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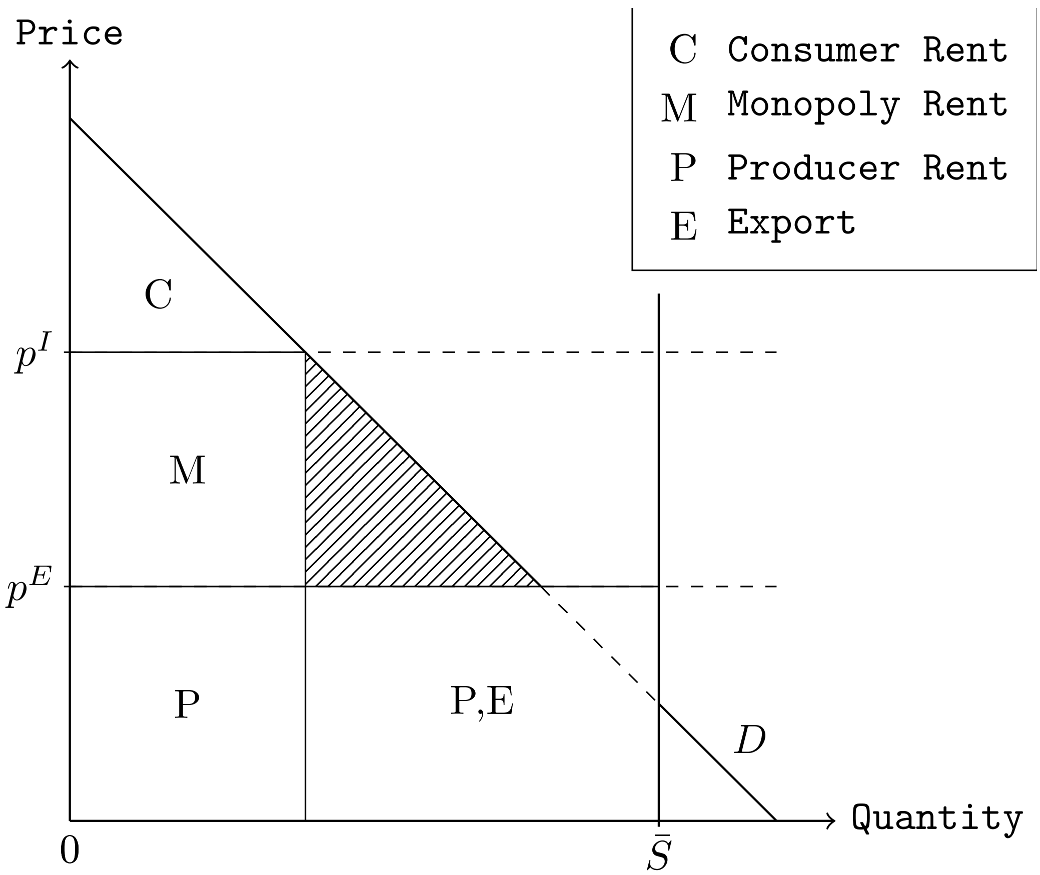
Interim report dated 31.10.2023

Charting energy platforms and market outcomes under varying policy measures



Source: Authors' model. Distribution of rents in a local energy market between consumers, producers, and a monopolistic platform with p^I as import electricity price and p^E as export electricity price and high exogenous supply.

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Zusammenfassung

Das Projekt befasst sich mit der Entwicklung einer simulationsbasierten Grundlage für die Regulierung von lokalen Energiemärkten. Ziel ist es, die Dynamik dieses neuen Markttyps unter verschiedenen regulatorischen Rahmenbedingungen zu analysieren und den Regulierungsbehörden eine "Kartographie" von möglichem volkswirtschaftlich schädlichen Verhalten der Marktteilnehmer und insbesondere Marktmachtmissbrauchs zur Verfügung zu stellen. Ein Schwerpunkt liegt dabei auf der Verknüpfung der ökonomischen Theorie von Energieplattformen mit wettbewerbspolitischen Erfahrungen im Bereich digitaler Plattformen sowie Modellen für mehrseitige Märkte.

Im ersten Projektjahr wurden die Grundlagen geschaffen, um die mögliche Ausübung von Marktmacht durch Akteure in diesem neuartigen Marktumfeld zu analysieren. Dies beinhaltet insbesondere:

- die Evaluierung bestehender Energieplattformen,
- die Charakterisierung von potenziellem Missbrauch von Marktmacht anhand der Erfahrungen mit digitalen Plattformen,
- die Ökonomie von Plattform- und dezentralen Märkten,
- die Entwicklung eines simplen ökonomischen Modellrahmens der wichtigsten Charakteristika von Energieplattformen, sowie
- eine erste Exploration von Daten einer existierenden Energieplattform.

In der aktuellen Phase konzentrieren wir uns nun auf die Entwicklung eines detaillierteren ökonomischen Modells, welches die Analyse der Akteure auf diesen neuen Markttypen ermöglicht.

Résumé

Le projet s'attache à élaborer une fondation basée sur la simulation pour la régulation des marchés locaux de l'énergie. Son objectif principal consiste à analyser la dynamique de ce nouveau type de marché sous différentes contraintes réglementaires. Il a pour but de mettre à disposition aux autorités de régulation une "cartographie" des comportements potentiellement préjudiciables pour l'économie nationale, en mettant particulièrement l'accent sur les abus de pouvoir de marché. Cette analyse se base sur la théorie économique des marchés locaux de l'énergie et s'appuie sur l'expérience acquise dans la régulation des marchés de plateformes, ainsi que sur les modèles de marchés multilatéraux.

Au cours de la première année du projet, nous avons posé les fondations nécessaires pour analyser la possible exploitation d'un pouvoir de marché par les acteurs impliqués. Cela a inclus:

- l'évaluation des plateformes énergétiques existantes,
- la caractérisation des abus potentiels de pouvoir de marché en se basant sur les enseignements tirés des plateformes en ligne,
- l'étude de l'économie des marchés des plateformes et des marchés décentralisés,
- le développement d'un cadre de modélisation économique simple des principales caractéristiques des marchés locaux de l'énergie, et
- une première exploration des données provenant d'une plateforme énergétique existante.

À présent, nous concentrons nos efforts sur le développement d'un modèle économique plus détaillé, qui nous permettra d'analyser les acteurs de ces nouveaux types de marchés de manière approfondie.

Summary

The project deals with the development of a simulation-based foundation for the regulation of local energy markets. The aim is to analyze the dynamics of this new market type under different regulatory frameworks and provide regulators with a "cartography" of possible economically harmful behavior of market participants, particularly the abuse of market power. A focus lies on linking the economic theory of energy platforms with competition policy experience with digital platforms and models of multi-sided markets.

In the project's first year, the groundwork has been laid for analyzing the potential exercise of market power by actors in this novel market environment. This includes:

- the evaluation of existing energy platforms,
- the characterization of potential abuses of market power based on experience with digital platforms,
- the economics of platform and decentralized markets,
- the development of a simple economic model framework of the key characteristics of energy platforms, and
- a first exploration of data from an existing energy platform.

In the current phase, we are now focusing on developing a more detailed economic model to analyze the actors in these new market types.

Contents

Abbreviations

LEM	Local Energy Market
SCC	Self-Consumption Community
DER	Distributed Energy Resources
P2P	Peer-to-Peer
PF-M	Platform-mediated
BMG	Brooklyn Microgrid
LIC	Lugaggia Innovation Community
SDR	Supply-Demand Ratio

1 Introduction

1.1 Background information and current situation

As of 2023, a number of energy trading platforms have emerged, such as Power Peers (NL), Sonnen Community (D) or the Lugaggia Innovation Community (CH). Such platforms allow individual participants (such as private households or local energy producers) to engage in active energy trading among each other. Thus, energy trading platforms align with the current push for local and decentralized energy generation. In digital markets, the emergence of platforms such as Amazon, Google, or Airbnb has had a profound impact. The emergence of energy platforms and decentralized energy production, such as in Self-Consumption Communities (SCCs) or local energy markets (LEMs), suggests that a similar transition is underway in energy markets. Recognizing the potential of SCCs and LEMs, a new law is currently in the post-parliamentary phase in Switzerland to permit the formation of local energy communities. Under this new legislation, residential agents could directly trade energy within their local communities, representing a transformation in the Swiss energy market framework (Abschnitt 2c, Bundesgesetz über eine sichere Stromversorgung mit erneuerbaren Energien vom 29. September 2023).

The critical importance of energy infrastructure requires a well-coordinated and predictable transition that avoids many of the pitfalls associated with the 'wild growth' of digital platforms. Regulators have increasingly scrutinized their rise, leading policymakers to propose significant new regulation of digital platforms (e.g., the Digital Markets Act). A solid understanding of the behavior of prosumers and platforms, especially regarding potentially harmful behavior and market power abuse, is a key element for a smooth transition to decentralized energy production and a prerequisite for establishing a reliable regulatory framework.

1.2 Purpose of the project

For LEMs and SCCs, there is neither a widely accepted economic model nor sufficient real-world evidence for calibration. We therefore use both a theoretical model and an agent-based simulation to investigate agents' dynamics and interactions within this new market structure. Within this model, we analyze the potential of a platform or individual market participants to acquire market power and their potential for abuse. Since this type of market is also prone to using artificial intelligence for optimization (either as an intermediary agent for all prosumers or individually), we will integrate reinforcement learning techniques, reflecting expected trends in this industry. We validate the outcomes with available data from LEMs and feedback from an advisory board.

The project provides Swiss policymakers with a conceptual framework for setting up regulations of SCCs and LEMs and for the creation of an appropriate monitoring framework. We will design and test regulations to address and mitigate market failures or market power abuses. Our work serves as a benchmark for energy platform regulation by highlighting harmful strategies of market participants operating under different regulatory constraints.

1.3 Objectives

Despite the ongoing legal processes and the significant opportunities within this domain, a consistent analysis of the long-term effects of the creation of Local Energy Markets (LEMs) on social welfare remains in progress. By understanding the economic dynamics governing LEM markets and identifying the key drivers of adverse market behavior, we can proactively address challenges that may arise, such as antitrust cases and monopolistic tendencies, within existing regulatory constraints (even though there will be no full liberalization in CH). Our primary aim is to elucidate LEM markets' economic dynamics and identify the key drivers of adverse market behavior. Specifically, our research questions are as follows:

- What are the specific vulnerabilities with respect to the creation and abuse of market power of local and interlocal energy markets?
- What regulatory measures can be implemented to mitigate such behavior effectively?
- What is the influence of artificial intelligence on the functioning of LEMs?
- How does the presence of LEMs impact the overall systemic stability of energy provision?

2 Procedures and methodology

Our methodology includes the development of an economic model and a simulation environment that reflects the practices of state-of-the-art energy platforms. We characterize energy platforms as multi-sided games with different actors and incentives, considering exogenous constraints as 'game rules'. We analyze agent behavior under different scenarios and policy constraints, ranging from simple rule-based agents to more complex learning agents.

Key steps in our methodology include:

1. Evaluation of existing platforms and literature review. The literature review and assessment of existing platforms have been completed. Data analysis of user behavior on existing energy platforms is ongoing.
2. Design of the economic model and analysis of its results. The outlining of the economic model from work package 1 is finalized, and the design of the economic model of work package 2 is in progress.
3. Develop a simulation engine based on the economic model, validated with real data from energy and digital platforms. Work on this will begin next year.
4. Establish an ongoing discussion and monitoring process involving market experts, energy providers, and regulators to ensure the plausibility of the results. An advisory board has been established.

3 Activities and results

Work Package 1 has been completed. We have worked on the following items:

3.1 Assessment of existing platforms.

We reviewed the literature on current local energy markets and their theoretical models, multi-agent reinforcement learning algorithms, and the literature on platforms and decentralized markets. There is a wide variety of digital energy platforms, including platforms in the transport sector (e.g., Chargetrip or We4Sea) or fintech (e.g., Abundance Investment). Our research project focuses exclusively on one type of digital platform: energy trading platforms.

Some examples of local energy trading platforms in practice:

- **Quartierstrom**, which was launched in Walenstadt, facilitates a local electricity market. Following the pilot of Quartierstrom 1.0, the subsequent project, Quartierstrom 2.0, devises a scalable method for energy suppliers. This system computes prices automatically depending on the local demand and supply, but it is no longer blockchain-based because of scalability difficulties. This project used market-based clearance in version 1.0 and platform-based clearance in version 2.0 (see 3.1.1).

- **Piclo** is a digital platform facilitating peer-to-peer energy flexibility trading between generators and business consumers. Using a matching algorithm, it pairs local energy production and consumption. The platform relies on meter data, generator pricing, and consumer preferences to align electricity supply and demand every 30 minutes. Generators can oversee their electricity sales, while consumers can choose and rank their preferred electricity sources. This project uses platform-based clearance (see 3.1.1) and a subscription fee.
- **SonnenCommunity**, created by German battery storage manufacturer SonnenBatterie, is a network of SonnenBatterie owners who exchange self-generated energy at a discounted rate. Members with a SonnenBatterie system and solar panels can fulfill their energy requirements on sunny days and produce surplus energy. Instead of sending this excess energy to the main power grid, it is stored in batteries to support the community during periods of insufficient production, such as during adverse weather.
- **The Brooklyn Microgrid** (BMG) is a community-based network in New York City that promotes local solar energy production and transforms. It connects solar array owners with individuals interested in purchasing local solar energy. Participants access the BMG energy marketplace via a mobile app to buy local solar energy credits through double auctions (market-based clearance). Consumers have the flexibility to choose their energy sources and set daily budgets.
- **Vandebron** is a Netherlands-based online platform that allows energy consumers to purchase electricity directly from independent producers like farmers with wind turbines. Acting as an energy supplier, Vandebron offers incentive tariffs to encourage energy exchanges between consumers and generators. Prosumers supplying excess energy to Vandebron benefit from buying energy at rates lower than other suppliers. This project uses platform-based clearance and has a subscription fee.
- **Powerpeers** connects customers to energy from fellow users with solar panels. Users can supplement with local sources like solar parks or windmills when there's a deficit. They select their preferred energy sources through a personal dashboard, ensuring a real-time match with available generators. If demand exceeds supply, it is topped up with other sustainable sources, such as offshore wind farms. This project uses platform-based clearance.
- **Lugaggia Innovation Community** (LIC) links the Lugaggia kindergarten with 18 nearby houses and 5 photovoltaic plants (64kWp total power). The goal is to maximize local electricity consumption within this community, adhering to self-consumption community laws. This is realized through a 60kWh shared battery, storing excess energy, and an AI-based supply-demand management system provided by Swiss firms Optimatik and Hive Power. The testing phase concluded in December 2021.

3.1.1 Pricing Mechanisms

The existing literature has discussed a variety of pricing mechanisms in local energy markets. We provide here a brief and simple classification of these pricing mechanisms, where we distinguish between **market-based** and **platform-based clearance,** building on the categorization of Capper (2022). A different categorization of pricing mechanisms can be found in Khorsany et al. (2018) who categorize clearing mechanisms into distributed methods, game theory, auction-based, and other methods. Tsaousoglu et al. (2022) distinguish between Lagrangian, game-theoretic, heuristic, and data-driven pricing mechanisms. Muhsen et al. (2022) provides a comprehensive list of individual pricing algorithms, complete with corresponding literature demonstrating their proof of concept.

In the context of **market-based clearance**, there are various mechanisms. An abundance of energy is expected to reduce the microgrid's energy cost, whereas a local energy shortage will drive up the market price.

- In a *single auction*, one type of market participant, usually the consumer, submits bids. Typically, sellers have a predetermined amount of energy available for trading, with the platform's primary role being to communicate this information to potential buyers. Buyers then place bids for their desired amount of energy at a selected price. See, for example, PankiRaj et al. (2019).
- In contrast, in *double auctions*, buyers and sellers actively submit bids for their preferred amounts of energy. An auctioneer intervenes to set the final transaction price and selects the participating buyers and sellers. The credibility and integrity of the auctioneer are paramount in these markets. See, for example, Vytelingum et al. (2010) and Mengelkamp et al. (2018) for a case study of the Brooklyn Microgrid.
- *Negotiated clearing* relies on individual, one-to-one interactions between market participants who negotiate directly to agree on transaction prices based on their preferences and current market conditions. This system is a feature found in peer-to-peer (P2P) energy trading platforms that promote the direct exchange of energy between individuals or small groups. For example, Sorin et al. (2018) and Etukudor et al. (2020).
- An *equilibrium-based clearing* method, which derives prices from market bids and offers. Methods such as Nash equilibrium are used to achieve a consistent price equilibrium that reflects market dynamics. Lagrangian methods and supply-demand ratio also fall into this category. See, for example, Zhang et al. (2016) and Marzband et al. (2018).

With **platform-based clearance,** in turn, prices are determined by the platform operator according to established criteria without being influenced by market bids or offers. Prices may be fixed or subject to fluctuations based on time of use. Techniques from cooperative game theory, such as the Shapley value, have been suggested to ensure equal distribution of benefits among participants in local energy schemes—for example, Narayanan et al. (2018) and Zhou et al. (2018).

Classifying platforms by their pricing mechanism however does not capture the main economic forces relevant for our research, as our subsequent analysis shows. Instead, for an economic assessment of LEMs, it is much more useful to differentiate by the degree of centralization of an LEM: **platform-mediated or** purely **P2P**.

3.1.2 Types local energy markets

We therefore propose a different characterization that focuses on the most fundamental market mechanisms, separating local energy markets into two types: platform-mediated (or intermediated) and peer-to-peer (P2P) local energy markets (LEMs).

- In an **intermediated LEM**, a central agent acts as a bridge between supply and demand, managing the trade within the market. This means there is no direct communication between energy suppliers and buyers (examples include Quartierstrom 2.0 or Sonnen Community). The intermediary can engage with the primary grid to achieve demand-supply equilibrium within the LEM. This could enable the intermediary to participate in trade with conventional suppliers actively.
- In contrast, **P2P LEMs** operate without a platform agent. In these markets, electricity buyers and sellers can independently and directly negotiate the terms of their energy transactions (for example, Quartierstrom 1.0, Brooklyn MG) or, as an outside option, buy energy from the grid or sell to the grid at the feed-in tariff.

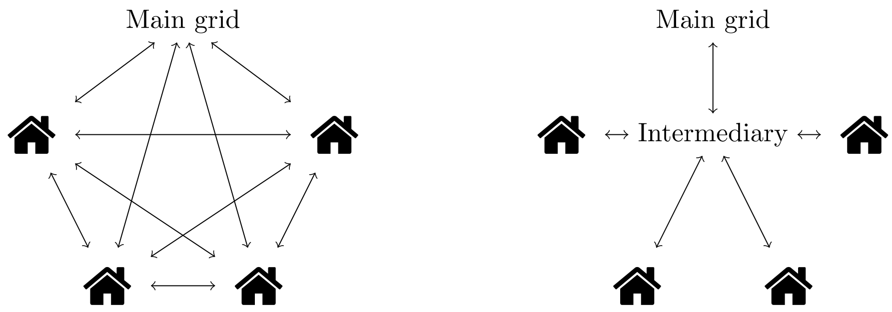

Figure 1. P2P local energy market (left) and intermediated local energy market (right).

Our primary emphasis is on energy platforms interconnected with the main grid and subject to local constraints. A further categorization involves a microgrid that operates independently without grid connectivity and an energy platform that operates without local constraints (interlocal LEM). In the upcoming steps, we will broaden our focus on interlocal energy trading markets as well.

3.2 Establishing stakeholder contact

We have created an advisory board consisting of three professors, two researchers, two individuals from regulatory bodies, and one from the industry.

3.3 Survey of policy concerns and infringements

In this work package, we conducted a literature survey and analyzed antitrust case studies focusing on the challenges of digital platforms and multi-sided markets. We categorized the concerns in view of abuse of market power. We placed them in the context of practical energy platform operations.

3.3.1 Economic factors in digital markets

First, we evaluated key factors that can give rise to market power on LEMs: transaction costs, network effects, economies of scale, switching costs, asymmetric information, and congestion. These factors are briefly explained below.

Transaction costs refer to expenses or inefficiencies associated with economic transactions. Local energy markets utilize intermediaries to optimize residential interactions and minimize transaction costs. To efficiently match buyers and sellers, algorithms streamline identifying energy trading partners (e.g., the P2P energy trading platform Piclo in 3.1). Blockchain presents an intermediary alternative in LEMs through its transparent ledgers and utilization of smart contracts that can automate trading processes and provide trustless interactions. Nevertheless, results from Quartierstrom 1.0 suggest that users may hesitate to actively engage in P2P trading (Ableitner, 2020).

- **Network effects** are fundamental dynamics inherent in many digital platforms, amplifying their value as user numbers grow. This concept can be divided into two primary types: direct and indirect network effects. Direct network effects, prevalent in communication, manifest when the platform becomes increasingly appealing as the number of users on the same side of the platform expands.

Conversely, indirect network effects are observed when a platform becomes more attractive to one group of users as another group grows. This is typical of transaction facilitation. Within LEMs, the distinction between user groups is evident between energy consumers and prosumers. Here, sellers see greater value in LEMs and vice versa when there is an increase in buyers. Intermediaries that act as matchmakers exhibit these indirect network effects in unique ways. The matching quality is enhanced as the platform gathers more data and has a larger user base.

- **Economies of scale** refer to the reduced costs per unit arising from a product's increased total output. For digital platforms, as the user base grows, average costs decline. This is especially pronounced for digital platforms where, after initial development, adding new users to the platform is inexpensive.

  It is likely that local Energy Markets (LEMs) similarly enjoy economies of scale. As the user base of an LEM expands, marginal service provision costs decrease. This phenomenon arises from substantial fixed costs of creating the software compared to marginal costs of adding single users.

  Data has the potential to improve both network effects and economies of scale. Compared to platform-mediated LEMs, P2P LEMs have a distinct advantage regarding information privacy and autonomy. Typically, they require only limited information from peers, avoiding the need for comprehensive data collection that might infringe on customers' privacy (Morstyn et al., 2018).

- **Switching costs** are entry barriers for digital platforms and are expenses incurred by residential agents while changing Local Energy Markets (LEMs). They can take monetary forms, such as termination fees, or non-monetary forms, such as the challenge to familiarize oneself with a new LEM. These costs discourage competitors from obtaining customers, which is particularly relevant when residents have limited LEM options. Platform-mediated markets are predicted to have higher switching costs. Reasons for this issue include the inability to transfer reputation metrics, such as ratings, between different platforms and exclusive technological commitments, like specialized batteries (see SonnenCommunity).

- **Asymmetric information**: In platform-mediated LEMs, asymmetric information can manifest, creating disparities between the platform and residential agents. The platforms may possess comprehensive data on energy patterns, facilitating efficient energy matching but also fostering information disparities if data is unevenly shared or understood. Asymmetric information in energy trading platforms can stem from opaque insights into energy production, needs, or pricing.

  Moreover, the principal-agent dilemma emerges when platforms are entrusted with demand control. With this separation of ownership and control, as elucidated by Jensen et al (2019) platforms might not always prioritize users' best interests. Continuous supervision by the principal (buyer or prosumer) over the agent (platform) is impractical, leading to agency costs due to the potential negligence or misalignment of the agent's actions.

- **Congestion rent** serves as a form of merchandising surplus. Transmission line owners can benefit from it by purchasing low-priced electricity and selling it at elevated prices, therefore capturing this rent. This may suggest potential market power abuse. For instance, a generator located at a capacity-limited node might price its services significantly above its marginal cost, benefiting from its residual monopoly.

3.3.2 Observed competition policy challenges in digital markets.

Second, we analyzed the regulatory and competition policy challenges that emerge with LEM, comparing this market type with digital platforms. The challenges include exploitative abuse, refusal to deal, predatory pricing, tying and bundling, and hold-up.

- **Exploitative abuses:** Exploitative abuses driven by market power include imposing unfair prices and conditions on buyers. In digital platforms, dominant players may impose high fees, manipulate privacy, or restrict content portability, harming competition and prosumer welfare.
- **Foreclosure** arises when a leading firm unjustly restricts access to a crucial product, aiming to expand its monopoly from that central market segment to a neighboring segment where competition could arise.
- **Refusal to deal:** Refusal to deal involves denying access to essential resources to prevent fair competition. For example, exclusive access to energy management software (if essential) in energy trading markets can exclude competitors. Similarly, digital platforms may restrict access to essential data or services, hindering competition.
- With **predatory pricing**, energy trading intermediaries drive out competitors with unsustainably low prices. The distinction between genuine competition and predatory pricing is complex. Incumbents may respond to potential entry by lowering prices, deterring entrants.
- **Tying and bundling strategies** can stifle competition. Dominance in one product or service can stifle innovation and limit consumer choice. For example, a battery manufacturer that dominates the home battery market could tie membership in the LEM to purchasing that battery, discouraging users from considering other options.
- **Hold-up problem:** The hold-up problem occurs when two parties could benefit from cooperation but avoid it because of concerns that such cooperation might strengthen the position of the other party, potentially reducing their own profits. For example, a potential prosumer may be reluctant to enter and invest in a platform-mediated market, fearing that the platform will gain power over him and change the contract unfavorably.

A more detailed analysis of these challenges is part of the ongoing research. Detailed recent summaries of competition policy challenges in digital markets can be found in for example Monopolkommission (2020), OECD (2020, 2023) and Motta (2023)

3.4 Economic analysis of decentralized markets

We reviewed several academic papers on decentralized markets. Two modeling approaches for such markets were identified: one approach assumes trade happens through random matching of non-strategic agents with a continuum of potential partners (for references, see e.g. Gale (1986) and Duffie et al. (2009)). However, this model approach is currently less relevant to LEMs in Switzerland due to geographical constraints and the low number of potential trading partners. A proposed law suggests that LEMs should not exceed the maximum size of a municipality (Abschnitt 2c, Bundesgesetz über eine sichere Stromversorgung mit erneuerbaren Energien vom 29. September 2023). A second approach explores the concept of bilateral trading with random matching (e.g., Kranton et al. (2001); Bramoullé et al. (2014)).

3.5 Exploration of LIC data

Data availability remains a challenge for investigating the scientific questions outlined in Section 3, particularly for assessing the impact of different policies on market outcomes. Because energy platforms are still in their infancy, real-world data on the status quo of prosumer and platform behavior remains scarce.

Therefore, we recognized that it would be more beneficial to study the market mechanisms and understand the technical literature of these LEMs than to determine the demand elasticities of users on the LEMs at this point.

We currently have access to one openly available dataset and a confidential data set. For reference, see Ableitner (2020) for a scientific publication on user behavior in P2P markets in the Quartierstrom project.

3.6 Outline of economic model

In this work package, we defined the key characteristics of local energy markets:

- **Organization of LEM**: As outlined earlier, our categorization of Local Energy Market (LEM) types divides them into two categories: intermediated and peer-to-peer (P2P). Within the framework of an LEM, a fundamental aspect is the presence of a market mechanism that outlines the operational rules of the market. This regulatory mechanism can vary substantially, ranging from purely bilateral trading, characteristic of P2P LEMs, to more complex systems such as auction-based mechanisms or guided matching of trading partners facilitated by centralized optimization algorithms.

  In addition, the organization and governance structure of the LEM plays a crucial role in determining the scope of action available to participating traders. In cases where the LEM operates under the supervision of an intermediary, there could be a misalignment of interests between the intermediary and the consumers/prosumers. The intermediary could have a range of possible actions, including but not limited to setting membership fees, controlling consumer demand, imposing transaction fees, and handling data-related aspects, thereby exercising significant influence over the operational framework of the LEM.

- **Prosumers** are entities, such as households or businesses, that actively participate in the production and consumption of energy. They are characterized by their ability to produce *and* consume energy, contributing to a more decentralized and sustainable energy ecosystem. Prosumers are heterogeneous: It is plausible to distinguish between producers and consumers per period. Alternatively, it is plausible to classify users as flexible or inflexible (regardless of net demand or supply considerations). Examples of flexible users include households with devices such as batteries, electric vehicles, and time-controlled boilers. More flexible users can help reduce the overall import and export of electricity to and from the grid.

- To **import and export energy**, a LEM faces external prices such as import and export price. In the baseline model, prices are assumed to be constant. We will relax this assumption as the analysis progresses. Relevant are also the outside options for the prosumers. To cover the remaining electricity demand, the consumers entitled to main grid access may exercise their entitlement to access independently. The basic supply ("Grundversorgung") covers the remaining electricity requirements of firm end consumers and end consumers who waive their right to network access.

On one hand, we aim to uncover the fundamental economic drivers influencing energy trading platforms' strategies, while on the other hand, we seek to gain insights on how these platforms perform. The following model allows for the analysis of categories of different pricing mechanisms and their influence on prosumers in the model.

We now outline a simple economic framework of LEMs to understand their key characteristics. We consider a static model without friction and without energy storage devices[1]. The total electricity supply on the platform is a random variable S from a distribution $\mathcal{F}$ with support $[0, \hat{S}]$. Maximum supply $\hat{S}$ is defined by the total installation of photovoltaics by prosumers in the LEM. Every producer sells his full realized (net) supply on the LEM for p^P or to the grid with feed-in tariff (FIT) p^E.

Consumers on the LEM act non-strategically and are defined with a linear demand function. For the purposes of the graphical analysis, we assume that electricity is inelastic to price, i.e., for a 1% change in price, there is a change in quantity demanded of weakly less than 1%. For ease of demonstration, the graph shows a demand function with unit elasticity. The consumers can buy energy from the basic supply at p^I or on the LEM at p^D.

The price of the LEM importing electricity from the grid is p^I and the price for selling to the grid is p^E. This is a simplifying assumption for this model outline.

We first consider a monopolistic intermediary that can set prices for both user groups[2]. The intermediary sets prices such that both user groups prefer trading on the platform. Therefore, it sets $p^D = p^I - \epsilon$ and $p^S = p^E + \epsilon$ with ϵ small. The market outcome depends on the realized supply S. From now on, we will refer to realized supply as being "large", if $S > D(p^E)$, and as

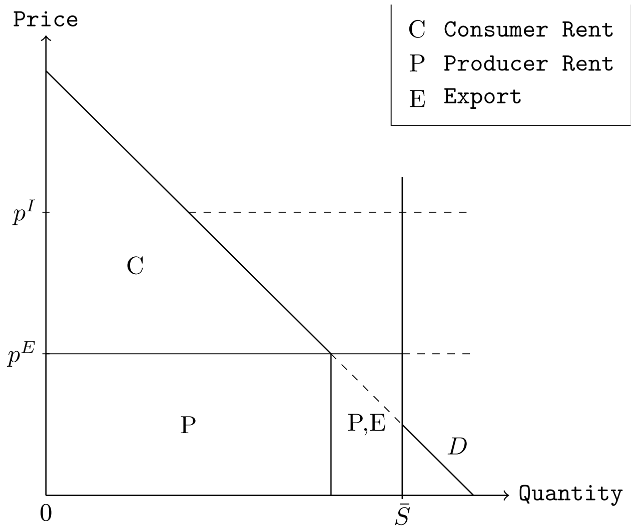

Figure 2. Distribution of rents in an LEM with a monopolistic intermediary and high realized electricity supply from platform suppliers. The monopolistic intermediary restricts exports to keep prices high for consumers on the platform.

[1] Energy production and consumption are equal per period, without any transfer of energy between periods. Dynamic modeling is necessary for further investigation of this issue.
[2] Instead of setting different prices for the two groups of users, the intermediary could also set a transaction fee on the platform, which would be expected in reality. For the sake of simplicity, we assume two different prices.

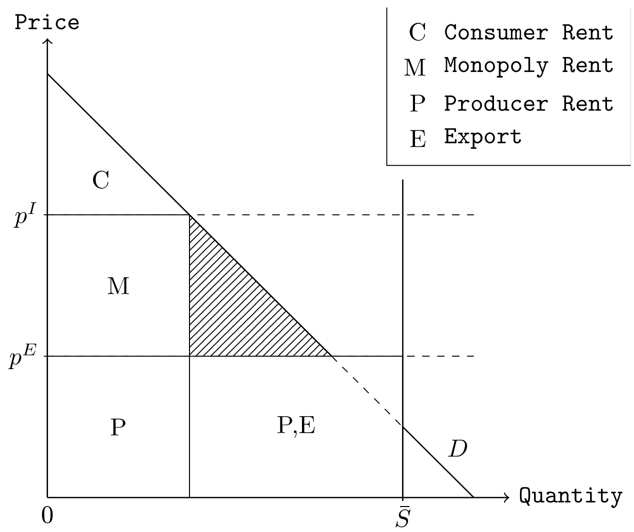

Figure 3. Distribution of rents on a LEM without monopolistic intermediary and high realized electricity supply from suppliers on the platform. Since supply is higher than demand on the platform, the residual energy is exported.

"low" if $S < D(p^I)$. The graphical analysis of the case with a monopolistic intermediary and large supply is shown in Figure 2.

In contrast, without a monopolistic intermediary, the volume of exports under high supply would be smaller and the overall rent in the LEM would be greater. See Figure 3 for a graphical analysis.

We are currently in the process of designing the economic model in Work Package 2. The outlined model above is a simple representation of an LEM that helps clarify the main economic mechanisms and opens many different directions of investigation:

- Multiple periods (and long-term investments)
- Inclusion of trading mechanisms/decentralized matching as a clearing mechanism. This also allows the analysis of average or marginal pricing.
- Stochastic supply analysis and forecasting
- Strategic demand
- Implementation of energy storage devises

The model also helps to organize the existing literature. For example, one important focus of the existing literature has been examining different market mechanism types (e.g., double auction, supply-demand-ratio or mid-market rate). Their effect can be understood in our simple framework as implementing different internal prices on the platform and thus a different division of rent in the market.

Existing literature explores various clearing mechanisms (see 3.1). These mechanisms define how the prices on the energy markets are set, affecting market dynamics. Our model simplifies this complexity and illustrates the impact of different mechanisms. For example:

- Supply-Demand Ratio (SDR): Prosumers submit energy bids to the coordinator. The balance between the total selling power and total buying power, represented by the SDR, and the exogenous import and export prices define the equilibrium prices for consumers and prosumers. The model allows to analyze the rents for the different user groups under different circumstances. If supply exceeds demand, demand and supply prices are equal to the export price. If supply is smaller than demand, the internal price of energy is not automatically p^I, but there are two separate prices for demand and supply, which share the rent, which gradually increases for the supply side as demand decreases (see, e.g., Liu et al. (2018)).

- With the mid-market rate (see, e.g., Zhou (2018)), the LEM price is $p^{p2p} = \frac{p^I+p^E}{2}$ when demand equals supply. If demand exceeds supply, the supply side still receives p^{p2p}, while the demand side pays $p^D \in (\frac{p^I+p^E}{2}, p^I)$, depending on the fraction of energy that is imported from the grid. If supply exceeds demand, the demand side pays p^{p2p}, and the supply side receives $p^P \in (p^E, \frac{p^I+p^E}{2})$, depending on the fraction of energy that is exported to the grid. The maximum rent possible under this pricing scheme for consumers and suppliers is smaller than under SDR.

4 Evaluation of results to date

The first phase of this research project involved the synthesis of relevant literature from various fields. Our work synthesizes research findings from local energy markets, decentralized markets, two-sided platforms, and market-power abuses facilitated by digital platforms. This knowledge is crucial for formulating a framework for understanding local energy markets and the potential challenges they pose from a competition economics perspective. This project is a pioneering effort to advance an analytical approach to LEMs from the perspective of market failures. The expressed interest of several subject matter experts who have agreed to serve on the project's advisory board underscores the importance of this research initiative.

Our ongoing analysis demonstrates the considerable potential for consistent economic analysis in the LEMs area, with the potential to provide valuable insights that can inform the development of future policy instruments.

5 Next steps

The coming year will be focused on the economic model. We will continue to design and analyze the detailed economic model. This will be followed by an in-depth analysis of its implications and discussions with the Advisory Board.

Following our theoretical investigation of energy trading platforms, the next step is to bring the created know-how into practice. We implement the different platform types within a flexible software infrastructure to achieve this. Viewing platforms and agents as multi-party/multi-player optimization markets, we introduce standard optimization algorithms to the created software environments. We subsequently analyze agents' performance in view of the abuse of market power, and we introduce 'regulatory rules' to investigate the impact of regulatory policies.

6 Communication

A presentation of the agent-based model setup is planned at the ABM4Energy conference on Agent-based modeling for energy economics and energy policy on March 21-22 in Freiburg (Germany).

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