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A taxonomy of the relevant actors in the European energy transition

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Abstract

The European energy market is comprised of a diverse range of actors, each with distinct roles and objectives. This paper proposes a taxonomy that categorizes these actors into five groups: governance, grid and transport, supply, demand, and investors. Utilizing extant literature, we identify salient characteristics and distinctions within these groups through analyzing their interconnections and interactions. By systematically mapping energy flows and investment patterns, we present a structured overview of the market's evolving landscape and its implications for the energy transition, particularly concerning the debate on the necessity of capacity mechanisms.

Keywords: Energy transition, Actor Heterogeneity, Firm Behavior, Finance, Capacity mechanisms

JEL Classification: Q40, L20, D22, 016, D24

Declaration of interests. The authors declare that they have no known competing conflict of interest or financial interests that could have appeared to influence the work reported in this paper.

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1. Introduction

The European energy market has significantly changed in recent decades. It has transitioned from a period of privatization to a more heterogeneous and dynamic landscape characterized by a diverse set of market actors (Prag et al., 2018). A thorough comprehension of the roles and interactions among these actors is imperative for developing effective policy and formulating pertinent research inquiries (Grimm et al., 2025). Prior studies review the role of different actors during the energy transition in different domains (e.g., Bjerkan et al., 2021, Schot et al., 2016). In this paper, we develop a taxonomy of European energy market actors and deliver a structured summary that categorizes actors according to their function, market engagement, and interactions. This study offers a structured contribution to the field by proposing a more profound understanding of the evolving European energy market. We derive insights to construct a valuable foundation for policymakers and market participants seeking to navigate the complexities of the energy transition. In addition, qualitative descriptions help to identify patterns and differences to define future studies (Gerring, 2012).

Achieving a carbon-neutral future requires financial commitments that enable decarbonization measures, including the decentralization of energy resources. The ongoing shift toward distributed energy systems has created a new cohort of market participants, niche foci, and innovative technologies. In addition, policy initiatives that reduce barriers for new entrants to build renewables, such as wind farms and solar installations, have increased. This transition has led to a diverse actor landscape, where stakeholders hold varying roles, such as generating electricity and funding investments. In this paper, we categorize actors in the European energy transition into the pertinent actors involved to provide a more comprehensive perspective. We enumerate each group’s heterogeneous members and analyze their roles in investment, technology adoption, and system-level coordination.

In this study, we develop a taxonomy of European energy market actors through a qualitative synthesis of existing literature and policy documents. The role of taxonomies is widely acknowledged in research literature (Glass and Vessey, 1995). Sabherwal and King (1995) argue how developing a taxonomy helps to diagnose variation in the prior research. We start by assessing academic literature following a systematic review to decide actors, which has been a common approach in the prior studies (Bekirsky et al., 2022). The approach involves reviewing more than 80 academic publications, institutional reports (e.g., from the European Commission, IEA, and EIB), and national statistics covering energy investments, ownership structures, and regulatory roles. We classify actors based on three guiding criteria: (1) objectives and strategic mandates; (2) modes of participation in the energy system (e.g., generation, consumption, regulation, financing); and (3) observed behavioral patterns related to investment, flexibility, and risk management. We support qualitative descriptions with quantitative indicators (e.g., installed capacity, investment volumes, financial assets), where examples are available to supplement the qualitative assessment. We refine the taxonomy to ensure analytical clarity while acknowledging overlaps and hybridity between actor categories. Lastly, we create visual schematics to map energy and financial flows, guided by empirical data and conceptual frameworks from the literature review.

A review of the literature reveals existing categories and the classification of actors within these subgroups. Prag et al. (2018) and Schittekatte et al. (2021) focus on the differentiating actors within the supply sector. They highlight differences between types of ownership and the different roles of incumbents and new entrants. Barazza and Strachan (2020) extend this categorization and introduce households as an additional important actor in the energy transition. As indicated in the study by Jansma et al. (2020), households’ behavior varies depending on their status as renters or homeowners. This highlights the need to comprehend the diverse actors comprising the demand side. Polzin and Sanders (2020) offer a comprehensive overview of the various financing institutions and their role in the energy transition. The role of institutional investors is highlighted in Persad et al. (2024). We construct this taxonomy by integrating previous literature, thereby facilitating the classification of actors across all pertinent sectors of the European energy market. This classification is based on three fundamental criteria: objectives, modes of participation in the energy market, and behavioral trends. We underscore the strategic choices that shape relevant actors’ roles in the market and how their roles affect the broader energy transition. The discussion commences with a overview of governance structures and transmission system operators. In light of the substantial research that has been conducted on these entities, our primary focus is on the remaining categories.

In addition to mapping actor categories, we highlight actors’ relevance for one of the central system-level challenges in the European energy transition: ensuring long-term security of supply. In a market increasingly shaped by renewable variability, decentralized production, and diverse ownership models, supply adequacy is no longer just a question of generation capacity. It is a governance challenge involving misaligned incentives, fragmented capacity mechanisms, regulatory uncertainty, and limited consumer flexibility. Our analysis reveals that institutional coordination among public and private actors is often lacking, while investment signals remain inconsistent across EU member states. Moreover, end-user expectations of uninterrupted supply, combined with low price elasticity, underscore the need for a broader debate on system resilience, demand response, and equity. As a result, actor heterogeneity not only enriches the electricity market but also complicates the institutional design of robust, socially accepted capacity frameworks.

A graphical overview of the relevant actors is proposed in Section 2. Section 3, briefly discusses the role of governance actors in the energy transition. While not the primary focus of our taxonomy, the grid and transport sector is addressed in Section 4. Section 5 is devoted to examining supply-side actors, with a focus on distinguishing between firms based on ownership structure, size, and market maturity. The present study will examine the distinct behaviors exhibited by state-owned enterprises (SOEs) and private firms, as well as the competitive dynamics between incumbent utilities and new entrants. The advent of renewable energy communities exemplifies the increasing interconnectedness of supply and demand. In Section 6, the demand-side actors are categorized into three sectors: residential, commercial, and industrial. This section also highlights the ongoing shift from passive electricity consumers to active prosumers. Achieving the energy transition requires substantial investment in renewable energy and energy efficiency measures. Consequently, Section 7 explores the role of investors and financial institutions, distinguishing between private investors, institutional investors, venture capitalists, and private and public investment banks. Sections 8

and 9 discuss our findings, focusing on security of supply and policy recommendations for future market design.

2. Relevant actors and their interactions

2.1. Overview

In this study, we aim to identify, categorize, and describe the relevant actors of the European energy transition. The identification of key actors is imperative for comprehending the dynamics of the European energy transition. There are many actors engaged in energy systems, and current actors switch their past behaviors with the increasing deployment of renewables (Bekirsky et al., 2022). While ensuring a clean energy infrastructure, there are bigger concerns in Europe regarding securing the energy supply. We investigate which types of actors' involvement affect the energy transition, and how their interactions are changing. We provide examples of actors' behavior, both in energy and financial flows, in the path to net-zero goals. This analysis encompasses state actors, energy firms, significant energy consumers, households, landlords, various types of energy transport infrastructure, investors, and financial actors.

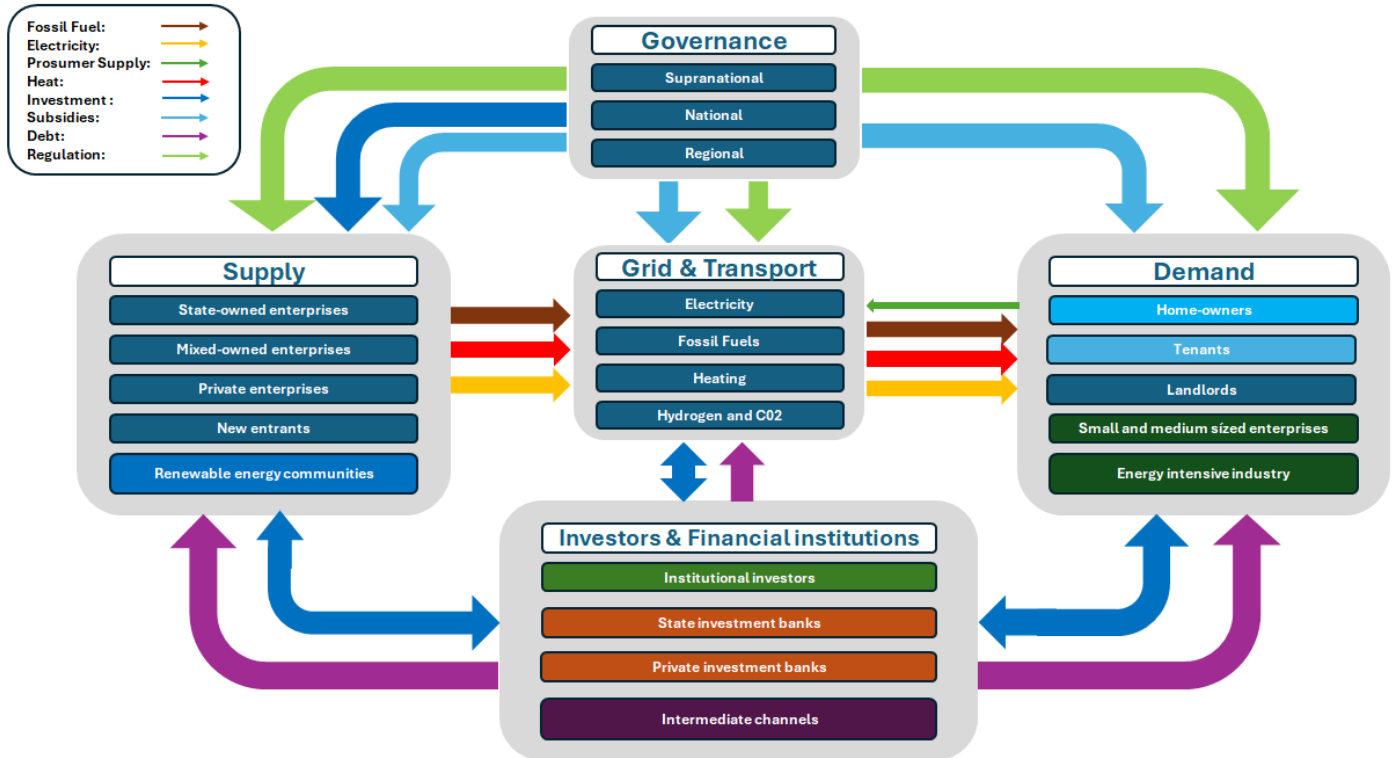
We categorize actors into five distinct groups. The initial category, entitled "governance," pertains to the regulatory functions of state actors, such as setting market rules, monitoring compliance, as well as funding fully or partially state-owned enterprises. Furthermore, state actors can act as investors through "financial institutions" such as state investment banks, or by providing subsidies (or taxes) to influence the energy transition, or by addressing issues such as distributional impacts or market failures when emerging technologies enter the market. The interrelation between supply and demand is facilitated by the "transport infrastructure." The "supply sector" comprises a diverse array of energy-generating or providing firms, including potential new entrants from sectors beyond the original energy sector, as well as more modern forms such as renewable energy communities. Conversely, "demand" comprises energy consumers, categorized into two distinct groups: households residing in property and tenants. It is also imperative to acknowledge the pivotal role of landlords and rental corporations in this context.

Furthermore, small and medium enterprises, predominantly situated in the service and manufacturing sectors, are relevant yet generally more passive actors, as they primarily receive electricity and do not actively engage in independent action. However, these entities must also allocate resources to the acquisition of heating systems and energy efficiency measures, thereby engaging in interactions with their respective landlords or rental corporations.

Of particular significance within the context of the energy transition are energy-intensive industries, which not only consume substantial amounts of electricity but also possess considerable capabilities for their own generation and energy utilization. Investors and financial institutions, in particular, play a pivotal role in providing capital for developing supply, demand, and transport infrastructure. Concurrently, governmental entities also engage with state-controlled or public institutions within this category. In the context of energy flows, the supply actors assume responsibility for the provision of electricity, heat, and fossil fuels to the demand actors through the transportation infrastructure. In their capacity as prosumers, demand actors can be regarded as

re-supplying energy, as illustrated by solar PV electricity fed to the grid. As illustrated in Figure 1, a visual representation of the actors and their interactions is provided.

Figure 1: Overview of the relevant actors of the European energy transition



Source: Own creation based on the Taxonomy

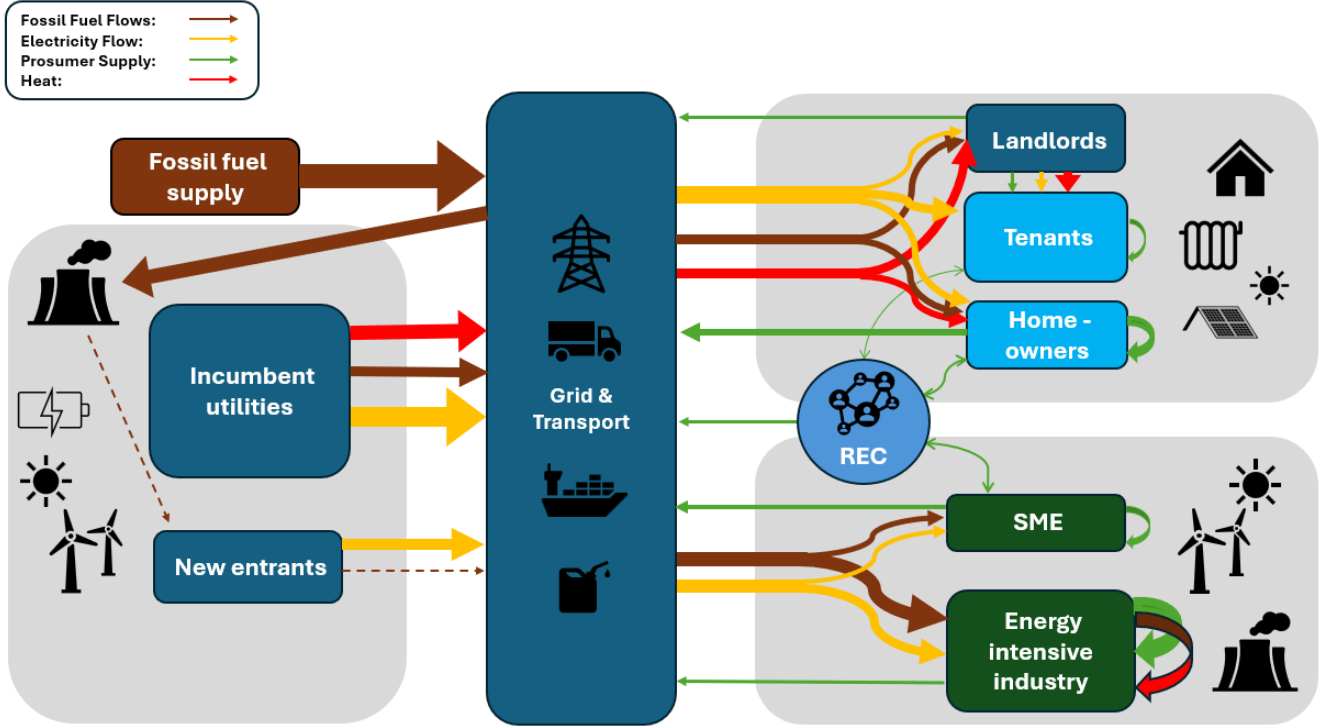
The following sections, designated from 3 to 7, provide a comprehensive overview of the five categories and the individuals who comprise them. In particular, the sections undertake a comprehensive analysis of salient facts and the general behavior of the actors in question.

2.2. Energy flows

As illustrated in Figure 1, the dynamic interplay of energy flows among diverse actors is represented in Figure 2. The arrow sizes represent the relative amounts of energy flows. The energy flows are illustrated as occurring between supply, located at the left, and demand, situated at the right. The facilitation of these flows is enabled by grid and transport infrastructure, as illustrated in the central region of the figure. In the context of this analysis, categories such as governance, investors, and financial institutions are not directly relevant.

The left side of the figure emphasizes two distinct categories of suppliers: emerging players in power provision and incumbent utilities. The latter, traditionally vertically integrated entities responsible for generation, transmission, and distribution, occupy the dominant position. These entities operate under a variety of ownership models, including state-owned, mixed-ownership, or

Figure 2: Energy flows between the relevant actors of the European energy transition



Abbreviations: SME (small and medium-sized enterprises), REC (renewable energy communities).
Source: Own creation based on the Taxonomy

fully private structures. While the distinction between these entities does not have a substantial impact on the depiction of energy flows, it is acknowledged that the relative relevance of firm classification may influence the respective sizes of energy flows. The incumbents possess a diversified portfolio, predominantly comprised of thermal power plants. The procurement of fossil fuels is facilitated through the grid and transport infrastructure, with the primary distribution of energy occurring in the form of electricity and heat to the demand sector. However, these entities also function as intermediaries between fossil fuel import or generation companies and consumers. This is illustrated by their direct sale of natural gas or heating oil to consumers. Intriguingly, grid and transport infrastructure firms engage in a similar practice, thereby entering a competitive dynamic with the aforementioned incumbent utilities. In general, incumbent utilities may also possess grid and transport infrastructure, import fossil fuels, or even generate some fossil fuels domestically. In contrast, new entrants in the energy sector tend to prioritize the development of renewable energy production and storage technologies. The electricity they generate is integrated into the existing grid and transport infrastructure, ultimately reaching consumers on the demand side of the flow chart.

The consumers depicted on the right side of the chart are divided into two distinct categories. The residential sector occupies the upper section of the chart, while the industrial and commercial

sectors are situated at the lower end. Households that reside in their own property have the option of directly heating their residences after receiving gas or oil from the grid. In contrast, renters are obligated to utilize the services of an intermediary, such as a landlord, to satisfy their heating requirements. Investing in rooftop photovoltaic (PV) systems enables households to engage in prosumerism, meaning they can generate their own electricity and feed it directly back into the grid. Households also have the option to engage in renewable energy communities, wherein multiple small entities collaborate to provide their own electricity supply. As illustrated in 2, small- and medium-sized enterprises (SMEs), which are represented in the lower demand segment, are incentivized to participate in renewable energy communities. This participation leads to a reduction in demand for electricity from large suppliers. Depending on their energy intensity, it may even be advantageous for SMEs to invest in larger renewable energy projects, such as the construction of a wind farm. This phenomenon is of particular relevance to energy-intensive industries. By allocating resources toward self-sufficient power generation, enterprises can curtail expenditures and mitigate their exposure to the volatilities of spot market prices. Furthermore, energy-intensive industries employ combined heat and power plants to convert fossil fuels into thermal energy for production purposes.

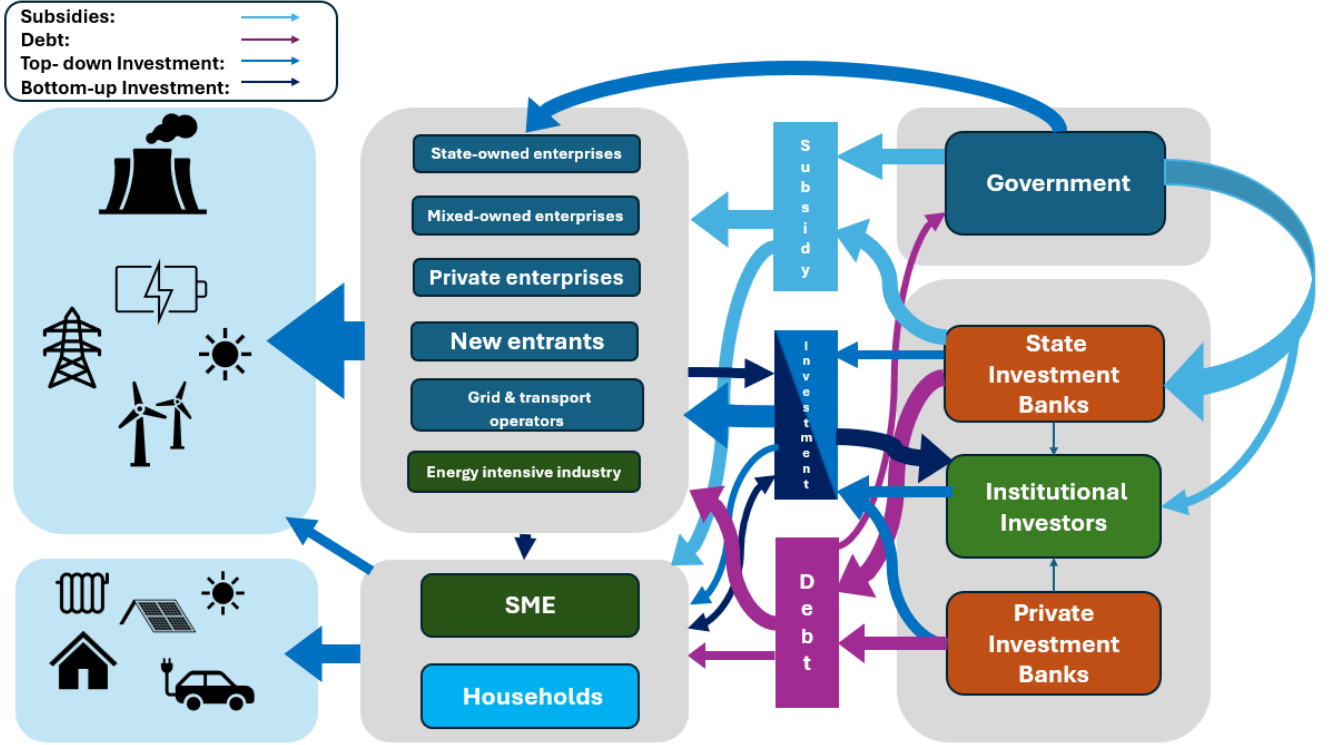
2.3. *Financial flows*

Figure 3 illustrates the financial flows between the various actors. We draw arrow sizes to represent relative financial volumes. The actors have been grouped according to their ability to invest in different technologies and provide capital. The right side of the figure shows the capital providers, including governments, banks, and institutional investors. The central portion illustrates actors investing directly in technologies. The potential technologies in which these entities can invest are displayed on the left side of the figure. Different colored arrows illustrate the various forms of financial flows.

There are two ways in which the government can provide capital for the energy system. First, they can invest directly through state-owned enterprises. Second, they can grant subsidies to specific technologies, thereby influencing the investment decisions of other actors and providing secure cash flows. State investment banks play a key role in this framework by facilitating loans, subsidies, and investments in accordance with government-established regulatory parameters. Institutional investors, such as pension funds, receive capital from the government as well as from households and companies. This process is depicted as bottom-up investment flows here. These funds are then used for top-down investments in companies involved in constructing energy plants, transmission systems, and transportation networks. These investments typically have a longer investment horizon, a pattern that will be explained in greater detail in Section 7. In addition to providing debt to firms and households, private investment banks engage directly with companies through top-down investments. Consequently, the entities represented on the right side of the graph provide capital for the energy transition through subsidies, investments, and debt.

The specific technologies to be invested in are determined by the actors displayed in the middle of the graph. The scope of investment varies across categories. Households and SMEs primarily allocate their investments toward smaller-scale initiatives, such as rooftop PV, electric vehicles,

Figure 3: Financial Flows between relevant actors of the European energy transition



Abbreviations: SME (small and medium-sized enterprises)
Source: Own creation based on the Taxonomy

battery storage, and heating and energy efficiency measures. These investments have the potential to transform these entities from consumers to prosumers, a concept elaborated upon in Section 6. Conversely, larger companies in the energy sector and the energy-intensive industry predominantly focus on large-scale projects, including thermal power plants, storage facilities, transmission infrastructure, and wind and solar parks. Section 5 elaborates on the differences between investment patterns in greater detail.

3. Governance

Governance plays an important role in the European energy transition by establishing regulatory frameworks, providing subsidies, and owning companies directly. The manner in which governments and regulatory entities exercise their influence varies across supranational, national, and regional levels. Government actors seek consistent policy structures, sufficient public funding, and strategic public-private partnerships to ensure adequate energy investment under competitive market conditions.

The European Commission (EC) is leading the transition by setting regulations and creating frameworks, such as the European Green Deal. It is also providing funding mechanisms, including

the Net-Zero Industry Act, the Just Transition Fund, and the Innovation Fund (De Bruyn et al., 2020, Temple-West, 2024). Several key institutions, such as the Agency for the Cooperation of Energy Regulators (ACER), also play a crucial role in EU regulation. ACER standardizes cross-border market rules, oversees infrastructure investments, and ensures transparent energy trading. At the national level, energy supply and fair market conditions are ensured by national authorities. In Germany, these include, for example, the Bundeskartellamt and the Bundesnetzagentur (Bundeskartellamt, 2024).

These governance structures regulate the energy market, set targets such as the Green Deal, and invest in infrastructure and power plant construction projects by providing funds and subsidies. According to the EC, the total investment needed for the green transition in Europe is 1.5 trillion euros annually until 2030 (ECB, 2024). The EU allocates about 300 billion euros of public funds, which covers about 20% of the total needs for green investment (Darvas and Wolff, 2021). The remaining 80% is expected to come from private investors, companies, and banks. National governments create frameworks to attract private investors and provide subsidies, such as feed-in tariffs (FITs), investment grants, and tax incentives. This is an essential factor in investment decisions as it lowers the cost of capital, a known barrier to decarbonization efforts, especially for SMEs (Prag et al., 2018, Barazza and Strachan, 2020). National governments can also directly own companies, such as the French government’s ownership of EDF. However, it is more common for regional or municipal governments to own energy-related enterprises, like EnBW and Stadtwerke München in Germany. Investment patterns are elaborated on in greater detail in Section 5.

4. Transport infrastructure

Electricity. Transmission system operators (TSOs) and distribution system operators (DSOs) manage and balance network access and flows. These companies are either natural monopolies, independent regulators, or state-owned firms, but they are in any case subject to strong regulation and control (Prag et al., 2018). However, even within this group, different investment patterns can be observed. For example, dominant or incumbent companies typically prioritize maintaining or gaining market share rather than investing in new infrastructure or smart grids (European Investment Bank (EIB), 2020). In keeping with this, Ferdinand et al. (2014) found that smaller DSOs tend to invest more than larger ones. Additionally, as distributed energy resources, including solar and wind, become more important, DSOs are playing a larger role in managing and balancing grid frequencies.

Fossil fuels. In addition to electricity grids, there is extensive infrastructure for transporting and storing oil and natural gas. The main difference from electricity grids is that this infrastructure is dependent on imports in most European countries. Germany, for example, has no significant production of natural gas or oil and relies entirely on imports. In contrast, Norway is a major exporter of natural gas. As existing infrastructure becomes obsolete in the near future, stranded assets may pose a problem for utilities. However, a commitment to clean infrastructure instead of transporting fossil fuels can lead to new opportunities.

Heating. At the local level, district heating and smaller local heating networks are of immediate importance. In particular, district heating is seen as playing a key role in decarbonizing heating in densely populated areas.

Hydrogen and CO₂. Additional infrastructure (and companies to build it) will be needed if hydrogen and underground CO₂ storage become widespread. Hydrogen and CO₂ can be stored and transported by different means. The most promising option for transporting hydrogen is long-distance shipping. This method requires transforming hydrogen into ammonium or placing it into a liquid organic hydrogen carrier (LOHC). Another option is simply to liquidize the hydrogen. All three methods require substantial infrastructure at the beginning of the transportation process but lower investment volumes at the end, where the release point is less complicated. Liquid hydrogen can also be transported by pipeline or truck to its final destination, which could make it the most competitive solution.

5. Supply

A closer look at the supply side of European electricity markets reveals a considerable degree of variety and diversity among the relevant actors, as well as their increasing transition and focus on renewable energy sources (BMWK, 2024). Historically, European utilities were vertically integrated, state-owned, or regulated (natural) monopolies that owned generation capacity and grids and sold electricity directly to customers (Kolk et al., 2014). Liberalization and unbundling policies implemented over the past three decades dissolved many state monopolies and opened the sector to private competition and new entrants, many of whom have focused on generating renewable energy.

This transition is capital-intensive, with EU countries investing nearly 110 billion euros in renewable energy projects in 2023 (Holmann and Lefort, 2024). Overall, Europe is now investing ten times more in clean energy than in fossil fuels. However, the level of commitment and involvement in such projects varies widely among public versus private firms, as well as among small versus large and established versus emerging firms. Additionally, there are differences among countries. While private companies are generally more focused on shareholders and returns, their average investment in renewable electricity generation is lower than that of state-owned enterprises (SOEs), as these companies also consider non-commercial objectives, as cited in Prag et al. (2018). Nevertheless, private companies account for a significant portion of total investment. In addition, limited access to internal and external funding sources may prevent smaller firms from investing more frequently than large utilities (De Haas et al., 2021). Additionally, incumbent utilities benefit from somewhat lower costs of capital and some vertical integration, while new entrants face higher costs of capital and no vertical integration or network ownership (Barazza and Strachan, 2020). The following subsections will further analyze firms' different investment behaviors and strategies for renewable generation assets.

5.1. State-owned enterprises

Fully state-owned, unlisted enterprises. In this subsection, we introduce unlisted fully state-owned enterprises (SOE). There are firms in this category, such as Vattenfall SE and several Stadtwerke in Germany. Approximately 14% of energy-sector companies in Europe are publicly listed, with the majority being state-owned, and 45% being fully state-owned.

State-owned enterprises tend to maintain a strategic focus on infrastructure-heavy, large-scale projects such as offshore wind, hydropower, and nuclear modernization, reflecting their access to lower-cost capital and government mandates for long-term national energy goals (European Commission, 2016, Prag et al., 2018). The private sector generally disfavors such ventures due to the long-term financial commitments and increased risk involved. Additionally, state-owned enterprises prioritize improved energy access and affordability over revenue maximization. This is consistent with Barazza and Strachan (2020), who found that these companies are more likely to absorb losses within their primary business activities. Empirical evidence shows that state ownership positively correlates with more and higher investments in energy efficiency and renewable energy projects (Prag et al., 2018). This trend can be attributed to the fact that SOEs have easier access to funding sources, even for long-term and infrastructure projects, and that revenues are reinvested due to the absence of shareholders (Barazza and Strachan (2020), The World Bank (2020b)). However, it is important to note that this effect is only present if renewable energy is a priority for the government, as Steffen et al. (2022) found. Therefore, differences between countries must be recognized, even though the EU energy transition is a comprehensive geographical strategy. When governments prioritize green energy investments, many SOEs focus on solar PV, onshore wind, and biomass over traditional sources like natural gas, which are well covered by private companies (Barazza and Strachan, 2020). SOEs lead renewable investment in Europe, helping governments meet their climate targets by devoting a large share of their investments to clean energy. For example, Vattenfall’s green investment plan totals 15 billion euros from 2025 to 2029. Similarly, the French government recently stated that EDF may require €25 billion per year to extend reactors and deploy renewables. While some of this budget will go to nuclear energy, we estimate that EDF will invest around €1 billion in renewable energy. In addition to SOEs, larger municipalities are investing in offshore wind farms, as well as onshore and PV wind farms. For example, Stadtwerke München (SWM) allocated €1.5 billion for renewable energy expansion between 2024 and 2028 (Stadtwerke München GmbH, 2023). Furthermore, SWM co-owns the DanTysk offshore wind farm in the North Sea with private companies. This demonstrates how municipal and state enterprises collaborate through joint ventures to increase investment and distribute risk. This institutional hybridity is similar to the broader group of mixed-ownership enterprises, where ownership and strategic control are split between the state and private investors. Mixed-ownership firms will be introduced in the next subsection.

Publicly listed and predominantly state-owned companies. This category comprises most state-owned firms traded on stock exchanges. Governments hold a controlling stake ($>50\%$), while minority shares are publicly traded. Examples include Denmark’s Ørsted, Finland’s Fortum, the Czech Republic’s CEZ, Poland’s PGE, and Austria’s Verbund. These companies blend the strategic

oversight of the public sector with capital-market financing.

The state’s ownership establishes these firms’ corporate strategy, enabling them to prioritize national interests such as energy independence or a green transition while operating alongside private investors motivated by profit. Predominantly state-owned companies are among the largest investors in renewable energy in Europe and often leverage their state backing to undertake ambitious green projects. For example, Ørsted is one of the world’s leading offshore wind developers, investing roughly €4 billion in capital spending primarily for renewables (Ørsted A/S, 2025). Predominantly state-owned firms generally show a very high level of investment in renewables relative to their size. These companies also tend to reinvest earnings. For instance, Ørsted has paused dividends to preserve capital for expanding renewable energy projects. The combination of state ownership and public listing often results in strong balance sheets and credit ratings, enabling substantial project financing, which is ideal for renewable investments.

Mixed-owned enterprises. “Mixed ownership” companies and private investors have significant, yet non-controlling, government stakes. In many cases, utilities that were previously fully state-owned have been partially privatised, yet still remain under majority public ownership. As with EnBW in Germany and Eni in Italy, the state typically retains a controlling stake of between 20% and 49% in the firm. The state uses its share to shape investment trajectories toward renewables, while private shareholders introduce performance pressures and capital discipline (Perimtec (2021), Prag et al. (2018)). Due to this shareholding structure, the government can push the company toward renewable energy investments. However, there is generally more independence and a greater focus on profitability than in wholly state-owned companies. Their investment strategies balance government expectations with shareholder returns. For instance, Engie, a French natural gas company in which the French state owns 24% of the shares, invests approximately €3 billion in renewables and related infrastructure. The state’s influence ensures Engie maintains a strong renewable focus, leveraging its scale and partial state support to become a global renewable investor (ENGIE, 2025). This illustrates that, even without majority control, governments can influence the clean energy transition with market investors.

5.2. Fully private or listed companies without any state ownership, e.g., E.ON, Royal Dutch Shell

This subsection introduces fully private energy firms without government ownership. These enterprises are owned by dispersed shareholders, institutional investors, or founding families and are entirely market-driven. This group includes Europe’s private-sector oil and gas supermajors, such as Shell, BP, and TotalEnergies, as well as large, investor-owned electric utilities, including Iberdrola, RWE, and E.ON. Once a utility becomes fully private and publicly traded, it becomes subject to private-sector pressures. At that point, revenues and shareholders are critical to the firm’s viability. National governments do not hold equity in these companies. As a result, such utilities may not respond to policies in the same way as SOEs and may differ significantly in their investment behavior (Prag et al., 2018). However, foreign state investment funds may hold small stakes as financial investors. Additionally, some private companies have higher revenues compared to SOEs, allowing for greater investment in research and development, as well as energy

efficiency and renewable energy projects (Stein, 2024). For instance, RWE has adopted renewables as a growth strategy, and Iberdrola has become one of the world’s leading wind power producers. Iberdrola plans to invest about €5 billion annually by 2026 (Iberdrola S.A., 2024). In addition, independent power producers have a more opportunistic investment style, favoring gas and nuclear power sources as well as onshore and offshore wind farms (Barazza and Strachan, 2020). They are more speculative with investments and losses, and they are willing to take on riskier projects to achieve a higher return on investment (ROI). However, they also face slightly higher capital costs than SOEs. Ultimately, Europe’s energy transition is being propelled by all ownership types, albeit in different ways. Fully and majority state-owned enterprises often act as trailblazers for large-scale renewable deployment, sometimes absorbing higher risks or lower returns to serve policy goals. Mixed-ownership and private utilities are increasingly competitive investors in renewables as the sector now offers growth opportunities and stable cash flows.

5.3. *New entrants*

The energy transition can be an opportunity for new technologies and entrants, but it can also be a hurdle for incumbent utilities with large fossil fuel assets and shares. In Germany, for example, the four dominant players, E.ON, EnBW, RWE, and Vattenfall, have apparently slowed down the energy transition by continuing to focus on coal, gas, and nuclear even after the passing of the renewable energy law, which expressed clear national intentions for the transition to renewables (Erhardt, 2022, Lauber and Jacobsson, 2016). This underscores the importance of competitive markets and the pressure that new entrants exert to drive change, transition, and innovation. As the majority of start-ups and new entrants in Europe focus exclusively on renewables and innovation, they are essential for the sustainable decarbonization of the European energy sector ((Barazza and Strachan, 2020, Wesseling et al., 2017)). However, due to the high upfront costs and long payback periods associated with energy infrastructure, securing capital is often challenging for them. Policymakers have sought to lower these barriers by mandating non-discriminatory grid access and offering research and development subsidies, feed-in premiums, and soft financing for renewable projects. New entrants can take advantage of policies that reduce barriers to entry, such as ensuring access to the grid, and also benefit from government subsidies for research and development, as well as renewable energy and energy efficiency initiatives (The World Bank, 2020a).

A rapidly emerging market is that of distributed energy resources, such as PV and wind farms, where some established companies, including Tesla Motors Limited, are expanding their business. Numerous startups and smaller companies, such as Pico Flex, next Kraftwerke, and Sonnen GmbH, are increasingly focusing on managing virtual power plants. Virtual power plants can be defined as the aggregation of relatively small-scale renewable energy facilities that are pooled together to feed into the grid. Companies that specialize in providing smart hardware or software solutions can build and manage networks of small energy-producing or -storing devices. These contributions stabilize the grid because intermittent renewable energy sources cause frequency fluctuations. According to the IEA, early-stage funding for all energy start-ups doubled in Germany in 2022, and the value of these start-ups is trending upward (IEA, 2024).

5.4. *Renewable energy communities*

In addition to the involvement of utilities, the decentralized structure of renewable energy empowers households and non-professionals to participate directly in electricity markets, challenging the traditional model of acting only as consumers of electricity (Schittekatte et al., 2021). Homeowners, landlords, and businesses can install small-scale solar PV systems to either trade electricity peer-to-peer with community members or be part of a larger network where small-scale energy is aggregated through virtual power plants and fed into the grid. Additionally, renewable energy communities can facilitate collective investment in other energy sources, as well as large-scale projects or campaigns (Schittekatte et al., 2021). Even though individuals could simply continue to consume electricity from the grid, many choose to invest in PV and participate in such communities. In addition to financial savings through lower bills and increased home value, environmental motivations such as consuming carbon-neutral electricity play an important role, (Dóci and Vasileiadou, 2015). Furthermore, ensuring security of supply and preventing uncertainties are significant drivers for people to engage in renewable energy communities. In the EU, energy communities are becoming more popular. According to European Commission (2022), there are currently 9,000 energy communities in the EU, supported by public authorities or small companies. The majority of these communities are in Germany and Denmark. In Germany, PV cooperatives and community-owned wind farms are the most common form of organization, (Babilon et al., 2022).

6. Demand

The demand side plays a pivotal role in Europe’s energy transition. While much attention is placed on the supply of renewable energy, how electricity is consumed, managed, and generated on-site by end users is equally crucial. Across different sectors—from private households and landlords to small and medium-sized enterprises (SMEs) and energy-intensive industries (EIIs)—actors are increasingly taking steps to reduce consumption, improve efficiency, and invest in renewable generation. Homeowners and landlords influence residential emissions through their decisions on solar PV, heat pumps, and building insulation. Tenants, though more constrained, are also showing demand for cleaner, more efficient housing. SMEs in the business sector face challenges in financing green upgrades, yet they are showing a growing interest in self-generation and efficiency improvements. Meanwhile, EIIs are combining long-term procurement strategies with direct investments to secure energy and reduce exposure to carbon costs. This section explores how different consumer groups across the economy can contribute to, and are constrained in, their efforts to reduce electricity demand and support a cleaner, more decentralized energy system.

6.1. *Households*

As mentioned above, consumers play a key role in the European energy transition. This is particularly true for households, which are not only major consumers of electricity and heating energy, but increasingly important actors in managing, reducing, and reshaping demand. Their

influence extends beyond sheer consumption volumes to include energy efficiency upgrades, behavioral shifts, and greater flexibility in when and how electricity is used. Households can respond to price signals or digital demand-response schemes, shifting consumption away from peak hours and thereby helping to balance grids dominated by variable renewables. Additionally, the adoption of technologies such as smart thermostats, battery storage, and heat pumps enhances their ability to modulate demand and integrate self-generated energy. By investing in renewable systems like solar PV, households can also become prosumers—generating electricity for their own use and feeding surplus back to the grid or into renewable energy communities (Kolk, 2012). These investments are especially attractive in detached and semi-detached homes, where ownership and roof access are straightforward, unlike in apartment buildings or condominiums, which represent 22% of housing in Germany and 42% in the European Union (Weber, 2024). While 82% of residential buildings in Germany are single- or two-family homes, they account for only 60% of total living space—highlighting the need to overcome structural barriers in multi-family and rental housing to fully unlock the household sector’s potential for demand-side decarbonization (Miara, 2021a, Hagen et al., 2023).

In property living. The motivations for homeowners to purchase solar PV systems or heat pumps—or to undertake energy efficiency renovations such as insulation upgrades—are primarily financial, but also resemble the incentives of individuals who participate in renewable energy communities (Jansma et al., 2020, Rubio, 2017, Barazza and Strachan, 2020). First and foremost, property owners seek to cover their own energy consumption, thereby lowering utility costs and achieving greater independence from the electricity grid. This is especially evident in Germany, where more than half of all installed solar PV capacity is located on the rooftops of private homes (Rode, 2024). In addition to meeting their own needs, households can feed surplus electricity into the grid, creating a modest but stable source of income (Jansma et al., 2020, Rubio, 2017, Barazza and Strachan, 2020). However, financial returns from rooftop PV are mainly derived not from high feed-in tariffs, but from avoided costs such as grid fees, levies, and electricity taxes—making self-consumption the most profitable use case under current tariff structures.

In 2024, German photovoltaics produced approximately 72.2 TWh of electricity, of which 12.4 TWh was used directly for household self-consumption (Fraunhofer ISE, 2025). By 2022, 4.7% of German households were earning an average of €183 per month from feeding excess solar electricity into the grid (Statistisches Bundesamt, 2024a), primarily from the nearly 3.3 million rooftop systems installed across the country—representing two-thirds of total PV capacity (Umweltbundesamt, 2025b).

Beyond generation, households hold significant potential for demand reduction and increased system flexibility. Residential buildings in Germany account for around one-quarter of total final energy demand, with over two-thirds of this used for heating (Umweltbundesamt, 2025a). Replacing fossil-fuel-based heating systems with electric heat pumps not only reduces emissions but also shifts electricity demand in time—potentially enabling load shifting through smart controls or dynamic pricing schemes. While roughly 50% of German households still rely on gas for heating, heat pump adoption has accelerated in recent years, particularly after the 2022 energy crisis, supported

by government subsidies (Miara (2021b), Statistisches Bundesamt (2024c)). In newly built one- and two-family homes, 68.9% of completions in 2023 featured heat pumps as the primary heating system. However, a large share of the housing stock—around 75%—is over 40 years old, making retrofits more urgent yet more challenging. Still, one in four heating system replacements now involves a heat pump, with 1.45 million units in operation by 2022 (Bundesverband Wärmepumpe e.V., 2023).

Despite these gains, Germany lags behind in EU comparisons. With only 6.7 heat pumps per 1,000 households, it trails far behind countries like Finland, which leads with 69.4 (Hagen et al., 2023). Insulation and efficiency measures—such as improved windows and facade retrofits—also reduce electricity and heating demand. In 2016, German households achieved an average savings of €500 per capita through such renovations (BMWK, 2017). These upgrades, when combined with smart metering, time-of-use tariffs, and home energy management systems, could enhance demand flexibility and help stabilize electricity grids with high shares of renewables.

However, despite the technical potential, regulatory complexity, up-front costs, and uncertainty about policy continuity still deter many households from investing in demand-side measures or renewable self-generation (Jansma et al., 2020, Rubio, 2017, Barazza and Strachan, 2020). To fully activate their role in the energy transition, homeowners must be supported not only through financial incentives but also with clear long-term regulatory frameworks and accessible tools to monitor and shift their electricity demand.

Tenants. In contrast to homeowners or landlords, tenants have limited options and depend on landlords or rental companies to install solar PV systems (Jansma et al., 2020, Reidl and Wüstenhagen, 2025). While tenants may influence decisions about the electricity provider, heating systems and energy-efficiency renovations, their motivation to do so is not only driven by cost measures, given that investment decisions are characterized by a longer time frame and greater financial outlay compared to individual rental decisions. However, HomeLet (2023), Leaders Romans Group (2024) found that tenants prefer energy-efficient homes and clean energy generators. While tenants may support such initiatives, they are not necessarily willing to pay higher rents to facilitate them. This is an important issue to address, as in many European countries, a high proportion of the population lives in rented accommodation (Statistisches Bundesamt, 2024b). Germany has the highest proportion of renters in Europe; in 2023, 52.4% of households lived in rented buildings. In France, the proportion was 36.9%, and in Poland, it was only 12.7%.

6.2. Landlords

Rental corporations tend to have large property portfolios and act for profit, whereas private landlords invest in housing independently. The energy provision decision-making processes of private landlords and rental corporations are primarily influenced by three factors: landlord-tenant electricity supply, principal-agent market failure, and ownership structure. The first factor favors energy projects and the installation of solar PV because it represents an additional source of income for the landlord (BMWK, 2022). In Germany, for instance, landlords receive a premium for supplying their tenants with electricity generated from renewable sources. However, when

energy bills are the responsibility of tenants, the so-called principal-agent market failure comes into play (Petrov and Ryan, 2021). The lack of incentive for landlords to reduce costs leads to underinvestment in energy efficiency. This may explain why rental properties tend to have lower levels of investment in energy efficiency and fuel switching measures than buildings used by private owners. In addition, the ownership structure of co-ops or condominiums can make PV or fuel switching difficult, as the majority must agree and invest (Weber, 2024).

Private landlords. In Germany and the EU, private landlords face a classic split-incentive: They fund capital upgrades, such as insulation, heat pumps, and photovoltaic systems, but tenants reap the energy-cost savings. Consequently, rented apartments tend to be more electricity-intensive than owner-occupied homes. From 2023 to 2024, only 1,970 photovoltaic (PV) systems (133 megawatts [MW]) were installed on multi-family rental buildings in Germany, just 0.4% of all new rooftop installations. In contrast, owner-occupiers installed nearly 477,000 systems (over 10 GW) in the same period.

Recent reforms like EEG 2023 and Solarpaket I in Germany have eased supply rules for tenants, removed size caps on tenant PV projects, and introduced a higher full feed-in tariff aimed at rented properties. KfW grants and Modernisierungsumlage rent surcharge allowances also support energy efficiency retrofits. However, many small landlords still cite administrative hurdles, limited access to capital, and rent-increase caps (max. 8% of costs) as barriers. Without substantial alignment of cost-recovery mechanisms or regulatory minimum performance standards, private rentals will continue to lag in reducing electricity demand and deploying on-site renewables.

Rental corporations. Large housing companies and cooperatives have a significant number of residential units and substantially influence electricity demand. Rental corporations have more resources to modernize their properties than private landlords do. In line with the EU’s decarbonization goals, rental corporations primarily invest in photovoltaic (PV) systems to promote renewable energy generation. For example, Vonovia, one of Germany’s largest residential landlords, grew its PV capacity from 53.1 MWp to 133 MWp in 2024 (Vonovia, 2023). Corporate landlords are also constructing thermal shells to reduce heat loss and installing LED lighting to decrease electricity usage.

However, rental corporations face a split incentive: owners bear renovation costs while tenants benefit through lower bills. Although Mieterstrom (tenant solar) models and energy service contracting are emerging, regulatory complexity and limited rent surcharge ceilings hinder adoption. EU directives such as the EPBD Renovation Wave and national mandates, e.g., France’s ban on the worst-performing rentals starting in 2025, aim to force broader upgrades. In Germany, upcoming minimum energy label requirements for rentals and continued subsidy programs will be crucial to mobilizing both private and corporate landlords. Without these measures, the rental sector risks remaining a drag on the decarbonization of electricity demand.

6.3. Small and medium-sized enterprises

Many factors influence firms’ decisions to invest in green or energy-efficient products. These include investment history, knowledge, regulatory uncertainty, access to financing sources, and

green management practices, among others (Rodriguez Lopez et al., 2017, De Haas et al., 2021). There is a growing awareness of renewable energy, as evidenced by the fact that in Germany, approximately 54% of companies use green electricity, either through a special contract or through their own generation (Kreditinstitut für Wiederaufbau (KfW), 2024). However, while investment history, knowledge, perceived uncertainty, and green management practices positively influence green investments, credit constraints and a lack of green management are negatively correlated with energy demand reduction measures and investments (Rodriguez Lopez et al., 2017, De Haas et al., 2021).

Company size affects investment behavior. Many small and medium-sized companies lack access to financing and face higher capital costs than large companies. This may explain why large companies are twice as likely to invest in energy efficiency as small and medium-sized enterprises, as shown by European Investment Bank (EIB) (2020), Rubio (2017) and De Haas et al. (2021). However, SMEs are increasingly engaged in researching and developing utilities as opposed to costly, long-term, proprietary projects. Beyond sustainability and resilience, businesses also gain commercial benefits such as lower energy and carbon costs, access to grants, and the generation of a new revenue stream by selling excess energy back to the grid, as discussed in Rubio (2017) and Chadwick et al. (2023).

6.4. Energy-intensive industry

Industry is one of the largest energy consumers in the EU, alongside households and transportation. The industrial sector consumed 36% of the EU’s electricity in 2022 (European Commission, 2024a). Additionally, manufacturers consume more heat than households. In Germany, for example, industrial consumers use 61% of gas demand, while the residential and service sectors use only 39% (Bundesnetzagentur (BNA), 2025). Energy-intensive industries, such as those producing basic metals, chemicals, non-metallic minerals, paper, and refined petroleum products, are central to industrial energy demand due to their energy-intensive production processes. To meet this high demand, many large industrial sites generate power on-site through power plants or combined heat and power (CHP) units, which produce both electricity and heat. This improves efficiency, reduces costs, and increases reliability. Consequently, a significant amount of industrial electricity is generated behind the meter. For instance, industrial companies in Germany produced up to 60 TWh of electricity in 2022, accounting for nearly one-third of total industrial consumption. This includes on-site generation from coal (22.1 TWh) and natural gas (30 TWh) (Burger and Hanisch, 2024). Thus, the industry accounts for a large share of emissions in Europe. Although fossil fuels still power over half of the EU industry, the shift to cleaner energy is accelerating. By 2023, coal-fired auto production had fallen dramatically as plants were retired, while gas-fired generation remained stable at around 29.6 TWh. This shift reflects a broader trend: industries are phasing out coal and increasingly turning to cleaner alternatives as renewable energy sources increase their share of industrial energy consumption. By 2022, 11% of industrial energy demand was generated from renewable sources.

As renewable energy sources grow faster than ever before and calls for deep decarbonization grow louder, industrial operators feel pressured to rethink their entire energy strategy. In response,

energy-intensive companies are investing in sustainable technologies. Moreover, with increasing pressure on EIIIs from both governments and investors, companies in energy-intensive industries have "acknowledged their responsibility for the green transition", according to the European Round Table Report for Industry (ERT, 2024). Driven by stakeholder and customer demands, companies are motivated to maintain reliable prices amid an energy crisis marked by high demand. EIIIs with high electricity demand are particularly vulnerable to higher energy costs, and the rising cost of the EU ETS is increasing investments in sustainable technologies and production processes (European Round Table for Industry (ERT), 2024). Furthermore, these industries are developing strategies to secure energy procurement through power purchase agreements (PPAs) and investing in renewable energy assets.

Price risk and hedging. Industrial companies secure their energy needs through long-term PPAs but also invest in energy generation to ensure reliable power operations. They invest in several ways to reduce emissions and secure energy needs: securing procurement through PPAs and investing in renewable energy projects, either on-site or in partnership with external projects, such as wind farms.

First, long-term PPAs are a common strategy in energy-intensive industries for sourcing renewable power without owning assets. With PPAs, companies commit to purchasing power from projects for an agreed-upon period, typically 10–20 years. PPAs provide price certainty for energy-intensive industries and decarbonization requirements, as well as project financing certainty for asset owners. For instance, the German chemical company Covestro signed one of the world's largest corporate wind PPAs in 2019. Covestro's 10-year agreement to purchase 100 MW of wind power from the new Borkum Riffgrund 3 wind farm (North Sea) starting in 2025 provides financial certainty. European corporate renewable PPAs reached a record 10.4 GW of contracted capacity in 2023, and energy-intensive industries are the second leading sector of the PPA market in Europe (Ferris, Nick, 2023). Despite the advantage of providing large volumes of energy at stable prices over the long term, there is price risk associated with signing PPAs. For instance, if the market price of electricity is lower than the fixed PPA rate, the buyer must still pay the higher PPA price. Additionally, there is a volume risk. If the industrial company increases production or the renewable power plant underperforms due to weather conditions, the off-taker bears the shortfall risk. Investing directly in renewable energy assets may help counteract these risks.

Energy-related investments. Direct investment by energy-intensive industries mainly includes investment in renewable energy facilities on-site or in partnership with external projects. On-site investments include installing solar PV systems on factory rooftops or on idle land, deploying wind turbines on industrial sites, and operating biomass/biogas-fueled CHP plants. Marszal et al. (2012) noted that on-site renewable energy investments require improved energy efficiency. Conversely, off-site renewable energy becomes more cost-effective at scale. Therefore, industrial companies can acquire or invest in power plants to secure their energy supply. For example, the German chemical company BASF acquired almost half of Vattenfall's Hollandse Kust Zuid wind farm and invested more than one billion to make it one of the largest offshore wind farms in Europe (Steffen et al., 2022). Energy-intensive industries are combining long-term renewable energy procurement,

self-generation, and efficiency improvements to reduce their dependence on fossil fuels. Increasing the share of clean energy through on-site and off-site investments makes the industry resilient to energy shocks and aligns with Europe’s energy goals.

Financing mechanism. Both the rising cost of carbon emissions in the EU ETS, which incentivizes companies to take action, and the ongoing shift by investors towards carbon-efficient and sustainable companies, as evidenced by pension funds selling shares in oil and gas companies, are making access to capital more difficult (European Central Bank (ECB), 2024, European Investment Bank (EIB), 2020, De Haas et al., 2021, The World Bank, 2020a). Conversely, a number of government incentives and funds are available for decarbonization investments, including clean steel technologies and the EU ETS innovation fund. However, two major obstacles may hinder or slow down the transition of energy-intensive industries. First, dominant firms in this sector operate in oligopolistic markets that are characterized by high fixed costs. These costs create significant barriers for new entrants and providers of disruptive technology.(Wesseling et al., 2017). This may impede progress, as competition and new entrants have been identified as key drivers.

In addition to these barriers, costs have been identified as the main obstacle to the transition of energy-intensive industries (De Bruyn et al., 2020, European Round Table for Industry (ERT), 2024). For energy-intensive industries, it can be challenging to cope with high initial investments in the energy transition between high energy costs and rising emission costs (European Round Table for Industry (ERT), 2024). Nevertheless, public and private funds are providing capital for industrial sustainability goals. A growing number of companies have issued green bonds to raise capital specifically for renewable energy and decarbonization projects (Leung and Bruegel, 2024).

Overall, energy-intensive industries are caught between tightening carbon costs and growing investor scrutiny, which makes capital scarcer, and public incentives and green bond markets designed to fund decarbonization projects. Despite these challenges, the convergence of government support, private finance, and rapid technological advances charts a viable path for EII to transition toward renewable projects, both on-site and off-site.

7. Investors and financial institutions

Another key role in the European energy market is played by investors and financial institutions that provide access to capital for businesses and households. Investors vary not only in size, organization, location, and preference for green investments, but also in which technology or sector they are most likely to invest. Not only political and financial support for net-zero, but also uncertainty of all kinds (including policy, duration, and technology), prior experience and knowledge, cost of capital, and the overall contractual framework and attractiveness influence investors’ decisions and behavior (Pratt, 2024, Jacobsson and Jacobsson, 2012, Bergek et al., 2013, Hirth and Steckel, 2016, Barazza and Strachan, 2020). Generally, decisions are heavily influenced and based on investors’ limited foresight and expectations about climate change and the pace of the energy transition, as well as future fuel, carbon, and technology costs (Barazza and Strachan, 2020). In addition, three key findings were identified with respect to green investments. First, green investments benefit

greatly from a more equity-based financial sector rather than a debt-based one (De Haas et al., 2021). Second, small sources of finance, such as individual private investors, diversify and stabilize the financial system, which is beneficial for green investments (Christophers, 2019). Finally, De Haas et al. (2021) observe a general shift in investment towards low-carbon sectors.

7.1. Investors

7.1.1. Institutional investors

Pension funds. Pension funds are empirically one of the most important sources of financing for clean energy companies and capital-intensive, long-term and low-risk projects such as transmission infrastructure (Polzin and Sanders, 2020). Within this investment group, there is an increasing focus towards carbon efficient sectors (De Haas et al., 2021). Institutional investors were found to be increasingly active in investing in renewable energy assets (Wüstenhagen and Menichetti, 2012). As a prominent example, some large European pension funds have divested from oil and gas companies in recent years and shifted their portfolios to renewable energy and other sectors. Among the large pension funds in Germany, such as the pension funds of North Rhine-Westphalia, also the largest fund in the Netherlands and the EU, ABP, with assets of more than €528 billion, are withdrawing investments in EU oil, gas, and coal companies (Finanzverwaltung des Landes Nordrheinwestfalen (NRW), 2023, Manager Magazin, 2021). Many other pension funds have either excluded oil and gas companies altogether, such as AkademikerPension, while others still try to directly pressure and influence the big players, such as the Dutch Pensioenfonds Zorg en Welzijn, which holds only seven oil and gas companies after radically divesting from 310 companies (AkademikerPension, 2023, PFWZ, 2024). In addition, Dutch Pensioenfonds Zorg en Welzijn is trying to shift its focus to the largest consumers of fossil fuels to encourage the adoption of cleaner technologies and products, thereby reducing demand for fossil fuels and pressuring oil and gas companies to accelerate their transition.

Insurance companies. Similarly, the main investment targets of insurance companies have been wind power projects and companies, as well as venture capital, private equity, public equity and debt in clean technology sectors (Polzin and Sanders, 2020). However, further regulations and policies can often accelerate the short-term focus of investments to the detriment of long-term infrastructure and technology projects (Polzin and Sanders, 2020).

Sovereign wealth funds. Sovereign wealth funds are also increasingly focused on green investments and often finance network infrastructure projects due to their substantial size and low risk profile (Polzin and Sanders, 2020). As Almunia (2008) noted, sovereign wealth funds have been increasingly investing and deploying capital in European markets. For example, the world’s largest sovereign wealth fund, Norway’s €1,800 billion sovereign wealth fund, is seeking to achieve climate neutrality and has committed to investing exclusively in sustainable assets (Fouche, 2025, Norges Bank Investment Management, 2025).

7.1.2. Private investors

When examining private investors, such as households, small and medium-sized enterprises, and larger companies, it should be noted that investment decisions are mostly based on and concentrated in national markets (Zachmann, 2015, Zachmann et al., 2024). In addition, investment horizons are long and private investors prefer mature technologies that have already passed the technology and cash flow "valley of death" (Zachmann et al., 2024, Masini and Menichetti, 2013). Knowledge plays a critical role, as do social, economic, and political influences and risk aversion. In addition, corporate environmental management practices and the sector in which the company operates influence investment decisions (De Haas et al., 2021). Even if an individual household cannot finance large energy or efficiency projects on its own, it can contribute by investing its capital in green funds or investment portfolios. According to Römer and Salzgeber (2024), 14% of German households have already invested either in green savings accounts, a new renewable energy power plant, or in green funds or securities. In addition, about 30% of German households can imagine investing in a green security. With a total value of financial assets of German private households of 8,000 billion €, these actors can become a significant source of financing for green projects. Furthermore, the reduction of greenwashing risks and a transparent framework for the green finance sector could attract even more people to green investments.

7.1.3. Venture capitalists and corporate investors

While venture capitalists provide capital especially between the R&D phase and commercialization with high-risk, high-reward investments, corporate investors tend to invest more in mature renewable energy and energy efficiency technologies (Polzin and Sanders, 2020). Venture capitalists typically seek investments based on the rationale of growth, scalability, and rapid payback, characteristics common in the R&D phase. These are known to have a high-risk and high-potential return character.

7.1.4. State investment banks

State investment banks (e.g. the German KfW or the European Investment Bank) have been shown to play an important role for large companies, as they can receive direct loans (European Commission, 2024b). For SMEs, intermediaries such as local banks are more important. However, start-ups in particular can benefit from the "mission-oriented role" of state investment banks and its early investments in technologies and high-risk renewable energy projects. Nevertheless, state investment banks also provide subsidies and state grants to households for the installation of solar PV or heat pumps. Given those findings, state investment banks in combination with other public banks could play a key role in seed financing politically-imported, high-risk projects such as hydrogen and CCS infrastructure. In this vein, the EIB has lent some €31 billion to promote energy efficiency and renewable energy, as well as €8.5 billion for networks and storage facilities (European Investment Bank (EIB), 2024b). As promising results, the EIB announces that enough renewable energy is being generated to power 14.7 million homes and that 100,400 households are living in energy-efficient homes. Some €68.2 billion has been used to finance various projects within the EU. The EIB also provides direct funding such as loans to key players in the electricity

sector. For example, the former oil operator ERG received a major loan of €243 million to enable the steps of ERG’s 2024 to 2026 business plan, including the repowering of existing wind farms and solar power plants in Italy, France and Germany (European Investment Bank (EIB), 2024a). These resources provide significant support and motivation for companies to engage in renewable energy and the green transition.

7.1.5. Private investment banks

As mentioned above, private investment banks are one of the main sources of finance for SMEs and projects (Polzin and Sanders, 2020). As such banks tend to be technologically conservative, they rarely finance R&D or untested, invented technologies (De Haas et al., 2021). In addition, banks’ increasingly ”market-based” business logic results in more short-term and high-risk investments, which can disadvantage green investments focused on long-term infrastructure or energy efficiency projects (Jacobsson and Jacobsson, 2012). Lending to fossil fuel or non-renewable energy companies, such as oil, gas and coal, shows that banks are exploiting different carbon tax regimes by shifting their credit flows to carbon tax-free countries (De Haas et al., 2021).

7.2. Intermediate channels

Despite the traditional channels such as banks, other intermediary channels are increasingly developing. For example, climate or green bonds have been used extensively to finance mature hydropower, but now include other renewable energy assets such as solar and wind projects (Polzin and Sanders, 2020). The general financial sector ”Green Finance” increasingly provides companies and renewable energy projects with more diverse and significant sources of funding and tends to become an attractive investment for both private and institutional investors (Hou et al., 2023). This sector has the greatest general impact on solar installations, as this is the sector with the highest dependency on external financing, followed by wind and biomass projects.

8. Discussion: Actor heterogeneity and security of supply

The transformation of the European energy system raises fundamental questions about ensuring security of supply in a future-oriented electricity market. Traditionally, this issue has been framed as a question of physical adequacy: Will there be enough generation capacity to meet peak demand, particularly during periods of low renewable energy production? However, in an increasingly complex and diverse electricity system, security of supply is a systemic and institutional challenge that spans regulatory design, investment logic, network integration, and consumer participation, not just a question of installed capacities.

Security of supply is shaped by the interplay of multiple actors with divergent objectives, including governments, regulators, market operators, utilities, investors, and end users. Each of these actors plays a distinct role in maintaining system stability, yet coordination between them is often imperfect or inconsistent. The state is a particularly multifaceted actor, simultaneously acting as a market designer (e.g., through ministries such as the Federal Ministry for Economic Affairs and Energy), a regulator (e.g., via the Federal Network Agency or competition authorities),

and an owner of energy companies. This institutional setup with multiple roles creates inherent conflicts of interest: Regulatory neutrality and competitive oversight can clash with state-owned enterprises pursuing strategic or industrial policy objectives.

This tension is especially evident in current debates around backup capacity planning, such as Germany’s program to build 20–25 GW of gas-fired plants. Without transparent procurement rules and clear investment signals, public intervention could replace rather than complement market incentives. In the long term, this could lead to the transformation of supply security into an implicit public service without a consistent definition or legitimate governance mechanism.

Private actors, particularly large energy companies, operate according to market rationality. Their willingness to invest in firm capacity depends on policy stability, clear remuneration schemes, and manageable risks. However, if governments intervene unpredictably or crowd out competition, the Energy-Only Market model may fail to incentivize sufficient firm capacity, especially for rare but critical stress events (e.g., cold winter spells with low renewable availability).

Meanwhile, consumers—both households and industries—expect uninterrupted electricity supply without considering the physical constraints of a renewable-based system. Households typically show limited price elasticity. While instruments such as demand-side response or dynamic tariffs are promising, uptake remains low. Importantly, these same consumers are also voters, indirectly shaping regulatory preferences.

Given this interplay between the state, the market, and consumers, future capacity mechanisms must reflect the full diversity of these actors and their sometimes conflicting logics. The current Energy-Only Market model may no longer suffice. Instead, differentiated mechanisms combining market incentives with transparent public mandates are required. The critical questions are how much capacity is needed and how it should be financed, governed, and socially accepted. Capacity planning requires a clear, shared definition of supply security, especially under stress scenarios. For example, guaranteeing uninterrupted supply to all households during extreme conditions—such as -30°C temperatures and zero renewable input, could imply the need for 40–50 GW of backup capacity, which is far beyond current plans.

Alternative models include greater demand flexibility, time-variable tariffs, and shared responsibility frameworks. However, this requires a societal shift away from the presumed right to uninterrupted supply and toward co-produced system resilience. In this light, the taxonomy developed in this paper provides a framework for identifying institutional misalignments and actor-based frictions. Future market design must explicitly account for the complex interplay between public roles, private incentives, and collective expectations if supply security is to be maintained in a decarbonized, diverse electricity system.

9. Conclusions and policy implications

This paper presents a comprehensive taxonomy of the key actors in the European energy transition, highlighting their diverse roles in governance, supply, transportation, demand, and finance. The paper reveals the diversity of market participants, ranging from homeowners and

rental corporations to SMEs and energy-intensive industries, as well as the asymmetries in their capabilities, incentives, and barriers to investment and behavioral change.

Three overarching dynamics influence the success of the transition across all actor groups: (1) the capacity to internalize long-term costs and climate signals, (2) the accessibility and availability of tailored financial instruments, and (3) the strength and stability of regulatory frameworks. This analysis shows that actors respond best when aligned incentives, policy certainty, and accessible capital intersect.

While decentralized actors, such as households, SMEs, and new energy communities, are vital to deploying distributed generation and reducing electricity demand, their potential is limited by split incentives, regulatory complexity, and financing gaps. Energy-intensive industries are unique in that they are major consumers and producers and are increasingly hedging against price risks via power purchase agreements (PPAs) and on-site generation. Large, incumbent utilities and state-owned enterprises dominate high-capital, grid-scale investments. Due to their long investment horizons and strategic mandates, these entities play a stabilizing role. Meanwhile, new entrants accelerate the deployment of renewable energies and new technologies, such as batteries, that are crucial for a successful energy transition. Financial actors, including state investment banks and institutional investors, enable this transformation through targeted capital deployment. However, they still shy away from higher-risk, early-stage technologies without clear policy backing.

To accelerate the energy transition, policymakers must prioritize stable, long-term regulatory frameworks that reduce investor uncertainty and support strategic planning. It is equally important to expand financial instruments targeting households, SMEs, and private landlords, who often face high upfront costs and administrative barriers. At the same time, policymakers should actively support demand-side flexibility through digital tools, dynamic pricing schemes, and smart energy management systems. This would enable decentralized actors to optimize consumption and contribute to grid stability. Subsidies, on-bill financing, and community aggregation models can democratize access to renewable technologies and efficiency measures while empowering prosumers and energy communities as integral grid participants. Reforms must also address structural barriers in the rental sector, where split incentives hinder the adoption of energy efficiency measures and on-site renewable energy sources. Mandating minimum energy performance standards coupled with fair cost-recovery mechanisms can bridge this gap.

Hybrid models combining public and private finance, alongside instruments like power purchase agreements (PPAs) and green hedging strategies, are essential for reducing the risk of large-scale investments in clean technologies, such as electrification and hydrogen, for energy-intensive industries. Financial actors, particularly institutional investors and state banks, must be incentivized to expand their role by supporting early-stage projects and scaling green infrastructure through standardized ESG frameworks and green bonds.

This paper has shown that ensuring security of supply in the European electricity market is a multidimensional challenge. It is not only about having sufficient capacity but also about how capacity is financed, dispatched, regulated, and valued by consumers and policymakers. While the current patchwork of national mechanisms addresses local needs, it risks undermining cross-border efficiency and investor confidence. While actor diversity enriches the market, it also complicates

the coordination required for supply security. The interplay of market design, policy clarity, and investment certainty is crucial. Aligning short-term operational needs with long-term strategic goals demands institutional coherence and stakeholder inclusion. A future-proof electricity system must balance adequacy, affordability, and fairness across all layers of society.

To safeguard supply security and advance the energy transition, policymakers must ensure institutional coherence by clearly separating the roles of state actors as regulators, market designers, and asset owners. This reduces conflicts of interest and boosts investor confidence. Harmonizing national capacity remuneration mechanisms at the EU level can enhance cross-border efficiency and provide clearer investment signals. Grid expansion and modernization must be prioritized through regulatory reforms that enable proactive investment by DSOs and TSOs. Demand-side flexibility must be systematically embedded into market design and supported by digital infrastructure, dynamic pricing, and public trust-building efforts. Tailored financial tools are needed to support households, SMEs, and tenants, particularly in overcoming split incentives in the rental sector, while strategic finance must also target flexible assets, such as storage and demand response. Regional coordination of adequacy targets and joint capacity mechanisms can improve resilience and reduce redundancy. Finally, all adequacy policies must be grounded in equity through social tariffs, inclusive energy community models, and support for vulnerable groups to ensure the benefits of secure supply are broadly shared.

In short, if it is effectively coordinated, actor heterogeneity is a resource, not a liability. A resilient electricity system requires physical adequacy and a coherent institutional architecture that fosters trust, enables investment, and aligns societal, technical, and economic objectives at all levels. Policymakers must design integrated frameworks that reflect the complexities and opportunities of Europe’s energy transition, moving beyond fragmented instruments.

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