Deliverable 6.1 provides the technical and regulatory baseline that will inform the design, simulation, and feasibility phases of the eduPED project. Its central, transferable finding is that a PV-first investment strategy, combined with full thermal electrification through heat pumps, is the most robust and broadly replicable pathway toward Positive Energy District status for European university campuses — while the pace of that transition remains bounded, in every national context studied, by the maturity of the surrounding energy-community and grid-access regulation.

This deliverable provides the essential technical baseline for transitioning to achieving Positive Energy District (PED) status in five Living Labs across five European countries. The report forms a core output of the "Educational Campuses as Drivers for Positive Energy Districts" (eduPED) project. The five Living Labs belong to:

- The Hague University of Applied Sciences (THUAS), The Hague, Netherlands.
- Politecnico di Torino (POLITO), Torino Esposizioni Campus, Turin, Italy.
- Universitat Politècnica de Catalunya (UPC), Terrassa Campus, Terrassa, Spain.
- Universitatea Tehnică din Cluj-Napoca (UTCN), Măraști Campus, Cluj-Napoca, Romania.
- Technische Universität Graz (TU Graz), Inffeldcampus, Graz, Austria.

The report is structured around three fundamental analytical pillars: quantifying local renewable energy potential, evaluating energy flexibility, and assessing the feasibility of multi-commodity sector coupling. By examining these interconnected elements, the study provides a roadmap for developing the sustainable and resilient energy systems required as the global landscape shifts toward a decentralized, decarbonized future.

The simulations confirm that all five Living Labs possess the technical capacity for a PED transition; however, achieving a successful and scalable realization hinges on an adaptive legal and regulatory framework. Such a framework must facilitate decentralized grid access, incentivize flexibility services, and support the integrated operation of these complex, multi-commodity systems.