SYSTEMIC IMPACT ASSESSMENT

RESIDENTIAL ENERGY MANAGEMENT SYSTEM

podero

As the first European venture capital fund, Planet A relies on its own scientific team to assess the environmental and climate impact of an innovation. Prior to an investment, a systemic impact assessment, like this one, is conducted and integral part of the investment decision. All assessments as well as the methodology are published for maximum transparency.

About Podero

Podero is a Vienna-based company offering a clean energy platform that unlocks new revenue streams for utilities. Their software enables utilities to synchronise consumer devices — such as heat pumps, electric vehicles, and battery storage systems — with electricity markets and backend software systems. This integration allows for the automatic management of device fleets, steering them in line with trading signals and seamlessly connecting to utility apps, backend systems, trading platforms, and customer support tools. By optimising energy consumption in response to market dynamics, Podero helps utilities lower electricity procurement costs, improve energy efficiency, and offer consumers more competitive electricity tariffs.

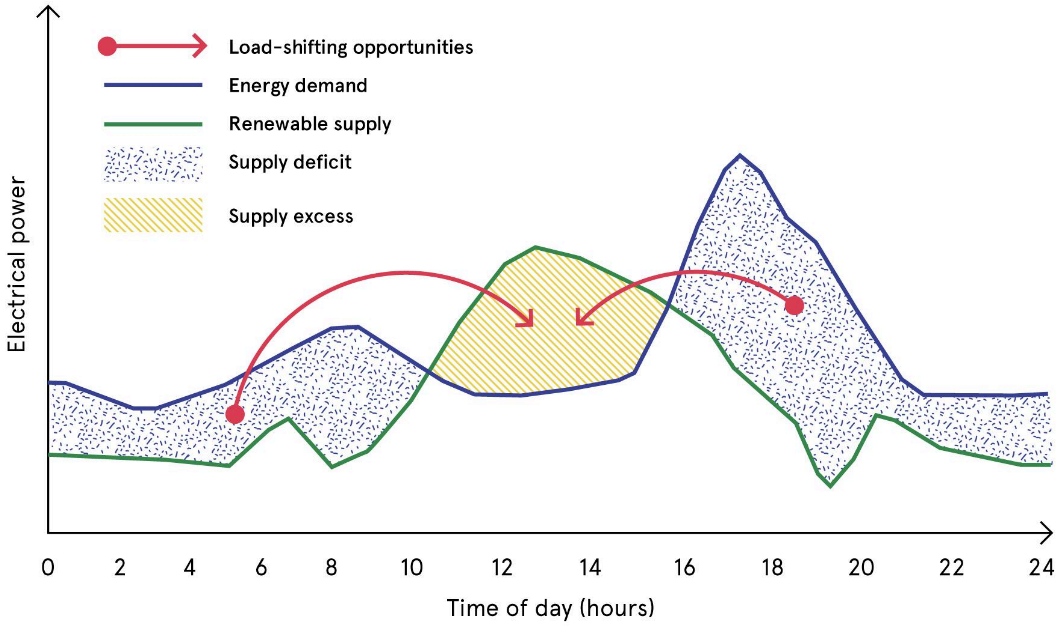
About this study

This study examines the systemic role of demand-side flexibility (DSF) in accelerating the energy transition. It explores the key challenges of balancing renewable energy supply with fluctuating demand and highlights the potential of residential, decentralised energy resources (DERs) to increase grid flexibility. Drawing on scientific research and case studies, the report outlines the environmental and economic benefits of DSF — including lower emissions, reduced energy costs, and decreased reliance on fossil fuels and large-scale storage. It also demonstrates how Podero's innovative energy management solutions enable utilities to fully leverage DSF, paving the way for a more efficient and sustainable energy system.

Table of content

1. The challenge: Transforming the energy system

The energy transition is a cornerstone of global efforts to combat climate change and reduce other negative impacts of our economic system. It demands the widespread deployment of sustainable, non-fossil energy technologies, along with new and modernised grid infrastructure, energy storage solutions, sector electrification, and both demand- and supply-side management. Achieving this transition also requires improvements in energy efficiency, the development of new energy markets, supportive policy and regulatory frameworks, and strong public engagement.



In 2024, renewables accounted for more than half of European power generation and by 2030 they are expected to constitute about 66% of the EU's electricity generation. Renewable energy production fluctuates with weather conditions, creating imbalances between supply and demand (see graph). To counteract this, more flexibility is needed in the grid, allowing a better alignment of supply and demand, for instance through load shifting and peak shaving. The European Commission projects a substantial rise in flexibility requirements across the EU electricity system, increasing from 11% in 2021 to 24% (288 TWh) of total electricity demand by 2030 and further to 30% (2,189 TWh) by 2050 (EU 2023). Matching supply and demand is key to the success of the energy transition.

2. The Solution

The transition to a low-carbon energy system hinges on optimizing both energy supply and demand. Residential decentralized energy resources (DERs) - including EV batteries, heat pumps, and home energy storage systems - can significantly reduce reliance on peak-load fossil fuel power plants, substations, and large-scale storage systems. By leveraging these assets for demand-side flexibility (DSF), emissions, grid strain, and energy costs can be substantially reduced. To fully unlock DSF and its economic and environmental benefits, several key infrastructure and policy enablers must be in place:

1. *Accelerated Smart Meter Rollout* – Essential for real-time monitoring and flexibility optimization.
2. *Dynamic Pricing Adoption* – Prevents inflexible demand spikes, stabilizes price spreads, and mitigates negative electricity pricing.
3. *Dynamic Grid Fees* – Ensures grid stability is prioritized in demand-side optimization, counteracting excessive EV charging during renewable overproduction periods.
4. *Digital Grid Infrastructure* – Capable of detecting real-time grid loads and enabling smarter energy management.
5. *Grid Expansion & Interconnection* – High flexibility requires intra- and inter-country grid expansions to ensure energy can be redistributed effectively.
6. *Bidirectional Energy Flow Infrastructure* – EVs, home storage systems, and transformers must support bidirectional energy flow to maximize grid integration.
7. *Targeted Load Segmentation* – Certain end-uses, such as heat pumps, should be managed separately to optimize their contribution to grid stability.
8. *Comprehensive Home Energy Management Systems (HEMS)* – HEMS act as the digital link between aggregators, customer energy systems, and smart meters, ensuring user preferences are integrated into flexibility strategies.

2.1. Environmental and economic impact of flexibilization

Grid flexibility is a critical component of the energy transition. However, the level of flexibility required depends on factors such as cost, market design, technological progress (in energy supply, storage, and grid infrastructure), as well as planning and policy support. These parameters determine the extent of flexibility needed — and, in turn, are themselves shaped by the degree of flexibility achieved. All these elements are closely interconnected. As a result, the environmental and economic impacts of grid flexibility are typically assessed using complex energy system models.

2.1.1. Energy system models

Energy system models are tools used to analyze and predict the future needs of energy systems, including the demand for grid flexibilization. These models simulate how energy systems evolve under different scenarios, taking into account factors like the growing share of renewable energy, electrification of sectors, and energy demand changes. By incorporating data on electricity generation, consumption, storage, and transmission, they assess the system's ability to adapt to variability and ensure balance. They also identify future requirements for flexibility solutions, such as energy storage, demand response, and sector coupling, to maintain stability and efficiency in decarbonized energy systems.

These models rely on a combination of exogenous variables and endogenous variables to simulate future energy needs and grid flexibilization. Exogenous variables are inputs determined outside the model, such as policy targets, population growth, technological advancements, and fuel price projections. These variables set the context for the analysis and define boundary conditions. On the other hand, endogenous variables are calculated within the model, based on its logic and assumptions. These include electricity generation, grid investments, storage deployment, and demand response behavior, all of which are optimized to meet system constraints and objectives.

The results of these models depend both on external parameters and on the structure of the models themselves. As such, they represent simulations of future scenarios, reflecting assumptions about how external factors will evolve and the model's ability to capture real-world dynamics accurately. By necessity, these models simplify the complex realities of the energy system, which is itself deeply interconnected with the broader economy, human society, and the environment. Despite these limitations, energy models offer valuable insights into potential future developments. In the following section, we summarise key findings from such models regarding the environmental impacts and economic implications of grid flexibility.

2.1.2. Review of scientific studies on the environmental impacts and economic implications of grid flexibility

Study 1: Godron et al. (2024) – Haushaltsnahe Flexibilitäten nutzen

- *Objective*: The study examines the effects of different electricity tariff structures on the operation of household flexibility options (electric vehicles, heat pumps, and home storage) in Germany and assesses the potential of these flexibilities to balance supply and demand.

- *Method:* The study models the behaviour of households aiming to minimize their electricity costs under four different price scenarios. This involves calculating quarter-hourly and household-specific load curves and the amount of flexibility achieved. The resulting load curves are used in a load flow simulation of German low-voltage networks, using representative network models to quantify grid expansion needs for the different scenarios. The resulting grid costs are then compared with the costs of alternative, generation-side flexibility options. The study focuses on the years 2029 and 2035. Twelve representative network topologies were created to model the German distribution grid. The study prioritizes single and two-family homes, which are easier to integrate into the system.

- *Outcomes*: The study shows that household flexibility can efficiently balance supply and demand, reducing emissions, the need for government subsidies and ultimately electricity prices. Additionally, required grid expansion is reduced by 45%. These efficiency gains could potentially reduce household electricity costs by up to 600€ per year.

Study 2: Ackermann et al. (2024) – Cost-benefit analysis and comparison of grid-stabilizing energy flexibility options

- *Objective*: The authors conduct a cost-benefit analysis and comparison of different energy flexibility options and their applications in the German energy system, identifying the most attractive options from a system perspective.
- *Method*: The study performs a quantitative analysis, matching various flexibility options (e.g., household flexibilization, CHP flexibilization, wind/PV flexibilization, batteries) with different flexibility applications. A cost-benefit index (CBI) is calculated for each match to determine its attractiveness for 2019 and 2030. The analysis is based on the German energy system and uses data from flexibility applications currently deployed in Germany. The study considers an existing and a future scenario.
- *Outcomes*: The study reveals that household flexibilization is one of the most economically viable options:
    - Flexibilization of existing CHP plants is identified as a particularly attractive option due to its low costs. This is because only heat storage upgrades are needed.
    - In 2030, “household flexibilisation - small scale heat pumps” exhibits the highest cost benefit among all compared options.
    - In the future, only 3 options provide a positive cost benefit: Household flexibilization - small heat pumps, CHP, and household flexibilization - controlled charging (ordered by cost benefit).
    - Large-scale batteries and PEM electrolysis, as well as controlled charging, will become increasingly beneficial in the future.
    - Power-to-methane is the worst-performing flexibility option due to the additional effort required from the system.

Study 3: European Environmental Agency (2023) – Flexibility solutions to support a decarbonised and secure EU electricity system

- *Objective*: To analyse flexibility needs for demand savings and shifting, with changes in daily, weekly, and seasonal flexibility
- *Method*: The study uses hourly generation and demand data from the ENTSO-E transparency platform as well as data from policy scenarios for delivering the European Green Deal, and historical hourly profiles.

- *Outcomes*:
  - Until 2030, excess supply of energy from renewables could increase to 118 TWh per year — this is equivalent to the annual generation of 19 baseload thermal power plants.
  - Deficits of energy supply from renewable sources will become an increasingly important topic in the future.
  - The daily, weekly and seasonal flexibility needs might reach 362, 242 and 168 TWh per year in 2030, respectively.
  - Flexibilization (peak electricity demand shifting of 5%) and electricity demand reductions of 10% during non-peak-demand hours result in an annual demand saving of 7% (231 TWh) across Europe in 2030. This furthermore reduces daily, weekly and annual flexibility needs of 7%, 9% and 12%, respectively.
  - Flexibility needs will increase even further: By 2050, flexibility needs will triple compared to 2030.
  - Flexible energy consumption of households will enable consumers to profit financially from variable electricity prices.

Study 4: Nagel et al. (2022) – The economic competitiveness of flexibility options

- *Objective*: The study analyzes the economic competitiveness of various flexibility options in the European energy transition, focusing on how profits for flexibility suppliers are affected by climate targets and competition.
- *Method*: The study uses the BALMOREL model to simulate a 2030 energy system. It compares scenarios where different flexibility options (transmission, electricity storage, heat storage, demand response (DR), power-to-heat (PtH), EV smart charging, and supply-side flexibility) are individually restricted, to a baseline scenario with full flexibility. Each scenario is run with different GHG emission reduction targets. The model includes an hourly temporal resolution and represents spatial detail at different hierarchical levels.
- *Outcomes*: Flexibility reduces systemic costs.
  - Introducing flexibility to the energy system could reduce system costs by 60% in a 95% GHG emission scenario.
  - Investments in transmission and sector coupling with the district heat sector are the biggest levers to reduce system costs.
  - In case of lower GHG emission reduction scenarios, demand side management (incl. household flexibility) is the most effective tool to reduce systemic costs.

Study 5: Seljom et al. (2024) – The effect and value of end-use flexibility

- *Objective*: The study analyses the role and value of end-use flexibility in the low-carbon transition of the Norwegian energy system and quantifies how flexibility in buildings interacts with the wider energy system.

- *Method*: The study uses an energy system optimisation model with a detailed representation of end-use. A stochastic modelling approach is used to capture the uncertainty of future European electricity prices. The study compares results from stochastic and deterministic models. It analyses the impact of end-use flexibility on investments, operations, costs, and revenues for different parts of the energy system. The study uses two storylines, "Energy Nation" and "Nature Nation", both with and without end-use flexibility options.

- *Outcomes*: End-use flexibility lowers the need for other flexible solutions in the energy system and reduces the costs of the energy transition.
    - The implementation of end-use flexibility lowers the total cost of the energy transition in Norway until 2050 by 4.4 to 8.3 billion €.
    - End-use flexibility reduces the need for hydrogen and thermal storage and offshore wind power generation. E.g., the need for hydrogen is reduced by 25 to 66%.
    - End-use flexibility lowers the peak load between 5 and 11% in winter..

Study 6: Sáez Armenteros et al. (2022) – 2030 Demand-Side Flexibility. Quantification of benefits in the EU

- *Objective*: To assess the potential benefits of demand-side flexibility (DSF) to the European power system in 2030, assuming DSF can access all markets.

- *Method*: The study combines industry insights and public data to model the European power market, using DNV's European Market Model. The model simulates the day-ahead spot price by optimising the unit commitment and economic dispatch of electricity generation in two scenarios: one with and one without DSF. The model simulations are done on an hourly time-resolution and include a detailed representation of generation, commodity prices and demand. Additional calculations are done outside the model to assess benefits related to adequacy, balancing and grid infrastructure.

- *Outcomes*: The implementation of demand side flexibility enables an upward flexibility of 397 TWh and a downward flexibility of 340.5 TWh in 2030. This entails high economic and environmental benefits
    - The economic net benefits of DSF are enormous: The study suggests that in the absence of DSF, additional generation assets would be needed, which would increase the cost of the system by 4.6 billion €. Additional costs to serve loads amount to 301.5 billion € if no DSF is implemented. If no DSF is implemented, curtailment of a load of 15.5 TWh might be needed, associated with a total financial loss of 9 billion €.

- The total net benefit in terms of GHG emissions is a reduction in GHG emissions of 37.5 million t CO_2-eq.

- The study notes that there is a lack of data on the infrastructure benefits of DSF, and that there is very little existing literature on this topic.

Study 7: Sousa et al. (2024) – The role of storage and flexibility in the energy transition: Substitution effect of resources with application to the Portuguese electricity system

- *Objective*: To evaluate the extent to which new electricity resources will complement or substitute each other in integrating non-dispatchable electricity generation in the Portuguese electricity system for the 2030 horizon.

- *Method*: The study uses the SWHORD simulator, which incorporates electric vehicles, storage, and hydrogen systems. It evaluates the coherence of the targets outlined in the Portuguese National Energy and Climate Plan (NECP) 2030. The energy system is modelled on an hourly basis. The analysis includes scenarios with and without hydrogen, with lower electric vehicle targets, and with and without battery storage. The study focuses on the electricity system operational outcomes.

- *Outcomes*: DSF is key to achieving targets set in the NECP.

While a direct comparison of qualitative results of reviewed studies is impossible because of differences in models, input data, geographical and temporal scope, quantitative conclusions can be drawn:

- More curtailment: If supply and demand are not adequately matched, supply from intermittent renewable energy sources might need to be curtailed.

- Higher fossil fuel demand: In times of high demand and low supply of energy from renewables, energy supply from fossil fuels is likely to match the demand if the demand cannot be met by stored energy.

- Higher demand for other energy storage: The greater the mismatch between supply and demand, the greater the need for storage capacities. This entails higher costs and environmental impacts than shifting demand.

- Higher demand on grid infrastructure: A higher peak load in the grid requires adequate grid infrastructure.

- Higher costs: All of the aforementioned aspects result in higher systemic and individual costs. Consumers and prosumers both pay a higher electricity price if they rely on static energy prices and do not profit from fluctuating electricity prices.

- Higher environmental impacts: All the aforementioned systemic inefficiencies result in higher GHG emissions and slower transformation in the energy system. Additional capacities, e.g. grid and storage, require resources and materials that need to be manufactured. This entails additional environmental impacts that can be prevented by implementing DSF.

In conclusion, fully unlocking the potential of demand-side flexibility is essential for a sustainable and efficient transformation of the energy system.

3. How Podero unlocks DSF for a Sustainable Energy Future

Podero offers enterprise-grade software that enables utilities to control, optimize, and monetize their customers' energy assets for grid stabilization and energy trading. Their proprietary steering algorithms and API integrations with home energy systems facilitate real-time energy management, helping utilities turn volatility into a profitability opportunity while benefiting both prosumers (producer-consumers) and consumers. Podero's core functionalities enable:

1. *Energy Trading* – Optimizing energy flows for price arbitrage and peak demand reduction.
2. *Home Energy Management* – Enabling greater efficiency through automated load shifting of household electricity consumers, e.g. heat pumps, electric vehicle chargers and air conditioning.
3. *Grid Stabilization* – Balancing supply and demand to reduce system inefficiencies and reliance on fossil-based peak generation.

By flexibilizing supply and demand through digitalization and dynamic pricing, Podero helps drive systemic efficiency and reduce environmental impact. Based on the reviewed literature, the key benefits of Podero include:

1. *Lower Renewable Energy Curtailment* – Improved demand-side flexibility reduces wasted renewable energy.
2. *Reduced Reliance on Fossil Fuel-Based Peak Power Plants* – Less need for polluting backup generation.
3. *Decreased Demand for Large-Scale Energy Storage* – Optimized energy use reduces the need for resource-intensive storage deployment, e.g. batteries.
4. *Lower Electricity Costs for All* – By stabilizing the grid and optimizing energy flows, consumers and prosumers benefit from reduced systemic costs.
5. *Reduction of Systemic Inefficiencies* – Preventing unnecessary overproduction, surplus capacity, and high fossil-based power demand.

By reducing grid congestion, Podero's solution lowers pressure on grid expansion, mitigating the environmental impact of extensive infrastructure development. Additionally, Podero enhances grid flexibility, reducing renewable energy curtailment and making renewable power plant operations more profitable. This, in turn, incentivizes further renewable energy deployment, accelerating grid decarbonization and driving a more sustainable and resilient energy sector. By lowering the cost of electricity for all consumers, Podero contributes to an equitable energy transition, making clean energy more accessible and affordable.

4. Conclusion

The energy transition calls for innovative solutions to tackle the challenges of grid flexibility, renewable energy integration, and cost optimisation. Demand-side flexibility (DSF) stands out as a critical enabler, helping to balance supply and demand, reduce systemic inefficiencies, and lower both the environmental and economic costs of the transition. The studies reviewed underscore DSF's transformative potential to cut dependence on fossil fuels, minimise renewable energy curtailment, and reduce the need for large-scale infrastructure investments.

Podero's advanced software solutions position the company as a key enabler in realising the full potential of DSF. Through smart algorithms, real-time energy management, and seamless integration with home energy systems, Podero empowers utilities to turn grid volatility into opportunities for efficiency and profitability. Their approach not only supports grid stability but also helps make clean energy more accessible and affordable, driving a fair and sustainable energy future.

In alignment with the EU Taxonomy, Podero's solutions contribute to building a climate-neutral energy system by cutting greenhouse gas emissions, advancing renewable energy integration, and optimising energy flows. Podero thus plays an essential role in the systemic transformation needed to achieve a resilient, decarbonised energy sector.

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