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Co-creating with partners that help to understand the needs of relevant stakeholders, we team up with intermediaries to provide an innovation eco-system supporting consortia for research, innovation, technical development, piloting and demonstration activities. These co-operations pave the way towards implementation in real-life environments and market introduction.

Beyond that, ERA-Net SES provides a Knowledge Community, involving key demo projects and experts from all over Europe, to facilitate learning between projects and programs from the local level up to the European level.

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EXECUTIVE SUMMARY

QuantEEFlex investigated a practical question at the heart of the energy transition: how much value can flexible electricity use create in urban districts, and which technical and organisational solutions are worth implementing? The project combined detailed modelling with Living Lab work in Austria and Türkiye. It assessed heat pumps, building thermal mass, photovoltaic generation, stationary batteries, electric-vehicle charging, local electricity sharing and grid interaction. The final consortium brought together e7 as project coordinator and energy-system modeller, Sakarya University of Applied Sciences (SUBU) as scientific and optimisation partner, and the Turkish distribution system operator OEDAS as Living Lab and implementation partner.

The work was deliberately designed around the three layers of the ERA-Net Smart Energy Systems innovation model. On the technology layer, the partners developed and tested digital models and control approaches. On the marketplace layer, they examined electricity tariffs, power charges, self-consumption, local energy sharing and the investment case for storage. On the stakeholder and adoption layer, they worked with a real-estate developer, electrical and energy-system planners, a municipality and a distribution system operator. This combination was essential: the project repeatedly found that flexibility is not created by technology alone, but by the interaction of technology, market rules and organisational responsibilities.

> **The central conclusion**
>
> District-level flexibility can deliver measurable benefits, but the most valuable solution is not always the most technically sophisticated one. In Austria, widening the group of consumers that could use locally generated PV electricity created substantially more value than installing a battery behind a narrow metering boundary. In Türkiye, assigning distinct roles to two battery systems produced a more robust result than applying one uniform optimisation strategy to both.

Table 1: QuantEEFlex results at a glance.

Area	Main result	What it means
Heat-pump flexibility	Annual gross electricity-cost savings of about 4-8% in the analysed rolling-horizon scenarios	Price-responsive control works, but savings must be assessed together with comfort and energy use.
Austrian Living Lab	Collective PV use raised self-consumption from 13% to 62% and reduced annual electricity costs by about 11%	Metering and organisational design can outperform a stand-alone battery business case.
Battery assessment	The best 50 kWh battery strategy reduced annual operating costs by about 2%; none of the tested variants paid back within 15 years	Storage value is highly site-specific and depends on load boundary, tariffs, export limits and seasonal demand.
Turkish Living Lab	A large battery was optimised for energy shifting and peak reduction, while a smaller battery provided rule-based grid smoothing	Role differentiation and time-scale separation improve field applicability and battery use.
Replication	A staged flexibility-planning workflow and practical replication guidance were developed	Preserve metering, communication and data options early; postpone equipment sizing until demand and responsibilities are clearer.

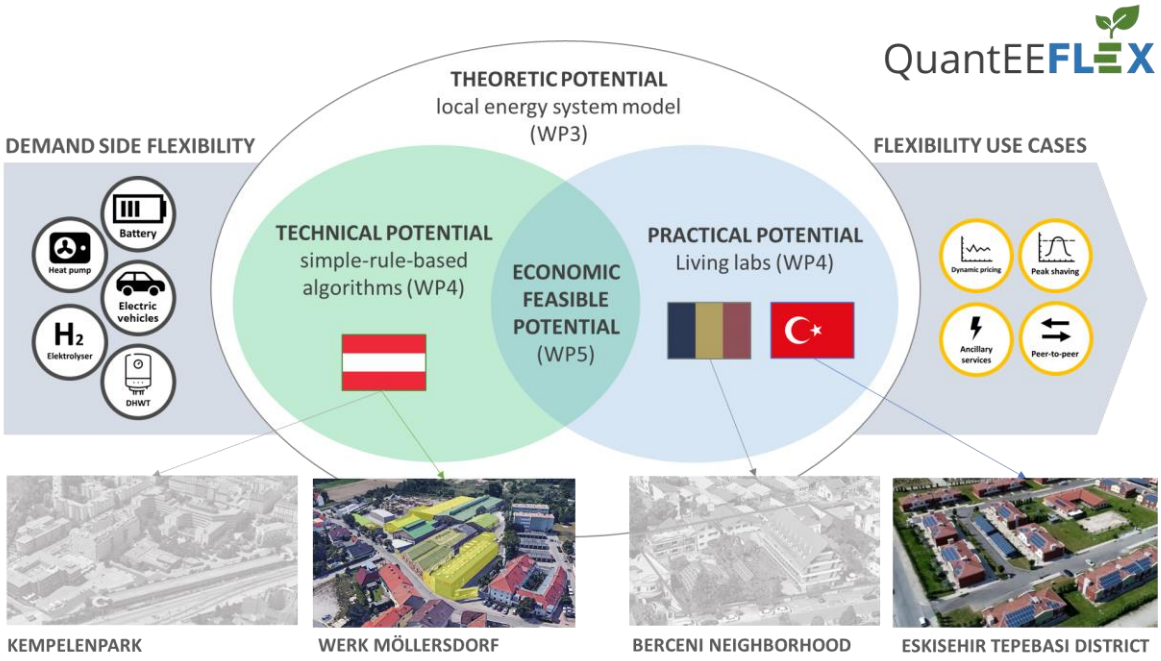

Figure 1: QuantEEFlex research design, linking theoretical potential, technical modelling, economic feasibility and Living Lab application. Source: QuantEEFlex project

What the project added

QuantEEFlex did not seek to demonstrate flexibility at any cost. It focused on economic and operational realism. The Austrian model showed that electricity-cost savings are driven mainly by better timing of consumption, not necessarily by lower energy use. Shorter control intervals reacted more strongly to electricity prices but also produced more comfort deviations. A six-hour rolling-horizon setup was identified as the most balanced reference case, while the results remained technically similar when a different price year was used. This provides a useful basis for future planning tools and model-predictive control studies.

The Living Labs added the implementation perspective. Werk Möllersdorf was still in development, so the Austrian work became an iterative planning laboratory rather than a conventional completed-site demonstration. The team repeatedly updated load assumptions, PV layouts, charging concepts, cooling strategies and metering structures. In Eskişehir Tepebaşı, an operational campus enabled the partners to work with existing PV, batteries, chargers, transformer measurements and real load data. Together, the two cases covered different stages of the innovation process: planning decisions in Austria and field-oriented energy management in Türkiye.

1. PROJECT CONTEXT AND RESEARCH DESIGN

Why urban districts need flexibility

Electrification is changing the energy profile of neighbourhoods. Heat pumps, electric vehicles, cooling systems and batteries increase electricity demand, while rooftop PV introduces generation that varies with weather and time of day. The technical challenge is no longer only to supply sufficient annual energy. Local grids and building connections must also cope with simultaneous power peaks, periods of surplus generation and changing price signals. Flexibility - the ability to shift generation, consumption or storage in time - can help match these patterns.

Urban districts are a promising scale for flexibility because they combine different users and technologies. A single household may have only a small and irregular surplus. A district can pool offices, homes, mobility, technical building services and shared infrastructure. Their demand profiles can complement one another, and investments can benefit from economies of scale. At the same time, district projects are organisationally demanding: generation and consumption may sit behind different meters, be owned by different parties and be subject to different tariffs or grid rules.

QuantEEFlex therefore asked not only what is technically possible, but what is practically and economically useful. The project differentiated between theoretical flexibility, technically feasible flexibility, economically viable flexibility and the flexibility that can actually be implemented in a Living Lab. This distinction prevented optimistic model results from being mistaken for investable business cases.

Objectives and implemented scope

Table 2: Project objectives and implemented outcomes

Original objective	Implemented result
Digitalisation and modelling	Dynamic building simulation, optimisation and Living Lab data were combined in a reusable flexibility-assessment workflow.
Integration of flexible assets	Heat pumps, thermal inertia, PV, batteries, EV charging and grid interaction were assessed in the Austrian and Turkish cases.
Economic and environmental value	Economic impacts were quantified in detail. Environmental effects were addressed through energy indicators and qualitative assessment rather than a full life-cycle analysis.
Simple and robust control strategies	Rolling-horizon optimisation was compared with baseline and rule-based operation; the Turkish case combined optimisation with rule-based grid smoothing.
Roadmap for replication	Technical, market and organisational lessons were translated into staged replication guidance and follow-up applications.

The original proposal also included a Romanian Living Lab and a hydrogen-storage workstream. These activities were not implemented because the Romanian partner did not receive national funding. The final project scope therefore concentrated on Austria and Türkiye. The loss of the Romanian work also meant that the planned comprehensive environmental assessment could not be completed. This report presents the implemented scope transparently.

The Austrian Living Lab also changed during the project. The original site no longer offered sufficient PV surplus or a compelling flexibility challenge. Werk Möllersdorf was selected as a more suitable replacement because it combined a large redevelopment area, substantial PV potential, heterogeneous future demand and concrete planning questions. The project objectives

remained unchanged: the site change improved the relevance of the assessment but shifted Austrian validation more towards planning-oriented decision support.

The three-layer innovation model

Table 3: QuantEEFlex in the ERA-Net SES three-layer innovation model

Technology	Marketplace	Stakeholder / adoption
Digital building and heat-pump model; GAMS optimisation; Python co-simulation; PV, storage and EV models; rule-based and hybrid control.	Dynamic electricity prices; power charges; collective self-consumption; energy communities; investment and lifecycle assessment.	Co-creation with a real-estate developer, planners, municipality and DSO; implementation roles; metering and data access; workshops and replication guidance.

The value of the three-layer approach became visible in both Living Labs. A technically valid battery schedule can fail economically if it increases the power charge. A financially attractive energy-sharing concept cannot be implemented if the metering architecture is fixed too late. An advanced optimiser may be unsuitable for a fast grid-smoothing task if it creates excessive switching or battery cycling. The project therefore treated technical, market and adoption questions as one connected design problem.

Transnational Living Lab approach

The two Living Labs were deliberately complementary. Werk Möllersdorf represented a district in the planning and redevelopment phase. This made it possible to influence decisions that are difficult to reverse later, including metering points, cable routes, grid connections, charging locations and communication interfaces. The Tepebaşı campus represented an operational system with existing PV, batteries, chargers and transformer monitoring. It provided a real-world environment for developing a hierarchical control strategy under technical constraints and data limitations.

Austria: planning-stage Living Lab

Focus on investment choices, metering architecture, collective PV use, storage economics and iterative coordination with the developer and planners.

Türkiye: operational Living Lab

Focus on PV, two batteries, EV charging, transformer interaction and a hybrid optimisation plus rule-based control architecture.

2. METHODS AND TOOLS

A triangulation approach

QuantEEFlex combined three forms of evidence. First, detailed optimisation quantified the theoretical and technically feasible flexibility of assets. Second, simplified or hybrid control strategies translated optimisation logic into approaches that could be implemented in practical energy-management systems. Third, Living Lab work tested the relevance of the models against actual planning processes, infrastructure and stakeholder needs. Economic assessment then compared operating benefits with investment and transaction costs.

This triangulation was important because each method has limitations. Optimisation can find a mathematically attractive schedule, but may rely on perfect information or ignore implementation effort. Rule-based control is easier to operate, but can miss value when conditions change. Living Lab evidence is realistic, but specific to the site and available data. Combining the three allowed the partners to identify not only potential benefits, but also the reasons why a technically promising idea might fail in practice.

Austrian co-simulation model

The Austrian heat-pump model couples a dynamic building simulation with a separate economic optimisation. The building and heat-pump system is represented in Modelica and exported as a Functional Mock-up Unit (FMU). It simulates indoor temperature, heat-pump electricity consumption, thermal output and the effect of previous control decisions. A linear dispatch optimisation is implemented in GAMS, while Python manages the exchange of states, feasible operating bounds, price inputs and optimised schedules.

At each control step, the FMU starts from the current thermal state of the building. Upper and lower comfort trajectories are simulated to define a time-dependent flexibility band. These physical bounds and the required energy are passed to GAMS together with an external electricity-price profile. The optimiser calculates the lowest-cost heat-pump schedule within the feasible band. Only the first part of the schedule is applied; the building state is then updated and the process repeats. This rolling-horizon structure reflects model-predictive control and avoids assuming that one perfect annual schedule can be applied unchanged.

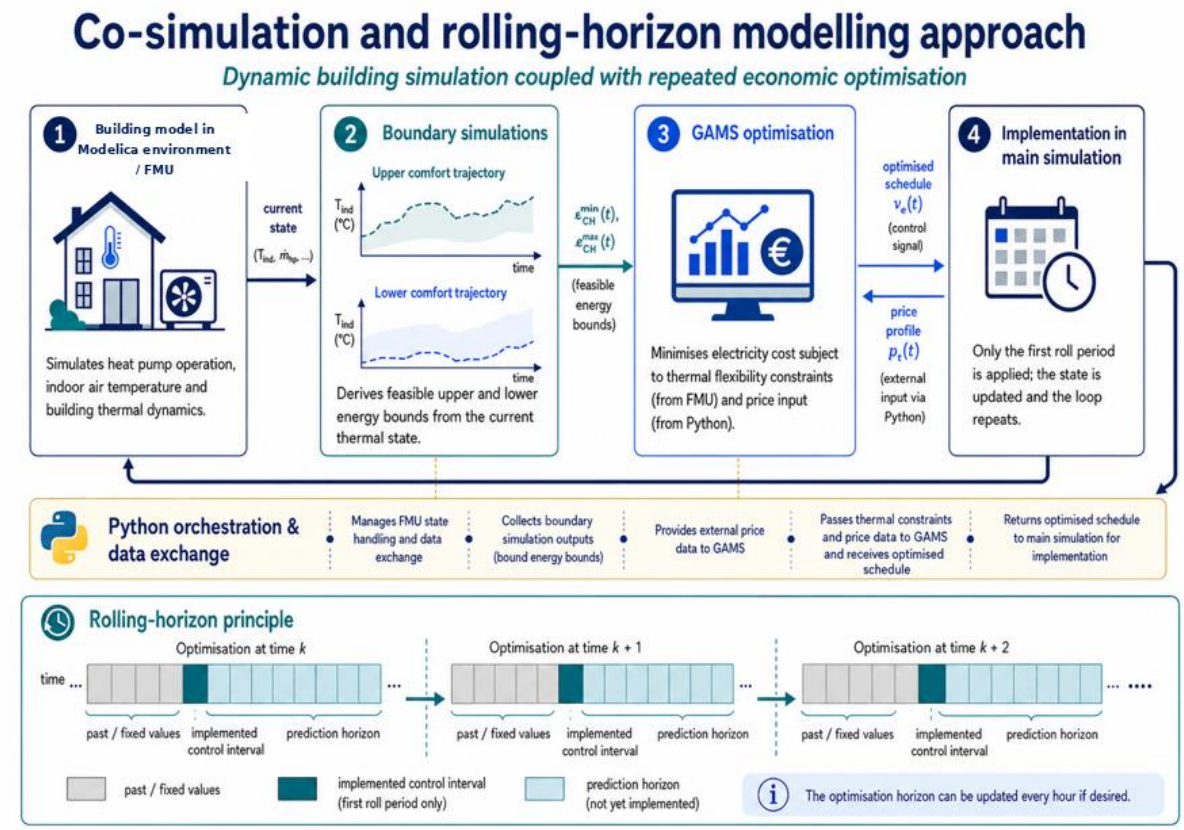

Figure 2: Co-simulation and rolling-horizon modelling approach. Source: QuantEEFlex D3.1

Scenario design and evaluation indicators

The heat-pump analysis used a 24-hour optimisation horizon, reflecting the availability of day-ahead electricity prices. The scenarios varied the interval after which the schedule was recalculated, the permitted indoor-temperature range and the electricity-price year. A continuous baseline simulation with a fixed temperature setpoint provided the reference. The analysis reported energy use, spot-market costs, gross electricity costs including representative non-energy charges, mean and extreme indoor temperatures, hours outside the comfort band and the correlation between price and electricity consumption.

Table 4: Scenario design for heat-pump flexibility optimisation

Scenario	Setup	Purpose
S1	Fixed-setpoint baseline	Reference without price-responsive control
S2	3 h roll period; 21-24 °C	Frequent re-optimisation and high price response
S3	6 h roll period; 21-24 °C	Balanced reference case
S4	12 h roll period; 21-24 °C	Less frequent and more stable control
S5	6 h; 21.5-23.5 °C	Tighter comfort constraints
S6	6 h; 20.5-24.5 °C	Wider thermal flexibility
S7	6 h; 21-24 °C; 2024 prices	Sensitivity to the market environment

Turkish hierarchical energy-management model

The Turkish model addressed a different operational problem: how to coordinate two batteries with different capacities and roles in a PV-rich low-voltage network. The larger battery, ESS1, was optimised with the Cheetah Optimisation Algorithm for energy shifting, peak reduction and electricity-cost minimisation under Türkiye's time-of-use tariff. The smaller and faster ESS2 was

assigned a rule-based grid-smoothing role. It responded to rapid fluctuations and protected technical limits without being forced into unnecessary long-horizon cycles.

The hierarchy separated strategic decisions from fast operational balancing. The upper level scheduled ESS1 subject to state-of-charge, power, energy and switching constraints. The lower level used rules to allocate PV surplus, smooth the grid exchange and protect the batteries. This architecture was designed for field conditions in which perfect forecasts, continuous communications and uniform control access cannot be assumed. It also recognised that battery lifetime is an operational objective: flexibility that relies on excessive micro-cycling is not a sustainable result.

Economic and implementation assessment

For Werk Möllersdorf, the project used quarter-hourly annual profiles and compared storage, peak shaving, dynamic-price operation, collective self-consumption and local energy-community options. The assessment included energy costs, power-related charges, export restrictions, battery losses, investment costs, support assumptions and a 15-year present-value calculation. The aim was not to forecast one final commercial offer, but to test which conclusions remained robust across realistic planning assumptions.

Implementation feasibility was assessed through repeated exchanges with the developer and technical planners. The model boundary, metering point and location of flexible assets were treated as decision variables because they determine which loads a controller can influence. The Turkish assessment similarly integrated data access, equipment roles, operating constraints and stakeholder coordination. Across both sites, the methods were used as decision support rather than as a black-box recommendation engine.

3. RESULTS: MODELLING HEAT-PUMP FLEXIBILITY

Price-responsive control creates value - but comfort is the resource

All rolling-horizon scenarios reduced gross electricity costs relative to their corresponding baseline. Annual savings ranged from approximately 3.7% to 8.4%. The strongest result came from the three-hour roll period, which reacted frequently to price changes. However, it also produced the largest number of low-temperature hours. The slower 12-hour case saved less but reduced the intensity of temperature deviations. The six-hour case offered the clearest compromise between cost reduction, thermal stability and control effort.

This trade-off is fundamental. The heat pump can shift electricity consumption because the building stores heat. The optimiser preheats during favourable periods or allows the indoor temperature to drift before reheating. Thermal comfort is therefore not an external side issue; it is the flexibility resource itself. Reporting cost savings without temperature indicators would overstate the practical potential.

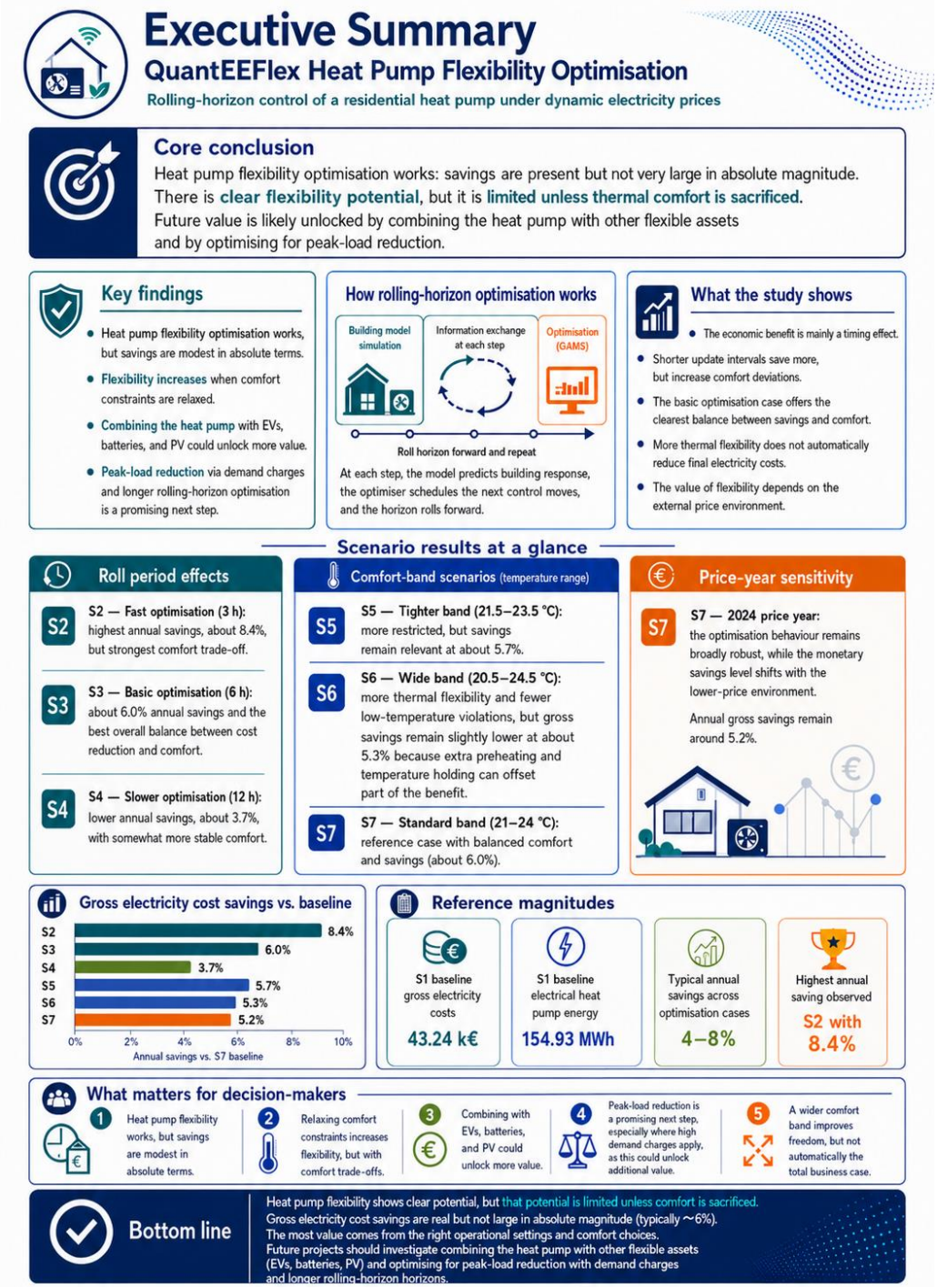

Figure 3: Executive summary of the heat-pump flexibility results. Source: QuantEEFlex D3.1

Control update frequency

S2, with a three-hour roll period, achieved the highest annual gross cost saving of 8.4%. Its electricity consumption was slightly lower than the baseline, but the controller used the comfort range aggressively and produced 1,295 hours below 21°C over the annual evaluation period. S3, with a six-hour roll period, reduced gross costs by 6.0% and lowered the number of hours below 21°C to 819. S4, with a 12-hour roll period, achieved a 3.7% saving and reduced low-temperature hours further to 311.

The comparison shows that more frequent re-optimisation is not automatically better. Short intervals increase responsiveness to price fluctuations, but they can also cause stronger switching and repeated use of the lower comfort boundary. Longer intervals produce smoother behaviour

but may miss short low-price windows. The appropriate interval therefore depends on the building, the acceptable comfort band, the reliability of forecasts and the value placed on operational simplicity.

Comfort-band sensitivity

The tight comfort-band scenario still achieved a 5.7% annual gross cost saving, showing that useful flexibility remains under stricter comfort requirements. The wider comfort band produced a stronger negative relationship between price and consumption, but total electricity use increased by 4.2%. Gross cost savings were therefore about 5.3%, slightly below the tight-band case. Additional preheating and temperature holding consumed energy and reduced the financial benefit of moving load to cheaper hours.

This is an important interpretation point: a wider comfort band increases technical flexibility, but not necessarily economic or environmental performance. An optimiser can shift more demand and lower the spot-price component while increasing the number of kilowatt-hours subject to network charges and taxes. Flexibility must therefore be evaluated with at least three indicators: when energy is used, how much energy is used, and what happens to comfort.

Market-year sensitivity

S7 used the same six-hour control configuration as S3 but applied the 2024 Austrian day-ahead price profile instead of the 2025 profile. The technical operation and comfort indicators were very similar, while annual gross cost savings remained around 5.2%. Absolute electricity costs were lower because the 2024 average price level was lower. The comparison demonstrates that the control logic is technically robust across the two price years, but the monetary value of the same flexibility depends strongly on the external price environment.

Spot-market savings were consistently larger than gross-cost savings because network charges, taxes and other price components apply to each consumed kilowatt-hour. This distinction matters for communication with building owners: headline spot-price opportunities are not the same as savings on the final electricity bill. The model therefore used gross electricity costs as the principal economic indicator.

Table 5: Interpretation of the heat-pump flexibility results

Finding	Evidence	Planning implication
Flexible heat-pump operation works	All optimised scenarios reduced gross costs	Include thermal flexibility in early energy-system screening
The benefit is mainly a timing effect	Several scenarios saved money despite equal or higher energy use	Separate energy-efficiency and flexibility objectives
Comfort constrains usable value	Shorter roll periods increased low-temperature hours	Define comfort priorities before selecting control parameters
Market conditions matter	Similar technical behaviour produced different absolute costs across price years	Use sensitivity analysis rather than one price forecast
Standalone value is limited	Typical annual gross savings were around 4-8%	Combine heat pumps with PV, EVs, batteries or peak management where appropriate

4. LIVING LAB AUSTRIA: WERK MÖLLERSDORF

A redevelopment project as a planning laboratory

Werk Möllersdorf is a former industrial site in Traiskirchen, south of Vienna. The approximately 24,000 m² area is being transformed into a mixed-use, climate-conscious neighbourhood while retaining elements of the historic building stock. This setting created a valuable Living Lab: energy decisions had to fit architectural reuse, changing tenant concepts, construction phases, mobility planning and the technical constraints of an evolving site.

Figure 4: Existing building stock at Werk Möllersdorf. Source: Kallinger Projekte

The project focused its detailed assessment on construction field 2 (BF2), comprising Halls 5, 6 and 7. BF2 combines substantial rooftop PV potential with a heterogeneous demand portfolio: commercial tenants, technical building services, a heat-pump-based energy centre and a planned high-power charging point. This diversity made it suitable for testing whether storage, load control or collective electricity sharing could improve local PV use.

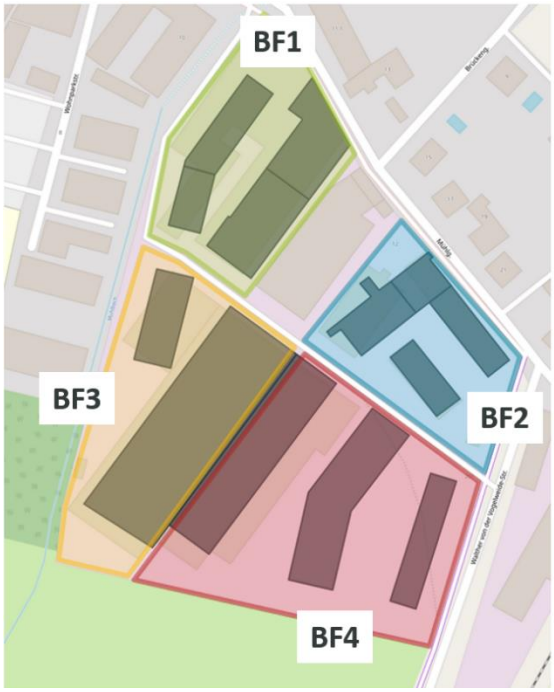

Figure 5: Site plan of Werk Möllersdorf. Source: e7

An iterative Living Lab process

The Austrian Living Lab was embedded in the real-estate planning process from October 2024 to January 2026. The team screened battery technologies, reviewed electrical plans, discussed the thermal flexibility of the planned heating networks, updated PV assumptions, modelled alternative metering structures and compared technical and organisational flexibility options. Workshops with the developer and planners were used to test assumptions and convert model results into design recommendations.

A consortium site visit on 28 October 2025 was especially important. The Austrian and Turkish partners inspected the physical development and its energy-related features before comparing the two Living Labs in a joint workshop at e7. This connected the modelling work with the actual spatial and organisational context. The final developer workshop by the end of the project presented the complete energy and flexibility concept and the recommended next steps for implementation.

System boundary and energy balance

The final BF2 planning case assumed 74.8 kWp of PV, with estimated annual generation of 69.6 MWh. Annual electricity demand was approximately 172 MWh, including around 15 MWh for one 50 kW DC charger. The decisive modelling question was not only the size of generation and demand, but which loads could be balanced behind the same metering boundary. A battery connected only to the energy-centre meter could not directly offset separately metered tenant demand. Collective self-consumption could coordinate a much broader and more continuous load portfolio.

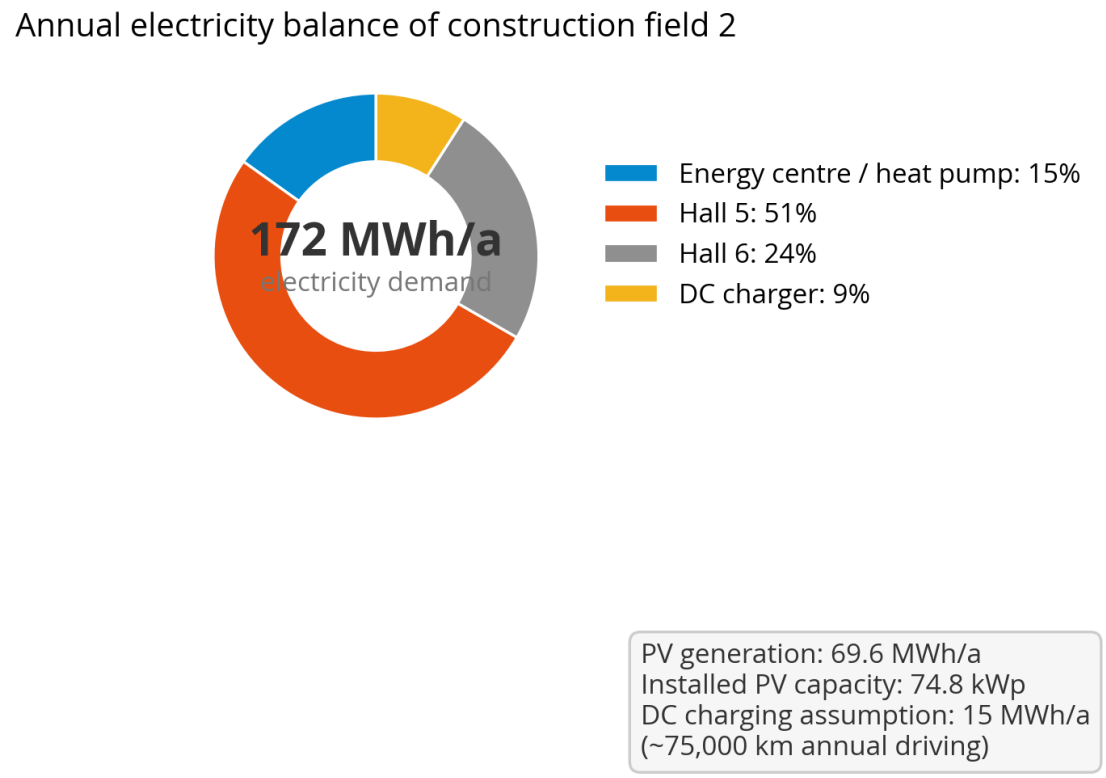

Figure 6: Annual electricity balance assumed for BF2. Source: QuantEEFlex calculations.

The planning process also used an export limit of 20 kW per metering point. This materially reduced the value of surplus generation and highlighted the importance of the electrical architecture. Possible responses - such as consolidating suitable loads, adding metering points or

creating direct connections - affect contracts, billing and responsibilities as well as cables and switchgear. They must therefore be addressed before the design is fixed.

Battery storage: a limited business case

A 50 kWh stationary battery at the BF2 energy-centre meter was assessed under three strategies: PV self-consumption, PV self-consumption plus peak shaving, and PV self-consumption plus dynamic-price arbitrage. The best operating result came from the peak-shaving case, which reduced annual electricity costs by approximately EUR 488, or 2%, and lowered the power-related charge. Pure PV optimisation saved around 1%. The dynamic-price case increased annual costs by about 3%.

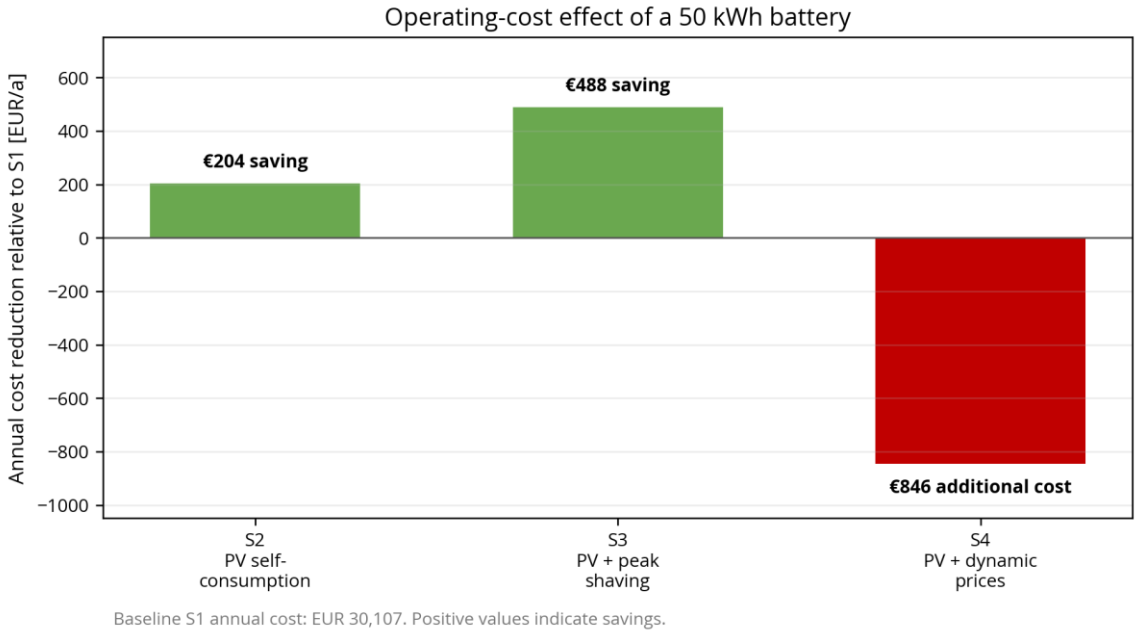

Figure 7: Annual operating-cost effect of the 50 kWh battery strategies. Source: QuantEEFlex calculations

The counter-intuitive dynamic-price result arose because intensive charging during low-price hours created a higher maximum grid demand. The resulting power charge outweighed the energy-price benefit, while the export limit restricted profitable discharge. The case illustrates why a controller cannot optimise against spot prices alone. Energy prices, demand charges, export constraints, efficiency, degradation and state-of-charge requirements must be considered together.

The investment assessment used a 15-year lifetime and battery costs that had already fallen substantially during the project. Even so, none of the variants achieved payback. Present-value costs were approximately 22% higher than the no-storage baseline for PV-oriented control, 13% higher for peak shaving and 59% higher for dynamic-price operation. The main reason was structural: high summer PV surplus coincided with very low technical-building demand, so the battery had too few valuable cycles.

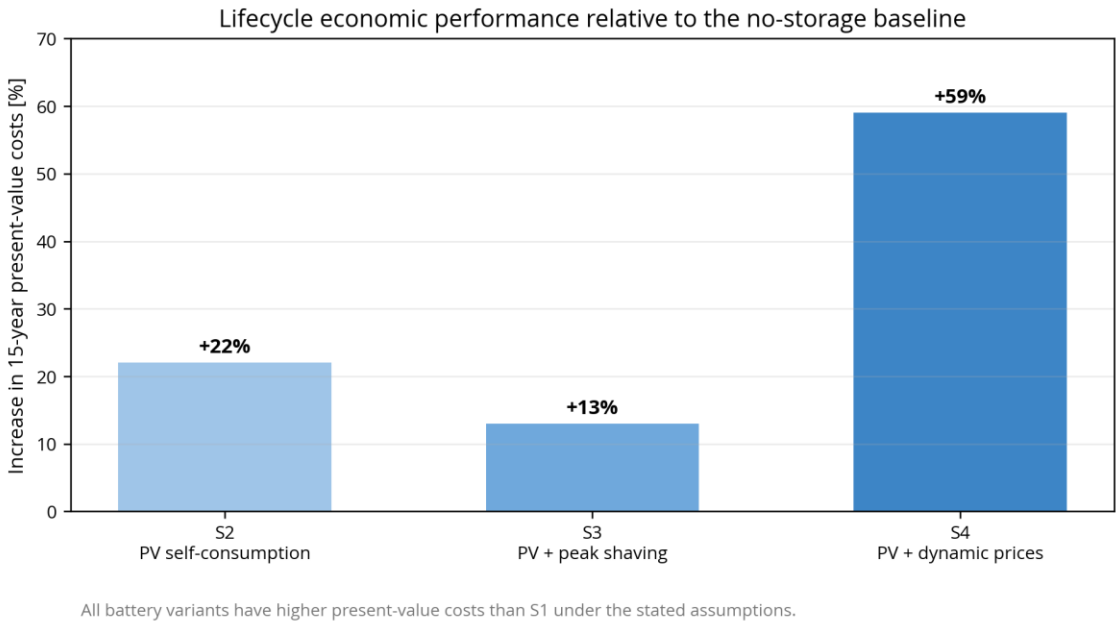

Figure 8: Increase in 15-year present-value costs of the battery scenarios relative to the no-storage case. Source: QuantEEFlex calculations.

Table 6: Technical and operating-cost results for the BF2 battery scenarios

Scenario	Annual cost	Change	PV self-consumption / self-sufficiency
No battery	EUR 30,107	Baseline	13% / 4%
50 kWh - PV optimisation	EUR 29,903	-1%	17% / 5%
50 kWh - PV + peak shaving	EUR 29,619	-2%	17% / 5%
50 kWh - PV + dynamic prices	EUR 30,953	+3%	16% / 4%

Collective PV use: the strongest Austrian result

The second assessment strand widened the usable load boundary. A collective self-consumption scheme behind a common connection increased PV self-consumption from 13% to 62% and self-sufficiency from 4% to 18%. Annual electricity costs fell by approximately EUR 3,223, or 11%. A local renewable energy community achieved the same physical allocation and a 9% cost reduction because some network charges remained.

Adding a 50 kWh battery to the collective scheme increased self-consumption further to 81% and self-sufficiency to 29%, but reduced annual costs by only an additional EUR 485 compared with collective self-consumption without storage. This was insufficient to justify the investment. The finding is central to the project: coordinating heterogeneous demand can solve the same temporal mismatch as storage, without battery investment and conversion losses.

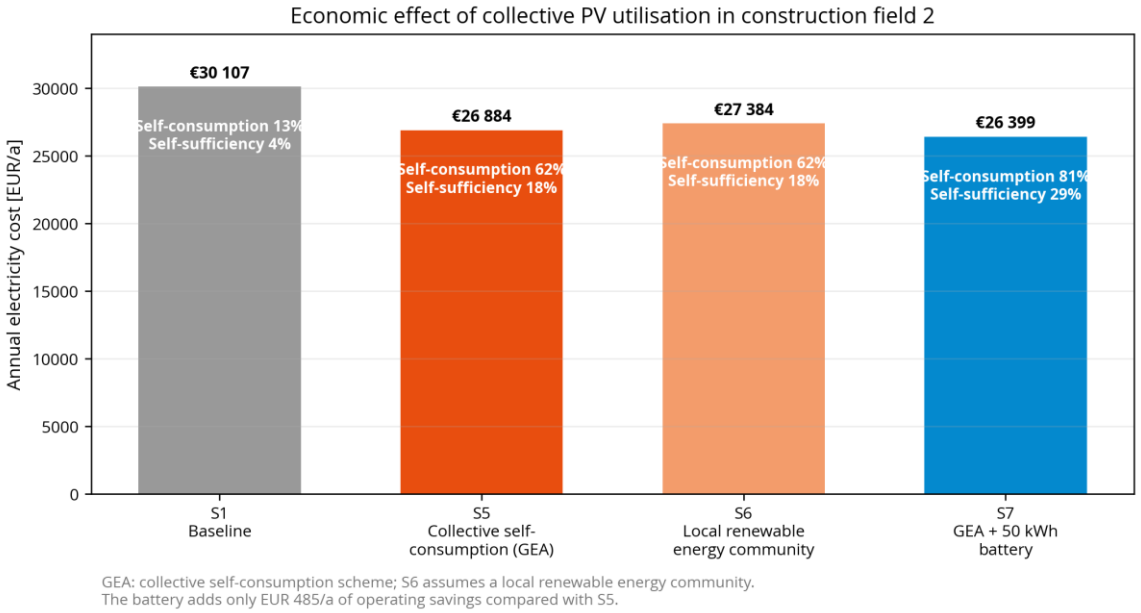

Figure 9: Economic effect of collective PV utilisation in BF2. Source: QuantEEFlex calculations

Table 7: Results of the collective PV-utilisation scenarios

Configuration	Annual cost	Reduction	PV self-consumption / self-sufficiency
Separate metering	EUR 30,107	Baseline	13% / 4%
Collective self-consumption	EUR 26,884	11%	62% / 18%
Local renewable energy community	EUR 27,384	9%	62% / 18%
Collective scheme + 50 kWh battery	EUR 26,399	12%	81% / 29%

Recommendations for implementation

The Living Lab produced a hierarchy of practical decisions. First, preserve the option to share electricity across tenants and technical loads through a suitable connection and metering design. Second, coordinate the location of the high-power charger with the PV, energy centre and connection limit. Third, reserve space, cable routes, communication interfaces and access to measurement data before construction progresses. Fourth, postpone battery procurement until final tenant loads, cooling demand, charging use and operational responsibilities are sufficiently certain.

The developer can implement a collective self-consumption scheme where a common connection is feasible and use a local energy community as a fallback where it is not. A site-wide energy community can be considered in later development stages. Storage should be revisited only where additional value streams - such as resilience, backup supply, a binding connection-capacity limit or a stronger demand charge - can be demonstrated. The most valuable early investment is therefore flexibility-ready infrastructure, not necessarily a battery.

> **Austrian Living Lab lesson**
>
> The system boundary is an economic design variable. Before adding storage, widen the group of loads that can use local generation, clarify metering and contracts, and test whether controllable demand can provide the required flexibility.

5. LIVING LAB TÜRKIYE: ESKIŞEHIR TEPEBAŞI

An operational campus with multiple flexible assets

The Turkish Living Lab is located at the Living Village and Alzheimer's Guest House Campus of Tepebaşı Municipality in Eskişehir. The campus is a socially oriented public environment that combines residences and communal facilities with a substantial smart-energy infrastructure. Its operational status made it possible to analyse grid interaction using real load and PV data while considering the constraints of existing equipment and ownership arrangements.

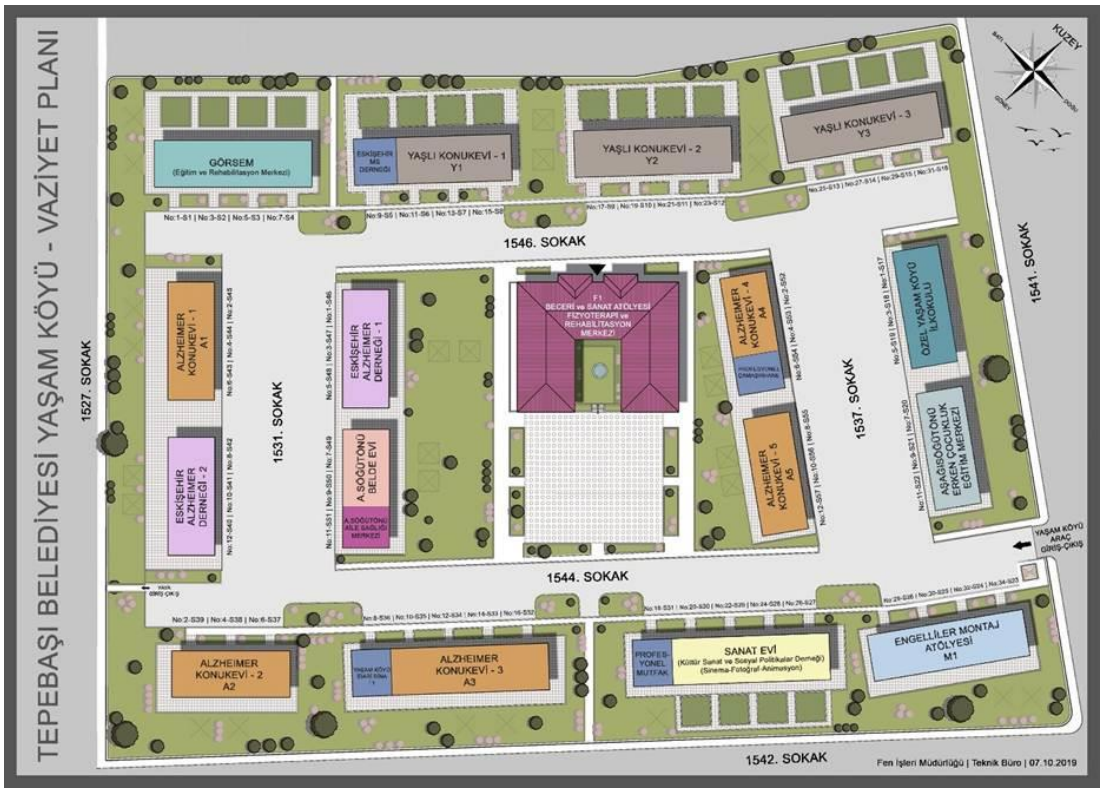

Figure 10: Site layout of the Tepebaşı Living Lab in Eskişehir. Source: OEDAS / QuantEEFlex D3.1

The campus is supplied through a 400 kVA medium-voltage/low-voltage transformer with real-time consumption and power-quality monitoring. Rooftop PV has a total capacity of approximately 150 kW. Two battery systems are available: a larger 336 kWh system capable of off-grid operation and a smaller 32 kWh system that can interact with the charging infrastructure. The site also includes a 50 kW smart-charging-compatible DC charger, a 10 kW V2G-compatible DC charger and centrally managed heat pumps.

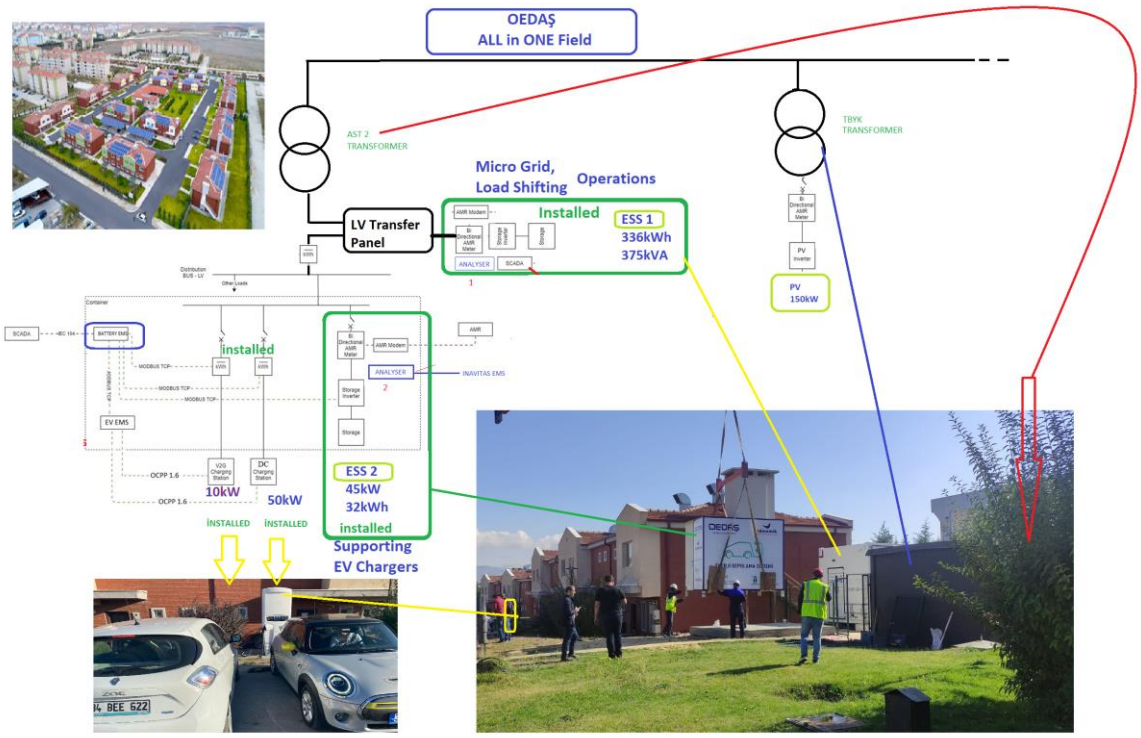

Figure 11: Main energy assets and electrical relationships in the Tepebaşı Living Lab. Source: OEDAS / QuantEEFlex D4.1

Table 8: Main assets in the Turkish Living Lab.

Asset	Key characteristics	Role in QuantEEFlex
Grid connection	400 kVA MV/LV transformer with power analyser	Reference point for grid load, peak demand and power quality
PV generation	Approx. 150 kW rooftop capacity	Local renewable supply and source of surplus for storage
ESS1	336 kWh; up to ±50 kW in the model	Economic energy shifting, peak reduction and strategic scheduling
ESS2	32 kWh; up to ±15 kW in the model	Fast rule-based grid smoothing and protection against short fluctuations
EV charging	50 kW smart charger and 10 kW V2G-compatible charger	Additional flexible demand and future bidirectional use case
Heat pumps	Central remote control with building/room-level functions	Existing controllable thermal demand and wider replication opportunity

Implementation under field constraints

The project initially planned to add advanced metering infrastructure to obtain a more current and complete dataset. Meter ownership, building ownership and administrative constraints prevented this upgrade. The partners therefore adapted the work to the existing monitoring and historical data. This did not prevent the main analysis, but it reinforced a lesson common to both Living Labs: data access and operational responsibility are part of the flexibility system and must be planned as carefully as the controller itself.

The Turkish work used existing load and PV profiles to design an integrated energy-management approach under the country's three-period electricity tariff. The model included energy balances, battery state-of-charge limits, charge/discharge power limits, end-of-day state requirements, switching penalties and cycle constraints. Export from the batteries to the grid was kept closed in

the analysed configuration. These constraints made the solution more representative of safe field operation than an unconstrained cost-minimisation model.

A hybrid control architecture

The central innovation was role differentiation. ESS1 was scheduled with the Cheetah Optimisation Algorithm. It handled slower, energy-intensive tasks: moving PV electricity across the day, reducing purchases during expensive tariff periods and trimming high grid demand. ESS2 was deliberately excluded from the long-horizon optimisation and controlled through rules. It reacted to short power fluctuations and smoothed the grid exchange.

This separation avoided using the smaller battery as if it were simply a scaled-down version of the larger one. A uniform optimiser could force both systems to follow similar charge/discharge patterns, creating unnecessary switching and micro-cycles in ESS2. The hierarchical structure instead matched each battery to the task for which its size and response characteristics were most suitable. It also maintained predictable behaviour when forecasts or communication were imperfect.

Results and operational lessons

The simulations with real Living Lab profiles showed that the combined approach reduced electricity costs, lowered peak demand from the grid and improved the use of local PV generation. The optimised schedule for ESS1 shifted energy away from expensive and high-load periods. The rule-based ESS2 smoothed rapid changes and limited unnecessary cycling. Battery role allocation was therefore as important as total installed capacity.

The Turkish results also broaden the meaning of resilience. Short-term peak reduction is useful, but an energy-management strategy should preserve state-of-charge margins, respect switching constraints and protect battery health over time. The project therefore treated resilience as sustained operational capability rather than a one-off maximum discharge. This perspective is relevant to distribution system operators and municipalities that need reliable, maintainable solutions rather than laboratory-optimal schedules.

The approach provides a reference for further OEDAS applications and for scientific development by SUBU. Future extensions could integrate real-time market signals, direct participation of EV charging, demand response from heat pumps and comparative tests at additional pilot sites. The modular structure makes it possible to retain simple rules for fast local tasks while adding optimisation where the additional value justifies the complexity.

> **Turkish Living Lab lesson**
>
> More capacity is not the only route to more flexibility. Assigning different time scales and responsibilities to available assets can improve PV use, reduce peaks and protect battery health without requiring one complex controller to manage every action.

6. CROSS-CASE FINDINGS THROUGH THE THREE-LAYER MODEL

Technology layer: physical realism and appropriate complexity

The Austrian and Turkish models used different methods because they addressed different system needs. The co-simulation model was designed to capture the feedback between heat-pump schedules and building temperature. The Turkish hierarchy was designed to coordinate batteries with distinct capacities and response requirements. In both cases, physical constraints were recalculated or enforced at every decision step. This prevented the optimisation from treating flexibility as an abstract energy volume detached from equipment state and user requirements.

The cross-case lesson is that model complexity should follow the decision. Detailed dynamic simulation is justified when the current thermal state determines future flexibility. Rule-based control is appropriate for fast, predictable tasks such as smoothing fluctuations. Optimisation is valuable for strategic scheduling across hours. A practical energy-management system can therefore be hybrid: use the simplest robust method for each layer and reserve computational complexity for decisions where it creates measurable value.

Marketplace layer: value depends on the full tariff and boundary

QuantEEFlex showed that flexibility value cannot be inferred from wholesale price spreads alone. The Austrian dynamic-price battery case increased total costs because the control created a higher power peak. The heat-pump analysis similarly found that spot-market savings were diluted by non-energy price components. A realistic business case must include network tariffs, power charges, taxes, losses, export restrictions, transaction costs and investment.

The strongest Austrian business case did not rely on a new flexibility market. It used local sharing to reduce external electricity purchases and network-related costs. This is an implicit market mechanism: participants create value by coordinating generation and demand behind or across meters. The Turkish case used a time-of-use tariff and peak reduction. Both demonstrate that existing retail and network structures can provide signals for flexibility, but those signals must be modelled in full.

Stakeholder and adoption layer: integration is the main implementation task

At Werk Möllersdorf, many decisive questions belonged to no single technology provider. The developer, electrical planner, energy-system planner, DSO, future operator, billing service and tenants all influence the solution. A common connection may improve energy sharing but change tenant contracts. A charger can improve PV use but create a connection peak. A battery may be technically beneficial but require an operator and maintenance concept. The Living Lab therefore needed a coordination function that translated the district-level objective into requirements for each discipline.

In Türkiye, the operational boundary was shaped by equipment access, meter ownership, municipal responsibilities and DSO data. The inability to install new advanced meters did not invalidate the project, but it limited the available evidence and required adaptation. Replication should therefore begin with a stakeholder and data-access map before algorithms are selected. An energy or flexibility coordinator can maintain shared assumptions, document changes and ensure that technical decisions are communicated across organisational boundaries.

Table 9: Cross-case comparison of the Austrian and Turkish Living Labs.

Question	Austria	Türkiye	Shared conclusion
Where does flexibility come from?	Building thermal mass, PV, charging, batteries and pooled demand	PV, two batteries, EV charging and grid interaction	Flexibility is a portfolio property, not a single-device feature
What created most value?	Collective PV use across a wider load boundary	Role separation between strategic storage and fast smoothing	System architecture can matter more than capacity
What limited implementation?	Changing plans, metering, tariffs, export limits and responsibilities	Data access, ownership constraints and existing equipment interfaces	Institutional and data constraints are part of the technical system
What should be replicated?	Staged planning and robust business-case assessment	Hierarchical hybrid control and role-based asset management	Match control complexity to the task and implementation environment

7. REPLICATION, EXPLOITATION AND IMPACT

Flexibility planning tool

The main Austrian exploitable result is a planning workflow that links physical building simulation, economic optimisation and implementation assessment. It can screen whether heat-pump flexibility is meaningful under a given price profile and comfort requirement, and it can be extended to PV, batteries, EVs, cooling and peak-power objectives. The tool is not a one-click forecast. Its value lies in making assumptions transparent, comparing scenarios and revealing unintended effects before investment or commissioning.

The workflow is already being transferred into consultancy assignments on battery sizing, collective self-consumption and energy-community concepts. It also informs an Austrian flagship project, which addresses interoperable aggregation and control of distributed flexibility. These follow-up activities move the model from a project-specific study towards a repeatable planning service.

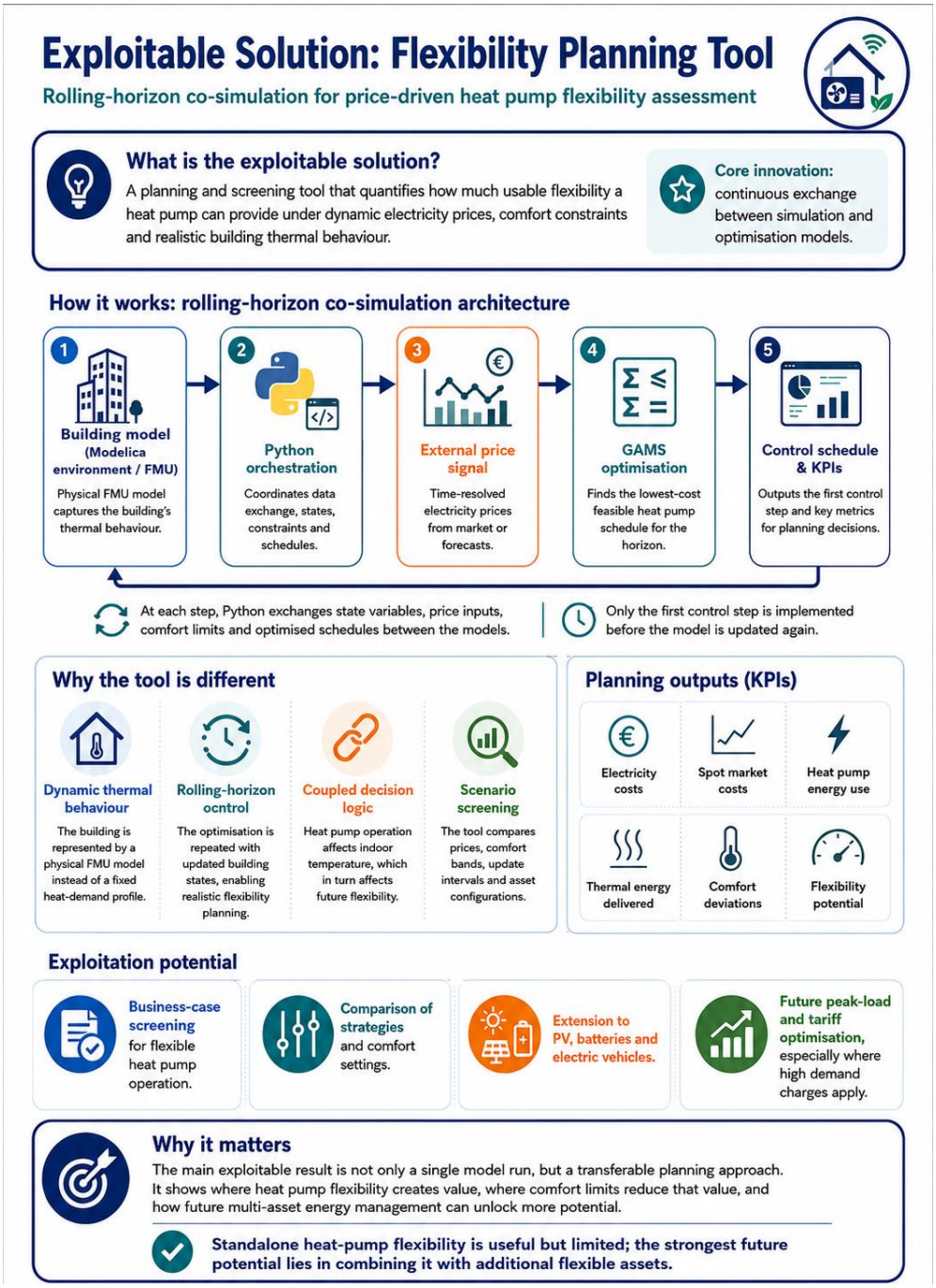

Figure 13: Factsheet of the QuantEEFlex flexibility planning tool. Source: QuantEEFlex D5.2.

Grid-management algorithms

The Turkish exploitable result is a modular energy-resilience management approach that combines optimisation with rule-based control. OEDAS can use the role-based architecture as a reference when assessing PV, storage and charging applications in other parts of its grid area. SUBU will continue developing the optimisation method in scientific work, teaching and future proposals. The approach is particularly suitable where equipment differs in capacity, response speed or available communication and where a uniform optimiser would be difficult to maintain.

A staged replication pathway

Table 10: Recommended staged replication process

Stage	Decision focus	Recommended output
1. Screening	Identify generation, demand, flexible assets, grid constraints and stakeholders	System boundary, data inventory and shortlist of use cases
2. Concept design	Compare metering, energy-sharing, tariff and control architectures	Scenario ranges and flexibility-ready infrastructure requirements
3. Detailed design	Update profiles and size equipment once assumptions stabilise	Controller specification, business case and responsibility matrix
4. Commissioning	Verify interfaces, metering and safe operating limits	Test protocol, baseline and accepted control parameters
5. Operation	Use measured data to validate and improve performance	Monitoring dashboard, periodic recalibration and evidence for replication

This sequence distinguishes irreversible infrastructure choices from equipment decisions that can be postponed. Metering space, cable routes, data interfaces, controllability and a suitable connection architecture may be expensive to retrofit. The final capacity of a battery or the exact optimisation parameters can often be decided later. Preserving options early reduces lock-in while avoiding premature investment.

Contribution to sustainability

The project contributes to ecological sustainability by enabling higher use of local renewable electricity and by identifying where additional equipment would not deliver sufficient value. At Werk Möllersdorf, collective PV use increased self-sufficiency by 14 percentage points and substantially reduced external electricity purchases. Avoiding an underutilised battery also avoids material, installation and replacement impacts that would not be justified by the operating benefit. The heat-pump model showed how existing building mass can provide flexibility without additional stationary storage, provided that comfort and energy consumption are controlled.

Economic sustainability was addressed directly. The Austrian collective self-consumption case reached the proposal's 10-15% target range for cost reduction, while the detailed battery analysis prevented a weak investment case from being presented as a universal solution. The Turkish approach reduced peaks and electricity costs through improved operation of existing assets. Social and organisational sustainability were supported through Living Lab engagement, transparent decision support and the Tepebaşı campus context, where smart-energy infrastructure serves a public facility for older and vulnerable users.

A comprehensive quantified life-cycle and carbon assessment was not completed after the Romanian workstream was removed. The project therefore reports energy, self-sufficiency, peak and cost effects rather than claiming a uniform carbon-reduction figure across both sites. Future replication should add location-specific marginal-emission signals and life-cycle data where these are decision-relevant.

8. CONCLUSIONS AND OUTLOOK

Main conclusions

QuantEEFlex confirms that urban districts can provide useful demand-side flexibility, but the economic value is usually more modest and more context-dependent than technical potential alone suggests. Heat-pump operation can be shifted in response to electricity prices, yet the benefit is constrained by comfort and may be offset by additional energy use. Battery storage can reduce peaks or increase self-consumption, but profitability depends on the usable load boundary, seasonal demand, tariffs, export rules and investment costs. Local sharing can be more effective than storage because it matches generation with heterogeneous demand before conversion losses and capital expenditure are incurred.

The transnational comparison also shows that there is no universal best control method. Detailed co-simulation is valuable where the state of a building determines future flexibility. Mathematical optimisation is useful for strategic scheduling. Rule-based control is effective for fast, transparent and safety-critical tasks. Hybrid architectures can combine these strengths. The correct level of complexity depends on the decision horizon, equipment roles, data quality and operational capacity of the organisation that will maintain the system.

Recommendations for decision-makers

1. Begin with the system boundary. Identify which generation and loads can actually be coordinated before sizing a battery or selecting a controller.
2. Assess complete electricity costs. Include power charges, network tariffs, taxes, export constraints, losses and transaction costs, not only spot-market prices.
3. Treat comfort and battery health as core performance indicators. Cost savings are not valid if they rely on unacceptable temperatures or damaging cycling.
4. Preserve flexibility-ready infrastructure early. Metering space, cable routes, data access and controllable interfaces are difficult to retrofit.
5. Use staged investment. Implement low-cost organisational and demand-side measures first, and procure storage only when additional value streams are demonstrated.
6. Match control complexity to the task. Combine optimisation for strategic decisions with simple rules for fast local responses where appropriate.
7. Keep models iterative. Update assumptions as tenants, mobility, cooling, tariffs and grid conditions evolve, and validate with measured data after commissioning.

Next research and implementation steps

Future work should extend the Austrian co-simulation to coordinated multi-asset operation. Combining heat pumps with PV, batteries, EV charging and peak-load objectives may unlock value that is not available to a standalone heat pump. Forecast modules for weather, occupancy, PV and charging could be integrated, while simplified control rules or machine-learning surrogates could translate detailed optimisation into practical building-management systems. Cooling and larger low-temperature networks are particularly relevant for year-round flexibility.

In Türkiye, the next step is wider validation across additional feeders or campuses, with improved advanced metering and real-time market or tariff signals. Direct integration of EV charging and V2G can test how mobility interacts with the battery hierarchy. Comparative field trials can

establish when the optimisation layer justifies its complexity and how much grid-smoothing value can be delivered without shortening battery life.

For both countries, successful scale-up will depend on clearer responsibilities and repeatable implementation procedures. Developers, DSOs, planners, equipment suppliers, operators and billing services need a shared process for defining system boundaries, exchanging data and assigning control rights. Standardised assessment tools and interfaces can reduce transaction costs, but they should support transparent local adaptation rather than hide critical assumptions.

> **Final message**
>
> Flexibility is most valuable when it is planned as a property of the whole district energy system. The project's strongest results came from coordinating assets, users, meters, tariffs and responsibilities - not from maximising the operation of one device in isolation.

Project partners

Table 11: Final QuantEEFlex consortium and responsibilities

Organisation	Role in QuantEEFlex
e7 energy innovation & engineering, Austria	Project coordination; district energy modelling; Austrian Living Lab; economic assessment; replication and dissemination
Sakarya University of Applied Sciences (SUBU), Türkiye	Scientific quality assurance; optimisation methods; Turkish model development; scientific replication
Osmangazi Elektrik Dağıtım A.Ş. (OEDAS), Türkiye	Distribution-system expertise; Tepebaşı Living Lab; operational data, equipment context and replication within the DSO environment

Project website: QuantEEFlex project website

ERA-Net Smart Energy Systems: ERA-Net Smart Energy Systems website